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Wireless Network Virtualization With SDN and C-RAN for 5G Networks: Requirements, Opportunities, and Challenges

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ABSTRACT Wireless network virtualization (WNV) has drawn attention from the researchers ranging from academia to industry as one of the significant technologies in the cellular network communication. It is considered as a pioneer to achieve effective resource utilization with decreased operating expenses and capital expenses by decoupling the networks functionalities of coexisting virtual networks. It facilitates fast deployment of new services and novel technologies. WNV paradigm is in the early stages, and there is a large room for the research community to develop new architectures, systems, and applications. The availability of software-defined networking (SDN) and cloud/centralized radio access network (C-RAN) steers up the hope for the WNV realization. This paper surveys WNV along with the recent developments in SDN and C-RAN technologies. Based on these technologies and WNV concepts, we identify the requirements and opportunities of future cellular networks. We then propose a general architectural framework for the WNV based on SDN. In-depth discussion of challenges and research issues as well as promising approaches for future networks communication improvements are also proposed. Finally, we give several promising candidates of future network services for residential customers and business customers.

INDEX TERMS 5G Networks, C-RAN, infrastructure provider, SDN, virtual networks, wireless network virtualization.

I. INTRODUCTION

Mobile Network Operators (MNOs) have experienced tremendous growth in wireless data traffic and services, the trend is expected to have an explosive growth in the next years. According to Cisco report of 2016 [1], the data traffic flow will surpass the zettabyte (ZB) threshold in 2016, reaching 88.7 exabytes (EB) per month. The report forecast that by 2020 the traffic flow will reach 2.3 ZB. The primary drivers for this include mobile internet and smart devices that lead to increasing video traffic, real-time gaming, and web-based applications services [2]. With such increase, network management and configuration become complex, hence MNOs need to increase both capital expenses (CAPEX) and operating expenses (OPEX). Unfortunately, the growth in the data traffic demand varies inversely with the revenues [3], [4]. Deploying the wireless network infrastructures to handle this growth rate is challenging and costly for MNOs [5]. It should be noticeable that increasing the number of base stations (BSs) for the purpose of increasing the network capacity is not the best solution due to the system complexity. Therefore, MNOs have conspired resources sharing as a key method to reduce new deployment and operational costs.

The emergence of the software-defined networks (SDN), wireless network virtualization (WNV) and cloud radio access network (C-RAN) provides a promising technological solutions for this challenge. These technologies facilitates the implementation of efficiency network resource sharing and flexible scheduling. SDN facilitate the separation of control plane and data plane which can increase the system flexibility and scalability. Such an approach also makes networks programmable, centrally managed, adaptable and cost effective. WNV provides the decoupling of network functionality of the physical networks, which accelerates the sharing of networks resources. Besides sharing of resources, WNV also makes easier migration to newer technologies while supporting legacy products through isolating part of the network [6], [7]. SDN and WNV provide a connecting and powerful network management mechanism for emerging heterogeneous wireless networks environments [8]. C-RAN [9] separates remote radio head (RRH) from baseband unit (BBU) of a traditional BS. Hundreds of RRHs can be connected to a single BBU through high speed fronthaul (usually the fiber optics). C-RAN as a new RAN architecture, can overcome several challenges in the current third generation/forth generation (3G/4G) networks such as interference problems and large power consumption in mobile networks [10]. Due to the flexibility and scalability of a cloud based implementation and its inherent centralization nature, C-RAN can facilitate fifth generation (5G) technologies such as full-duplex, ultra-dense networks and large scale antenna systems. C-RAN allows the spectrum and BBU resources to be shared by various heterogeneous networks. This simplifies handover in mobile VNs because the virtual BS is located in a centralized BBU [11], [12]. Hence the three technologies working together can produce the best performance for the future network system as each has a special functionality which compliments the other. This needs a new architecture design to accommodate and facilitate the new changes and demands for the future network systems.

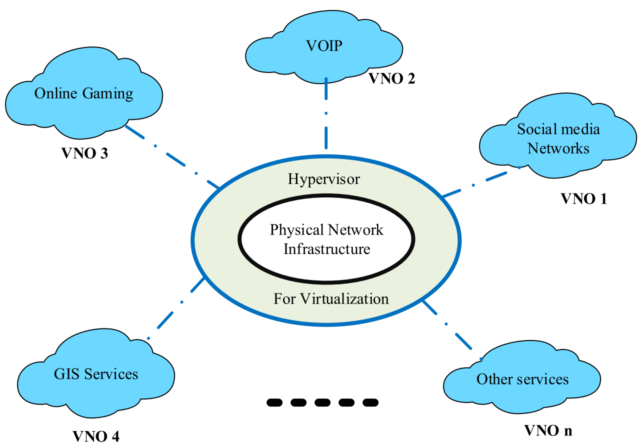

FIGURE 1. An overview of wireless network virtualization.

WNV can be dealt as an extension of wired network virtualization. Network virtualization is a splitting of the entire/part of the system into different isolated functional sections which can be used by various VNs. However, the distinctive properties of the wireless environment, such as time-various channels, attenuation, mobility, broadcast, interference, etc., make the problem more complicated [7]. Fig. 1 demonstrates a physical network infrastructure being virtualized and allocated to various virtual network operators (VNOs). The physical network comprises the infrastructures such as radio access networks (RANs), core networks (CNs), transport networks and the licensed spectrum. The infrastructure provider (InP) allocates virtualized resources to VNOs according to their demands and agreement. Each VNO can operate on the shared physical infrastructure independently.

WNV has a very broad scope ranging from spectrum sharing, infrastructure virtualization, to air interface virtualization. It brings efficient resource utilization, reduces operational and investment cost, raise revenue, encourages innovations and allows the new players in the business to enter into the markets at the lower cost.

Regardless the vision of the WNV, however, wireless virtualization is challenging. This is because wireless resources have to be shared and distributed to different VNOs in fairly manner. In additional, it is not enough to consider the shared, assign or scheduled resources at the BS but also the interference due to the resources utilization [13]. Radio resource (RR) abstraction and isolation are not a straightforward, due to the inherent broadcast nature of the wireless communication and stochastic nature of the wireless channel [4]. Before widespread of WNV however; many technical and managerial research challenges have to be addressed.

It requires a comprehensive research effort to provide reliable and sustainable solutions for the future networks. In this paper, we provide three-fold contributions as follows:

- We propose a SDN based architectural framework for the WNV, identify the requirements and opportunities of future cellular networks based on SDN, C-RAN technologies.
- We discuss the challenges and promising approaches of WNV for future improvement.
- Describe the promising solutions for future network services with focus on residential and business customer's services based on WNV and SDN.

The rest of this paper is organized as follows: section II gives a detailed discussion of promising concepts, definitions and basic architectural principles of WNV. Section III presents the recent developments in SDN and the C-RAN technologies. We identify the requirements and opportunities for future network systems in section IV. Section V presents the proposed SDN-based WNV framework along with resource management techniques for future networks. We provide the challenges, and research issues in section VI. Section VII provides promising solutions for future network services before concluding our remarks in section VIII.

II. CONCEPTS AND BASIC PRINCIPLES OF WNV

In this section, we first provide the concepts and basic principles of WNV. We then give the definitions, architecture, and advantages for future networks development such as 5G.

WNV [14] will become one of the leading trends in the next cellular systems. The virtualization mechanism abstracts (e.g., isolates) the physical resources to some virtual resources, which is shared by different consumers (e.g., service providers). WNV advantages include high resource utilization, improved system performance, reduced CAPEX and OPEX, better quality-of-experience (QoE) for users, and easier migration to newer technologies by isolating part of the network [4]. The virtualized wireless networks consist of an InP and mobile virtual network operator (MVNO). The InP owns the physical cellular infrastructures and radio resources while MVNO leases the resources from InP, creates and operates virtual resources, and assigns to the corresponding subscribers. The network resources can belong to one or more InPs which are virtualized into various slices. A slice represents the virtual resource with all network elements. The MVNO utilizes the slices depending on the experience level agreements (ELAs) [15] or service level agreements (SLAs) and provides service to the end users without knowing the fundamental physical network architecture. MVNO virtually owns the entire network resources such as base stations [16].

Basically WNV is a results of the NFV concept. NFV is the powerful emerging technique that describes the concept of taking network functions that traditionally runs on a devoted network hardware appliance and running those functions as application software in a general server infrastructure. In NFV environment, the physical hardware resources including the computing, storage and network are virtualized through virtualization layer (e.g. hypervisor). NFV changes the traditional network functions (e.g. load balancer, firewall) from specific proprietary hardware based into software applications (virtualized network functions-(VNF)) and run them on general purpose hardware. It take the advantages of high processing capabilities of information technology environment to create a more agile network environments. The computing hardware is considered to be Commercial-Off-The-Shelf instead of the purpose-built hardware.

A. INFRASTRUCTURE SHARING IN WNV

The backbone of any wireless network system is the Infrastructures. They are costly to invest and its maintenance. In current environments, whole or parts of the infrastructures are owned by the MNOs. As introduced earlier with the current trend sharing of the infrastructures is inevitable for reducing the CAPEX and OPEX while improving and providing services with high QoE to the users. Based on [11], network infrastructure sharing refers to the scenario in which multiple networks share the same physical network infrastructures under the agreed terms and conditions. The radio spectrum and access network elements are among the resources that can be shared. Therefore, physical network sharing can be referred to as the sharing of radio spectrum or wireless network infrastructure or both. Radio spectrum sharing involves the licensed or dedicated free bands, sub-channels or the physical resource blocks as referred in LTE. With the availability of the cognitive radio, the radio frequency has evolved into white spectrums (holes) which are the unused spectrum by the owner at a given time [17]. This can be shared by other users as long as it does not interfere to the licensed user.

Infrastructures sharing can either be passive or active. In passive sharing, refer to sharing non-network components such as sites or premises while active refer to sharing of the network elements such as eNBs, backhaul, routers, backbone transmission, etc. Also, sharing can be cooperative or non-cooperative. For resources being made for public then non-cooperative sharing can apply. Otherwise, cooperative sharing must be implemented.

The combination of spectrum and infrastructure sharing forms a full network sharing supported by two architectures configurations which are multi-operator core network (MOCN) and core gateway network (CGWN) in the 3GPP specification [18]. The former involves the sharing of the RANs including radio resource themselves while the latter goes beyond RANs sharing, it also shares some elements in the core networks such as MSCs and SGSNs.

B. LEVELS OF INFRASTRUCTURE VIRTUALIZATION

VN requests a slice from the MVNO, based on the different scenario requirements. The different needs by VN marks the various levels of the wireless virtualizations. These levels include spectrum level slicing, network level slicing and flow level slicing.

1) SPECTRUM LEVEL SLICING

This is considered as an extension of the dynamic spectrum access and sharing [19]. The radio resources are sliced and assigned to the MVNOs through frequency reuse or time/space multiplexing. The controller schedules the air interface between the BS and the UEs.

2) NETWORK LEVEL SLICING

Some physical network nodes, e.g., BSs, service gateway, CPU, etc. are decoupled based on some criterion such as resource requirements, link quality, budget, and power.

3) FLOW LEVEL SLICING

In this level, the slices can be in the form of resource-based such as time-slot or bandwidth-based such as data rate. If an MVNO has customers to serve but does not have, physical infrastructures can request some from the MNOs.

The availability of many different scenarios determines the virtualization levels, in this section we consider two scenarios to describe the various levels of the infrastructure virtualization as viewed in Fig. 2. We use one MNO owning the entire physical network infrastructure. The two scenarios are presented with two MVNOs as 1) MVNO1 having the core physical network (i.e. physical evolved packet core (P-EPC)) but doesn't have RAN and spectrum, and 2) MVNO2 Own nothing but has customers to serve. MVNO1 involves spectrum and network level slicing to acquire the RAN and spectrum while the flow level slicing takes place with MVNO2.

The MNO evolved packet core (EPC) can be described as a framework evolved to provide both voice and data services in a 4G networks. It involves several components such as: mobility management entity (MME) which is responsible for session states management, authenticates and tracks user across the network. Serving gateway (S-GW) responsible

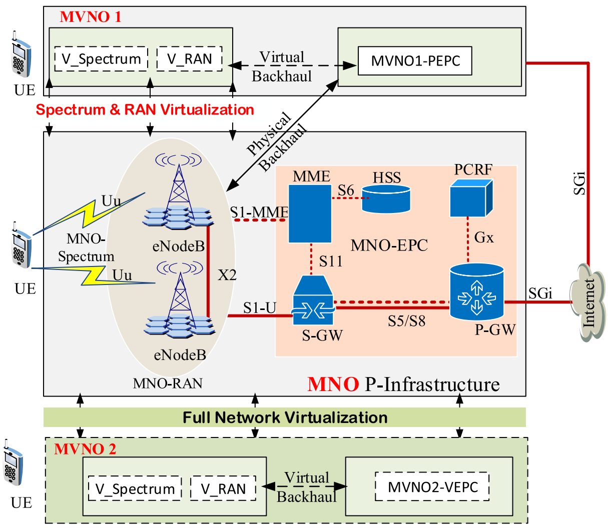

FIGURE 2. **Wireless network virtualization levels based on different scenarios.**

for rooting data packets through the access network while packet data node gateway (P-GW) works like an interface between the LTE network and other networks; quality of service management and deep packet inspection (DPI). And the duties of the policy and charging rules function (PCRF) are data flow detection, policy enforcement, and flow-based charging control.

III. SDN AND C-RAN: AN OVERVIEW AND ADVANCEMENTS

A. SOFTWARE DEFINED NETWORK

SDN in 5G [2], [20], [21] promises to provide and implement new capabilities and solutions for enabling the network control to be programmable, centrally managed, adaptable and cost effective which makes it suitable for a high bandwidth intensive applications such as video streaming. In fact, the underlying network infrastructure in SDN is totally abstracted from applications and the networking intelligence is logically managed in a centralized manner. Different standardization bodies and organizations such as the Open Networking Foundation (ONF) [22], the Software Defined Networking Research Group (SDNRG) of the Internet Research Task Force (IRTF) and the Internet Engineering Task Force (IETF) have been working for SDN standardization activities. Such standardization activities involve defining SDN architectural components and interfaces, specification of SDN and control capabilities for wireless and mobile networks using OpenFlow, classification of SDN models and their taxonomies, definitions of functional requirements and prospection of SDN for the future Internet.

From these standardization activities, the ONF defines the SDN as "*the physical separation of the network control plane from the forwarding plane, and where a control plane controls several devices*" [23]. Basically, the SDN decouples the control plane (CP) and the data plane (DP) which allows flexibility and centralized flow control of the entire network as well as provides capabilities of responding rapidly to changing network conditions, business, market and end-user's needs. Some of the advantages of SDN include:

- Providing granular network traffic control and high performance across devices from different network vendors. The network control provides an ability to network administrators to apply different QoE/QoS policies at the application levels, session and network devices.
- Centralized control and management of the entire network which improve automation and make it easier to centralize enterprise provisioning and management.
- Providing better experience to end-users through the network applications which are able to exploit the centralized network intelligence and state information to seamlessly adapt to network conditions and behaviors according to user's needs.
- Increasing network flexibility by providing new network services and capabilities with no need for configuring individual devices.
- Providing an increased reliability of the network and security through autonomic management of the network devices and policy enforcement uniformity.
- Providing an enhanced programmability opportunities/features/automation and network control to operators, enterprises, users as well as independent software vendors through a common programming environments. These opportunities help them in building a flexible and scalable network that can adapt rapidly to future changing business needs.

Traditionally, both the control and data plane elements of a networking architecture were closed packaged in proprietary, integrated code distributed by one or a combination of proprietary vendors. The closed and inflexible of the current commercial wireless networks which are integrated hardware based have led to significant challenges in adopting and deploying the innovations technologies [24]. The introduction of SDN in 2008 has solely changed the hardware-based networks in which most of the network devices have been decoupled into software based which is much flexible and easy to navigate to the innovations. Through SDN controller shown in Fig. 3, as described in [25], operators can manage and optimize resources allocation efficiently on time-varying network conditions and also control the vendor specific device dependent through standardized interfaces such as OpenFlow [26].

Due to the novel contributions of SDN, [27], [28] suggested that SDN need to be integrated in renovating the fronthaul designs, for payload scheduling and forwarding. Similarly, in efforts for renovating RAN, [29] applied SDN concepts in designing the software-defined hyper-cellular architecture (SDHCA) to provide a feasible way of integrating the control-traffic decoupled air interface, cloud-based RANs and software-defined RANs to enable green and elastic wireless access.

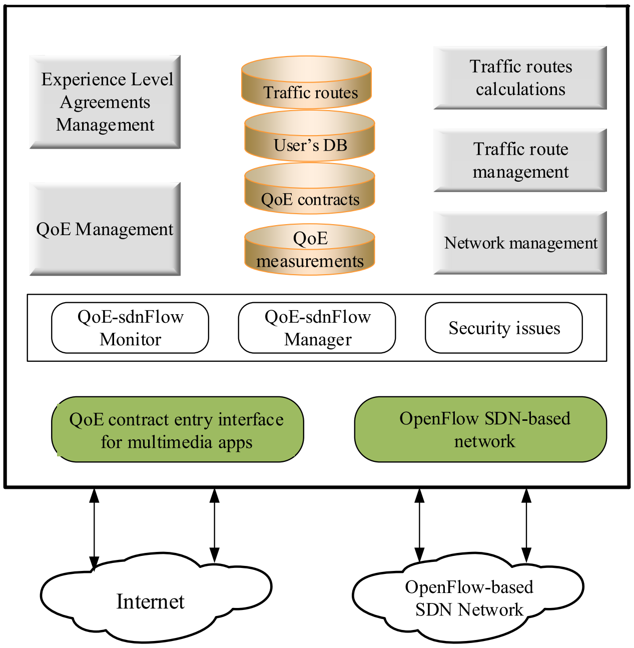

FIGURE 3. SDN controller with QoE entities [34].

Using SDN controller, MNOs are able to perform QoE control and management of multimedia services in different network domains through a well-defined SLA or the recent envisaged mechanisms called the Experience Level Agreements (ELAs) [15] which are defined purely based on QoE for improving the traditional SLAs. The QoE-sdnFlow Monitor and QoE-sdnFlow manager perform the QoE estimation and QoE measurements per multimedia traffic flow. It acquire network topology information and implement QoE based network policies and techniques by using different control algorithms for QoE traffic predictions, admission control, radio resource allocation, load balancing and user density prediction. In such as case, operators are able to provide services to the end-users with high QoE [25].

ONF describes the SDN architecture in three functional parts which are infrastructure layer, control layer and application layer [30], [32], [33]:

1) DATA/PHYSICAL PLANE

This consists the network elements such as physical switches, and virtual switches which expose their capabilities toward the control plane. The accessibility of these switches is through the open interface i.e. the data controller plane interface (D-CPI) to switch and forward packets. It composes heterogeneous network (HetNet) base stations here referred as eNodeB, which is responsible for forwarding and collecting information to the Control plane.

2) CONTROL LAYER/PLANE

This comprises a set of software-based SDN controllers which translates the application's requirements and consolidated control functionality through open APIs. The control plane is in charge of integrating all the available RANs and resources together. It supervises the network forwarding behavior through an open interface. Three communication interfaces which allow the controllers to interact each other includes southbound, northbound and east/westbound interfaces as shown in Fig. 4 [30]. The Northbound interface is defined as the connection between the controller and SDN applications, while the southbound interface is the link between the controller and the physical networking hardware.

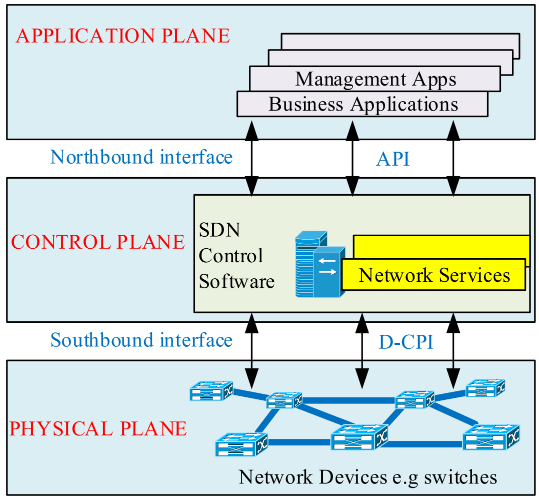

FIGURE 4. Overview of the SDN architecture [22], [24], [30].

3) APPLICATION PLANE/LAYER

It mainly consists of the end-user business applications that consume the SDN communications capabilities and the network services. These applications could include networking management, analytics, or business applications used to run large data centers. It communicates its requirements toward the controller plane through API.

The major problems with the current network setup or architecture are the scalability and the device vendor's dependents. First, the availability of the P-GW which centralizes the data plane functions such as access control, and QoS functionality become very expensive and the centralizing data-plane functions at the cellular internet boundary forces all traffic through the P-GW. This makes difficult to host popular content inside the mobile network. The proprietary based devices each runs vendors' specific protocols for their network devices hence; the operator faces challenges for adopting new services to their users [24], [26]. The current commercial cellular network systems rely on closed and inflexible hardware-based architectures both at the radio frontend and in the CN. This lead to the difficulties in adopting new services innovations, standards and preventing the growth of the technologies which can maximize the network capacity as well as increase coverage. Hence, the introduction of SDN gives the flexible design architecture for the future network systems.

B. CLOUD RADIO ACCESS NETWORK

The cloud-based radio access network (C-RAN) evolved from the traditional distributed BSs where a processing unit and the radio are integrated together. The processing capacity of these BSs are used for their mobile users and not being shared in a large geographical area. For example, this applies to the 4G architecture in which the inter-BS coordination is performed over X2 interface [34]. As the results during the day BSs in business areas are overloaded while those in residential areas are idle but continue to consume a significant amount of power, and vice versa. Due to the increase in the data traffic demands it becomes irresistible need to improve current RAN architecture to a better one which can minimize or solve the current problem and free up the capacity of these technologies. In order to overcome this challenge, the centralized architecture of the C-RAN was introduced [34].

C-RAN was introduced as a new design technology for the broadband wireless network access that provides a sophisticated level of cooperation and communication between BSs. It gives a better design to allow for dynamic reconfiguration of the computing and spectrum resources [34], [35]. It has a centralized processing, collaborative radio, real-time cloud computing, and efficient power infrastructure. This architecture combines all BS computational resources into a central pool called baseband processing units (BBUs) such as a set of physical servers in a data center, which enables communication among BSs with low latencies and exchange data at high speeds. The radio signals from distributed antennas are collected by remote radio heads (RRHs) and transmitted to the cloud platform through fronthaul usually optical transmission network (OTN) as illustrated in Fig. 5. The new architecture takes advantages of the multi-core processors which are becoming increasingly powerful. Hence, the cloud computing based on IT platform becomes a comfortable alternative for both IT service providers and cellular operators [22].

The fronthaul is a vital enabler for 5G systems, but its requirements can limit its usage in some 5G scenarios. The traditional fronthauling technique requires large bandwidth, low latency, tight synchronization, and allows for point-to-point logical topology. Due to the limitations in classical fronthaul, [27] proposed a fronthaul architecture which transports information other than time-domain I/Q samples and support the point-to-multipoint logical topology to fulfill the bandwidth and latency requirements for the next generation systems.

C-RAN aims to reduce the number of cell sites while maintaining similar coverage and reducing capital expenditures and operating expenses at the same time offering better services. A BBU pool serves a particular area with some RRHs of macro and small cells i.e. it has been designed to be appropriate for most typical RAN scenarios, as from macro cell to femtocell [36]. The implementation of the C-RAN employs the virtualization technology, in the BBU pool, there are many Virtual BSs (VBSs), in which all the processing (e.g. coding, modulation, fast Fourier transform (FFT) takes place by a single and powerful processor. The centralized feature for the C-RAN provides a flexibility and becomes appropriate to support cooperative techniques such as joint scheduling, beamforming, and interference reduction. Therefore, BBU pool is a virtualized cluster, consisting of general purpose processors for baseband processing [34].

The current RAN architecture consumes high power, China Mobile reported that RAN of BSs consumes the majority of power [12]. In order for operators to increase the broadband wireless network coverage to fulfill the high demand from the users they need to increase the number of BSs, which in turn raises the cost. The multiple standards is another shortcoming for the current RAN architecture. The available BSs in wireless network are based on proprietary hardware which follows the specific standard. An operator is required to buy almost the entire network equipment if there is a need for system upgrading, while maintaining the old ones to ensure technological coexistence. This contributes for the lagging behind in penetration of new technologies.

The limited cooperation among BSs also contributes to the insufficiency of the current RAN. The inter-BS message cannot be directly communicated among the BSs; instead, they have to be exchanged through a very expensive backhaul links even over one-level higher in the aggregated hierarchy. It does not utilize the advantages of the available cooperation scheme such as macro-diversity and the collaborative spatial multiplexing. Even for the proposed backhaul processing unit (BPU) where the neighboring cells are grouped into clusters, in which the BSs are connected, still the BPU i.e. clusters intercommunication needs to travel over the backhaul. In the practice, this leads to high latency, cost and difficulties in the inter-BS cooperation.

Lastly, based on the nature of the mobile networks, the current RAN architecture contributes to the underutilization of the resources. The mobile load at different location and time varies due to the user movements and activities (tidal effect). Since the current BS processing capability is used to serve users in a defined coverage, hence in some area/times, there are some BSs being overloaded and others being idle while continue to consume significant energy. The simple example can be taken during the working hours in the office areas where the BSs are overloaded while those in residential areas are idle.

C. C-RAN ARCHITECTURE

The general C-RAN architecture consists of three main parts. The RRH, BBU and the Fronthaul connections. The RRH is located to the remote cell area which is connected to the BBU via the Fronthaul connection. The BBU is equipped with very high speed programmable processors with a real-time virtualization technology for task processing and the fronthaul connection composed of the low latency high bandwidth fibers which connect the RRH with the VBS pool in the BBU.

The main features of the C-RAN include the centralized computing resources, spectrum reconfigurability, RRHs collaborative communications, and a real-time cloud computing

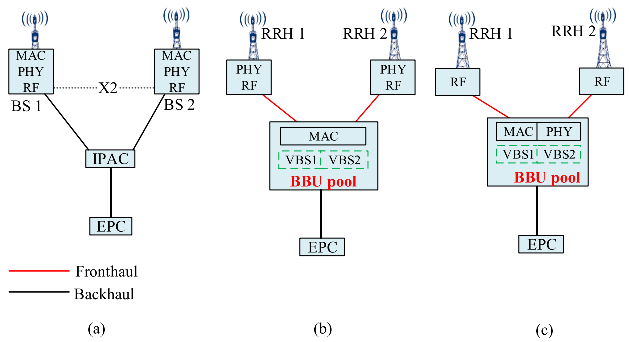

FIGURE 5. Distributed BS and C-RAN architectures [39], [41]. (a) Traditional Base station. (b) Partially Centralized. (c) Fully Centralized.

on generic platforms. Based on the functionalities, the C-RAN can be entirely or partially centralized. Fig. 5 illustrates the current RAN, both the fully and partially C-RAN architecture. This is based on the MAC and PHY functionalities separation. The partially C-RAN architecture is shown in Fig. 5 (b), where the RRH is integrated with the PHY processing capabilities while that of MAC is separated and being processed in the BBU pool. This helps in lowering the exchange of data volume between RRH and BBU [9], [11] at the same time the wireless resources can be scheduled on a global level. But, leaving the PHY cooperative techniques at RRH, some rooms for the equipment at the remote sites are required. In the C-RAN architecture shown in Fig. 5 (c), RRH is responsible for radio frequency (RF) functionalities only, the rest are processed at BBU pool. By this architecture, the cooperative techniques are more preferred although higher bandwidth for data exchange between RRH and BBU pool is required [35]–[37]. C-RAN brings various advantages in the communication system as described in [9] and [38]–[41]:

1) ENERGY EFFICIENCY

C-RAN reduces the number of individual distributed BSs from servicing 24 hours, 7 days in a week by freeing them from performing processing activities on the site. All processing functionalities, which were implemented in a remote site, are now centralized performed at BBU pool. This helps in reducing power consumption of air conditioning and other supporting equipment at the given location. Also, load congestion which many BSs can be turned to low power or some even be shut down selectively. With C-RAN the cooperative techniques for interference reduction can be applied. Hence, operators can install new heterogeneity RRHs i.e. the small cell with low transmission power, can be deployed which in turn helps to reduce the power consumption of both RAN, and MSs.

2) COST REDUCTION

With C-RAN all computation resources equipment supporting a large area is being aggregated in a few big rooms while the non-computation processing being left in the remote site RRHs. It simplifies the management, operation, and maintenance compared to the traditional RAN. Also, the RRHs functionalities are simplified which leads to size reduction and power consumption, hence reducing both CAPEX and OPEX. The RRHs can be even installed on top of the buildings with small site support and management requirements. Lastly, the construction of the site can be faster because the site installation mainly requires the antenna feeder systems.

3) EFFICIENCY SPECTRUM UTILIZATION

The centralization of the computational processing in a BBU pool, simplifies the sharing of the channel state information of each base station-user equipment (BS-UE) link, traffic data, and control services among BSs in cooperation with low latency. It promotes the schemes of multi-point cooperation and enables multiplexing more streams on the same channel with little or even no mutual interference, which in turn improves the spectral efficiency.

4) EASY TO ADD/UPGRADE TO NEW STANDARDS

The high-speed low latency interconnection and the C-RAN employing the general purpose processors and the software defined radio (SDR), make easier in the BBU pool for the development of the VBSs. Hence, for the operator to add or upgrade to new standard does not need to replace any equipment but to assign a VBSs platform to support it which can reduce or eliminate the cost associated with the system upgrading.

5) SIMPLIFY THE INTER-BS COORDINATION

With the centralization of the BSs functionalities at the BBU pool, the co-located BSs can talk to each other at very high gigabit speed with very low latency. This can help in finding the optimal decision on varies scenarios such as load balancing and scheduling, mobility management, interference controls, and the cooperative spatial multiplexing with macro diversity by fully utilizing the potentials of the cooperative techniques. Table 1. summarizes some research directions for the C-RAN.

IV. FUTURE CELLULAR NETWORK REQUIREMENTS AND OPPORTUNITIES

In this section, we present the future cellular network system requirements that need to offer based on the current services provided. The future systems design will be based on two primary keys principles which are flexibility and reliability [66]. The future user cases will be more diverse than ever and will require very broad link characteristics. For example the massive data transmissions require large packet sizes, and a lot of allocated resources. Also the flexibility is necessary as the first key in design as a new technology or system need to be future proof and can last in a span of at least ten years which can allow expansion, and accommodate the new technologies. The latter i.e. reliability is not only about equipment uptime, but it also relates to the perception of infinite capacity and coverage that future mobile networks need to deliver.

TABLE 1. Summary of the research issues on C-RAN.

Sources	Research Issues	Briefing
[42][43][44][45][46] [47]	Evaluation of the fronthaul transportation between RRH and BBU pool.	Optimization of the fiber optic transmission. Considering the wireless front-haul from traditional optical fiber networking.
[2][12][48][49][50][51]	Evolutions of the C-RAN energy and cost saving.	The quantification of the amount of savings from C-RAN have to be evaluated.
[52][53][54][55][56][57]	Quantifying the increase in throughput in C-RAN.	There various technologies that can incorporate and enhance the C-RAN throughput.
[58][59][60][61][62][63][64][65]	Realization of the SDN and NFV benefits for the software virtualization in BBU Pool.	There are many works for the hardware virtualization in wireless networks which are relevant to the BBU pool virtualization in the C-RAN technology.

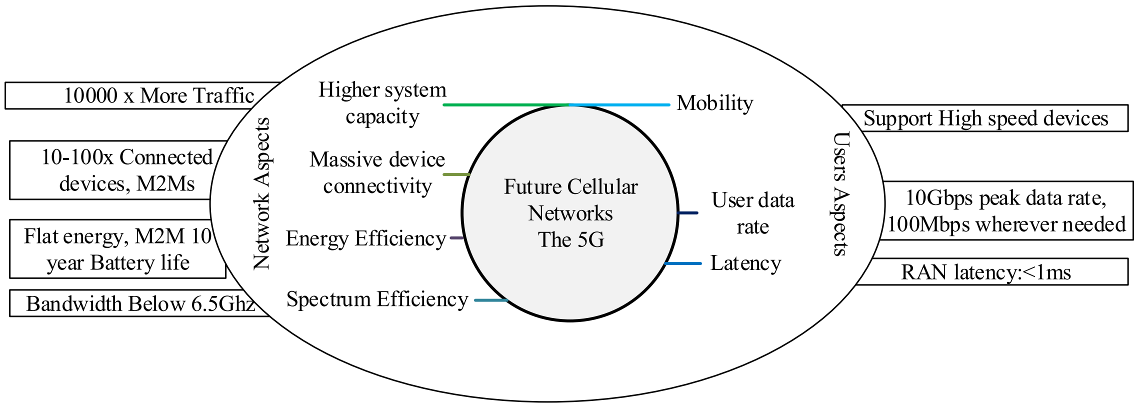

FIGURE 6. Requirements for future wireless network system.

The users' experience for the data delivery is to be received in the required time without being dependent on the technology used. There are varying user cases that drive and dictate the future cellular network, these include mobile broadband, automotive, smart society, smart grids, health, industrial, and the logistics / freight tracking [66]. The user case scenarios and the network design principles lead to the requirement that the future system needs to offer. Fig. 6 summarizes the key requirements for the future networks such as 5G needs to provide. Through achieving these requirements, the system will be able to manage the following components which are very useful in network systems [67], [68].

- *Efficient resource utilization*: Since the wireless resources such as spectrum are scarce, through network virtualization reconfigurability of the scheme, content-aware capabilities and sharing will lead to effective use of available resources. This will increase the transmission capacity of the wireless system in which MNOs will enhance their revenues.
- *Flexibility*: For the system to support diverse services to the end users; then sharing of both physical components and the frequency resources among multiple operators is very appealing. With the new intelligent technology based on the SDN and C-RAN, the system becomes very flexible in a sense that any changes in technology can be accommodated without incurring too much cost. The operators become flexible to expand or shrink their networks and the air interface resources. A VN can be configured based on the services or business offered without affecting others.
- *Quick optimizations*: Innovations in any aspect, can be easily introduced without the need for the new infrastructure to be deployed. This is due to the availability of the open standards interface being configured in software platform and not vendor's protocols. In the case of VNs, isolation helps to separate the faults among them so as do not affect other coexisting VNs. But errors and misconfigurations in the underlying physical network can also destabilize a virtualization environment which can lead to instability of all the hosted VNs. Therefore, systems have to ensure the stability environment and in a case of any uncertainty then it should optimize fast to their stable states.
- *Reduce investment and operational cost*: Traditionally the MNO to start operating needs to deploy the physical network infrastructure e.g. BSs. With WNV based on SDN and the C-RAN architecture, several virtual BSs can be created with different requirements and be processed by the general purpose processors (GPPs). The VBSs can be allocated to various MVNOs or service providers accordingly. This setting reduces the investment and operational cost significantly. The radio access parts withhold 50%-80% of energy, switching off some BSs sites will have a significant contribution in energy saving [69]. It was estimated that, WNV alone can reduce the OPEX and CAPEX up to 40% worldwide

within five years period [70]. With different levels of virtualization; it was also observed that by sharing sites and antennas 20%-30% of CAPEX can be reduced. Also, 25%-45% of CAPEX can be reduced by sharing the entire radio network, and the addition of 10% of CAPEX will be reduced by sharing the entire assets of the system [71]. It implies that 35%-55% of CAPEX reduction can achieved if there is sharing of the entire assets of the network.

- *New business model*: WNV enables an entirely new value chains. Small players can come into the market and provide new services to their customers through VNs [72], [73]. It allows an entirely new feature of the networks, e.g., isolating one VN (like a production system) from a best effort internet access network. Sharing the physical resources will enable these players to enter the market and provide their services wherever required. Besides the innovation will be tested in the real infrastructures without affecting the performance of the operating network systems. That is the experiments for innovations are done in the actual system [74]. In other word WNV encourages new innovations into the system.
- *Coexistence and isolation*: One of the purposes of the virtualizing network is to make multiple systems run on the same physical resources. That is multiple virtual networks should cohabit concurrently on the same physical network infrastructures. The availability of many coexisting radio access technologies can support the existence of the heterogeneity VNs. Isolation involves the capability of avoiding the conflict among the coexisting networks. That is to limit the impact of one VN on other VNs [5]. It ensures that any configuration, customization, topology change, and removal of any virtual networks do not affect the performance of other coexisting networks [7]. The changes in one virtual slice such as a change in traffic load or channel quality for a particular operator should not affect others. Isolation is the core issue which can guarantee fault tolerance, security, and privacy [75]. It was revealed in [56] that, wireless network especially the cellular networks, any changes in one cell, will cause high interferences to the neighbor cell while the mobility of the end users can cause instability in a given locality.
Coexistence is one of the fundamental principles of WNV. It makes scalability an essential part of VNs. Virtualization must support an increasing or decreasing number of coexisting VNs without affecting their performance. For a large scale, it is necessary to design the scalable VNs so that any modification or addition of further physical network becomes easily accessible.

V. AN SDN-BASED WNV ARCHITECTURAL FRAMEWORK

Based on the business model given in [76] it indicates that VN rent resources from one or more InPs. This signifies that InPs can share their infrastructures to provide a quality and reliable services to users while increasing their revenues. In this section, we provide WNV architecture to support multiple InPs.

In the current setting, a user is free to subscribe services from any MNO of his or her choice. In a crowded area where thousands of users are gathered for different purposes, each can enjoy the services from the provider. Fig. 7 shows the proposed architectural framework for the WNV with multiple InPs.

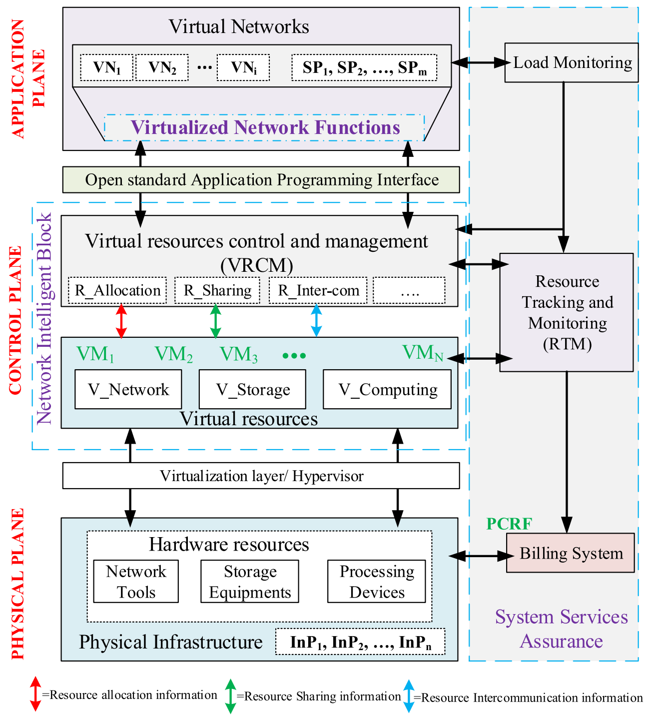

FIGURE 7. WNV architectural framework based on SDN.

Physical infrastructures are virtualized through virtualization layer in which virtual resources (VR) are created based on the needs. The available VRs are controlled and managed through VRCM where resources allocation, sharing, inter-communication, isolation, and reassignment are implemented. The SDN-based open standard application programming interface (OSAPI) and VRCM where the network intelligence is centralized, will reduce the thousands of standard protocols which had been processed before (i.e. vendor dependent specific rules) instead it will accept the instruction from one point. As a result, the network system becomes flexible, and the resources are effectively utilized. VRCM allows the VN to customize their allocated resources to fulfill their requirements. That is the MVNOs can configure their protocols and services which include scheduling and forwarding for their needs.

Network functions (NF) can be configured with respects to the services being provided by the VN. In current setting the NFs are specifically dependent on vendor's hardware and software. They need to be manually installed into the network environments which creates an operational challenges especially if there is a need for new innovations upgrade. But with virtualization technology all NFs are virtualized into software centered (Virtualized Network Functions (VNF)) which can be easily downloaded, installed, configured and deployed on top of network function virtualization infrastructures (NFVI). Network function virtualization (NFV) technology decouples the physical network infrastructure, creating several virtual machines (VMs) which runs the VNFs. It should be noted that, a VNF can be composed by multiple internal components in which each component can be hosted in one VM. However there are some cases in which the whole VNF can be deployed in single VM.

The architecture includes the billing system as it allows sharing of the resources from different owners when the need arises. The billing management allows every player in the system to be paid according to the resources being contributed in serving the end users. The contribution will be controlled by RTM assisted by Load monitoring block (LMB). The function of the LMB is to estimate continuously the load based on different characteristics/features of the networks. It will help in decision making for example at what time the resources have to be shared to provide reliable services to the users such as in the crowd areas.

According to the scenarios, requirements and key performance indicators (KPIs) in 5G defined in [77], some of the given scenarios solutions can be found based on this architectural framework. For example amazingly fast services and excellent services to the crowd. The two scenarios are among others that can be taken care. The high data rate at a large group can be achieved by having broad spectrum carrier and sharing the resources from different providers, being done automatically. The intelligence of this architectural framework is supported by software defined network (SDN) and software defined radio (SDR) where all the network functionalities are accomplished in software [78] and processed by very powerful GPPs from information technology (IT) industry.

A. DEMAND-AWARE COMMUNICATION SYSTEMS

SDN, WNV, and C-RAN creates the demand aware communication systems i.e. an automatically reconfigurable system to satisfy the requirements in future cellular networks the 5G. As described in previous sections, the current communication system architecture does not effectively manage the existing challenge of load balancing in crowded, and non crowded areas. Some areas are overloaded while others are idle but still consuming energy, while not satisfying the end users' services. The SDN, WNV, and C-RAN based architecture for the future cellular networks can automatic reconfigure to balance the load and ensure the QoE while utilizing the available resources effectively. Fig. 8 illustrates the features of the future communication systems in ensuring service satisfaction, efficiency resources utilization,and cost reduction.

In Fig. 8 the number of users in particular areas depends on time, and the related activities. It gives three locations regarded as sites with different functionalities. The sites are considered as the residential zone, entertainment zone, and the business zone. During the day, the business (offices) zone experience dense users while the residential and entertainment zones have few users Fig. 8(a), and the opposite case is given in Fig 8(b). With the current setting, the cellular network system allocates the resources equally without considering the load each site possesses. This problem was also

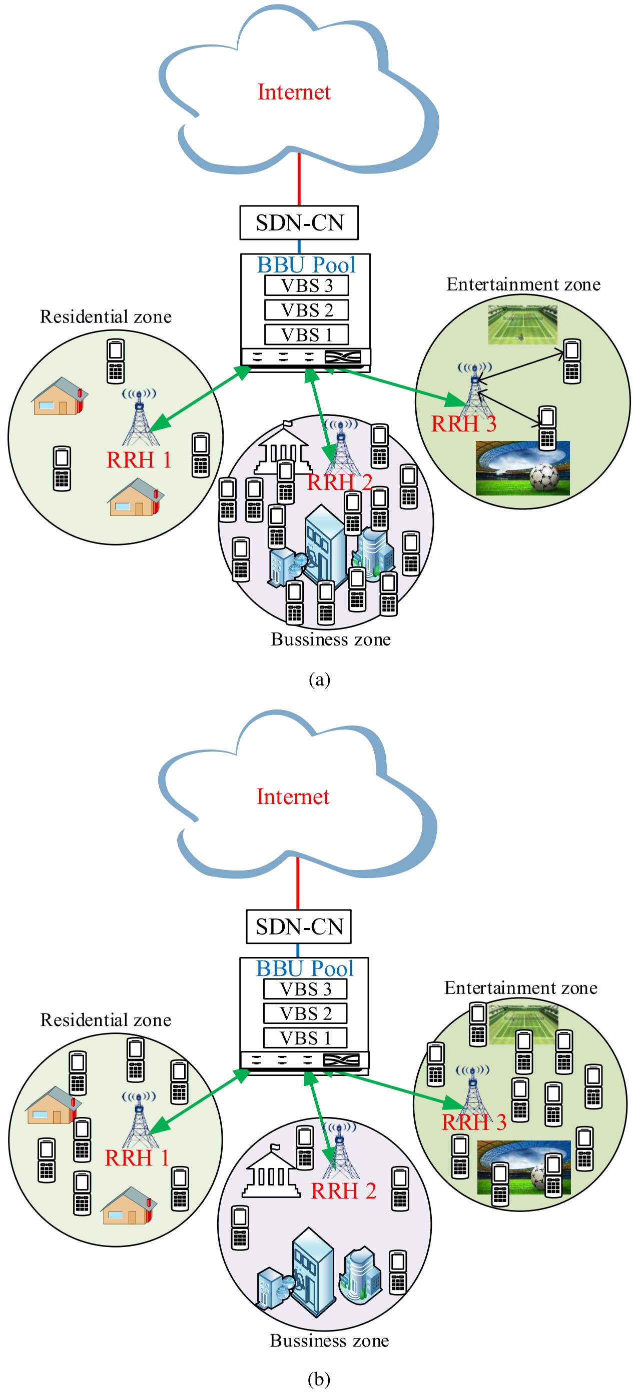

FIGURE 8. Demand- aware communication systems illustration [34], [38]. (a) Day time. (b) Night time.

TABLE 2. Some proposed methods and their challenges for resources management.

Proposed method	Contribution (s)	Challenges of the method
Hypervisor contract spectrum management [13].	Reduce Operation cost for SPs. Improves resources utilization.	Interferences between VNs is not considered. Increases latency time due to the introduction of the hypervisor. Difficulty in designing a hypervisor for a real time.
Time-Space Combined resource allocation scheme [82].	Improves resources utilization up to 117%.	Computational complexity. Some parameters require manual alteration.
Dynamic Greedy Algorithm [81].	Maximizes the InPs Revenue. Reduce the rejection rate. Resource grid was effectively utilized.	Assumes that VNOs know exactly the resources needed. The heterogeneous environment was not considered. Did not consider fairness in resources allocation, focus on priorities only.
Flow level virtualization [6][83].	Ensure isolation and customization.	The random nature of the wireless network was not considered. It considers only single MCS in all situations. Channel quality was not considered.
Bankruptcy Game- Based Resource allocation [84].	Provide flexible in resource allocation among big and small VNs. Improves resources utilization through cooperative sharing. Fairness resources allocation was considered.	It based on predefined contracts. It considers only cooperative scenarios. Heterogeneous environments were not considered.
Opportunistic spectrum sharing with genetic and heuristic algorithms [85].	Increases the InP revenues. It involves more than one InPs.	It assumes that each VN connects to only one InP. The economic relationship between VNs & InPs were not considered.

addressed in [79] where they proposed the dynamic BS sleeping and cell zooming to reduce energy consumption during the low traffic hours. Based on the assumptions being given, it was revealed that, about half of energy can be saved through BS sleeping and power control. When MNOs deploying many BSs with BS sleeping can help in saving more energy consumption.

Therefore, the integration of SDN, WNV, and C-RAN will involve the intelligence techniques in analyzing and balancing the load in each site. This integration reduces the number of remote sites which has an economic impacts. The locations with many users need more resources to be allocated to it, and the opposed is true while ensuring reliable communication at all the time [38].

B. RESOURCE ALLOCATION TECHNIQUES IN WNV

Since the resources are scarce, the available resources have to be well utilized and managed. One of the fundamental challenges in WNV is how to assign the isolated resources efficiently to the different virtual operators. Several researchers have proposed various resources allocation methods/techniques. Resources allocation can be based on multiple criteria e.g. bandwidth, data rate, power, interferences, pre-defined contracts, channel conditions, traffic load or a combination of these parameters [17]. In this section, we provide some proposed techniques for the resources management in the WNV as presented in Table 2.

VI. CHALLENGES AND RESEARCH ISSUES

Although SDN and WNV have been used in current networks with many useful features, there are still numerous significant concerns that need to be addressed (e.g. performance, availability, scalability and security). These are among the pioneer technologies that many researchers have shown their interest and belief in solving the growing user demand for the future network systems. The introduction of the C-RAN technology steers up the belief on the technologies. They are many steps for the user equipment to communicate with other UEs such as, session setup between source and destination, physical resource allocation to fulfill the requirement [85]. Furthermore, optimal and flexible resource management should guarantee QoE and provide higher system performance in the data forwarding procedure. In this section, we provide some challenges that need to be addressed for future networks system to satisfy the end user's demand.

A. SYSTEM SECURITY

The densified environment, with intelligent devices from different technologies is the home of the security threats. WNV encourages different networks to share the same resources for providing services to their end users. SDN enables the control of the centralized systems; the security mechanisms need to be well designed to ensure the privacy and confidentiality of the user data. Security is still a challenging issue even in the traditional wireless system; for example, mobile devices are becoming a focal point for the cyber-crime. The development and availability of the intelligent and content-aware devices in a heterogeneous environment bring new threats beyond to those in traditional wireless networks. A robust authentication system is required to ensure integrity, confidentiality and non-repudiation of the system. Since there are always some weak points in any systems, a multi-level protection is needed [86].

Distributed denial of service (DDoS) is among of the security threats, especially in resource pooling leading environment. Through decoupling of the control plane from the data plane, the security threats are fast increasing compared to the traditional networks [30], [31]. Several SDN security threats have been reported in [87] apart from DDoS others includes unauthorized access, data leakage, data modification, and malicious applications. The detailed information for DDoS threats can be found in [88].

B. INTERFERENCE AND FADING CHANNEL

The transmission channels in wired and wireless environments are completely different. In a wired network, the transmission media are guided, highly reliable and almost have a constant quality compared to wireless transmission media. However, due to the broadcast property of wireless channel, the communication between two nodes also affects the transmission of other nodes, while the process of signal propagation experiences random fading. To support dense devices in the same infrastructures without interference, then isolation is the essential function to enable the abstraction and sharing of resources among different tenants. It should be noted that the desires are that whenever any virtual wireless networks change their configuration, customization, and topology are not allowed to affect and interfere the coexisting Virtual networks. To confirm this in [81] proposed a time -space combined resource allocation scheme for WNV to increase isolation across different experiments but their scheme suffered from computational complexity due to large number of variables in which some are manually adjusted.

C. INTERFACING

In wired virtualization, the needs can be expressed in a standard specific language concerning virtual nodes and virtual link [89]. In WNV SPs require radio resources from one or more InPs, at the same time different RATs can be used by the SPs while using the same InP. Unlike the traditional wireless networks where user is connected to one MNO and probably using the same RATs throughout. A well-defined standard interface is required for the InPs to understand the radio requirements of the SPs [7]. Also, the standard language to explicitly express the sharing information among different InPs is required for the VNs to be realized. Finally, the proprietary dependent should be addressed to provide open standard interfaces.

D. NODES MOBILITY

One of the most important features of the mobile wireless network environment is the free movement of nodes and services. It is one of the advantages of wireless network systems particularly cellular networks. But this advantage leads to some challenges in WNV. This mobility rises the two new challenges for the mobility management. Since the user may perform a location update with different MNVOs or InPs, leads to the latency and handoff problem. It is contrary to the traditional wireless systems, where the user belongs to single MNO, and a single operator performs the location updates. It should be clear known that the user location and handover depend on each other [90]. Therefore, there is a need for a mobility management that can ensure the tracking and synchronization of all users' location updates in every scenario including the very-high-mobility (e.g., high-speed trains, planes), and with low to no mobility end users. In order to maximize users' QoE in a dynamic environment, a quality-oriented mobility management solution with efficient resource allocation is required.

E. PHYSICAL RESOURCE DISCOVERY

To consider resource allocation, the available resources should be first discovered and known. In a traditional network (wired network) this is a simple task since the whole topology of the system can often be known, which means the total resource capacity is known, and the remaining resources are simply the total capacity minus the resources which have been allocated to virtual networks [91]. However, the resources for wireless networks are dynamic and have randomness nature. For WNV to realize then, the InPs should be able to discover the available resources in underlying physical wireless networks. InPs are required to determine their resources to be virtualized and also leave some for their usage [92]. Coordination and communication protocols have to be well designed to be used between the InPs and the MVNOs.

F. RESOURCE ALLOCATION AND SCHEDULING

Resource allocation for the virtual wireless networks is among of the challenge that needs attention. Resources are allocated through the resource allocation schemes which are required to embed the virtual wireless networks (VWNs) on the physical network [7]. It is contrary with the wired networks; the resource allocation in virtual wireless is much complicated. Several reasons for the complexity include user mobility, the variability of the radio channel, frequency reuse, power control mechanism, coverage, and interference [93]. It should be noted that the resource allocation should consider both directions the downlink and the uplink. The NP-hard optimization can reduce embedding virtual networks with constraints on resources or requirements [94]. The sharing nature of the VWNs scheduling for the allocated resources has to be implemented. It is due to the wide range of the services provided by different SPs. To ensure the QoE for various SPs in serving their users then a dynamic resource scheduling is needed. Also, the unpredictable nature of the wireless network environment and the user being connected/updating its location through various SPs or InPs add more challenges. Therefore, optimized solutions for resources allocation and scheduling is required to ensure the effectiveness of the resource utilization and the performance of the virtualized wireless networks. Furthermore, the coordination mechanism among SPs and InPs should be developed to provide the exactly user's location which in turn will lead to a reliable and QoE provisioning to the end users.

G. REVENUE SHARING

In traditional setting, the MNOs are the owners of the network infrastructures and SPs. Most of them are not ready to share profits unless strong economic and regulatory reasons arise [95], [96]. Therefore, the WNV to be realized either the regulators or policy maker have to make the resource sharing policy and reinforce it. Furthermore, the economic technology issues have to be resolved, for example if all the InPs have to share their spectrum, then the evaluation on how each InPs contribute the spectrum should be considered. However when the physical resources (such as eNodes) are shared, at the point where there is an overlap among InPs or the demand for the resources is low, some of the eNodes can be turned off [97]. In addition, an open standard development for the network should be developed and enforces to reduce the self-centered vendors protocol dependents. This reduces the operation cost; energy consumptions and increases the revenue.

H. NETWORK MANAGEMENT

Management is necessary to guarantee the proper functioning of the physical infrastructures, the wireless services supported by the virtual networks and the host virtual wireless network. A virtual network can span over several underlying physical networks which bring new challenges in network management. The user state instability can make SPs to change dynamically the resources request. Therefore, there should be a clear network management mechanisms that can avoid the conflicting among the participating parties in the system. Moreover, the core network can be heterogeneous in which various components have different unique properties hence the special solution and mechanisms in managing the WNV are inevitable.

VII. FUTURE NETWORK SERVICES: SOLUTION AND SECURITY FORECAST

A. RESIDENTIAL CUSTOMER SERVICES

SDN promises to provide rapid service innovation and development through interfaces of application centric networking which can permits third party applications to leverage the networks capabilities. Such application and services includes the web filtering, an approach shown in Fig. 9 using SDN and NFV. This can have impact on residential services due to some of advantages such as an increased rate of services innovations, self-care and self-ordering of these services. Fig. 9 shows a use case scenario where an intrusion detection and prevention systems (IDPS) can be configured by SDN to analyze and outline a customer's traffic for the purpose of identifying unusual traffic patterns in future network services (e.g., 5G network services). SDN would permit short duration services to be provided as well as long premium services subscriptions. In fact, as shown in Fig. 9, SDN and steering could also provide on demand content filtering returning full control of the services to the end users. This could enable a service to be dropped in or out of the service chain depending on customer's particular circumstances.

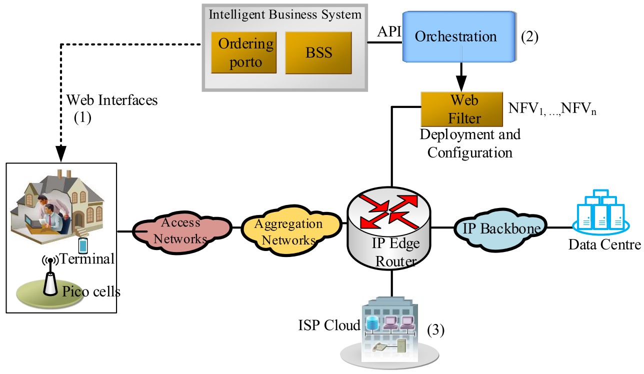

FIGURE 9. Customer configurable web filtering based on SDN and NFV approach.

The SDN and NFV deployment for content filtering in future network services have the benefits of making it easy to scale filtering up or down as required. For example, if the filtering will be implemented on a hardware machine with appropriate orchestration functions, then spare processing capacity can be rapidly applied on scale out the network filters in the event of unusual circumstances. In Fig. 9, the first step a customer determines new filtering requirements, performs ordering and configuration of filters via an ordering portal. The orchestration function then shown in step (2) instantiates web filtering in the ISP cloud and inserts it into the customers service chain. After, this instantiation of web filtering, all customer traffic is passed through the newly installed filter in the ISP cloud as shown in step (3).

Future mobile networks, may take advantage of the flexibility offered by service chaining to optimize their network's content delivery and content optimization so as to maximize a customer's QoE for their current access. In fact, NFV and service chaining within the IP network infrastructure should provide a significant benefits in terms of the cost and flexibility of these solutions. The end users QoE can be improved when optimization of the content types and traffic flows through the network, especially in the HetNets, the access network discovery and selection functions.

B. BUSINESS CUSTOMER SERVICES

Business customers today can be served by providing to them simple leased lines, backhaul services and potentially Virtual Private Networks (VPNs) in layer 2 and layer 3. For future network services, SDN promises to delegate control to the customer, provide a means of automating and streamline VPN configurations and removing the need to perform resource intensive configurations each time a customer network changes its path and routing requirements.

It would be possible to offer ordering services at configuration portal that let customers configure their own layer 3 VPN and maintain it. The portal would interface to the orchestration platform which would provide an end-to-end service and modify using SDN controllers such as floodlight within the network. Fig. 10 shows a DDoS mitigation based on SDN and NFV approach for future network services.

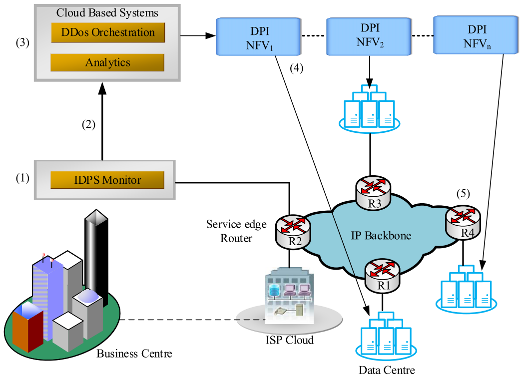

FIGURE 10. A DDoS mitigation based on SDN and NFV approach.

The IDPS is first installed in service chain for business customers as shown using (1). In case of unusual circumstances, the IDPS is able to detect and prevent abnormal events as shown in step (2). The central IDPS and the DDoS prevention system then determines the DDoS attacks and launches the necessary countermeasures in a cloud based systems. The network virtual functions shown in step (4) perform the necessary deployment network function configurations using tools like DPI. Finally, the NFV is installed and inserted into the service chain.

Future network carriers will be able to exploit the benefits of SDN and NFV and offer business customers services such as on demand storage and compute services on a distributed cloud platform as shown in Fig. 10. Such services enabled with a suitable orchestration and ordering system will basically allow new and innovative network applications to be created, advertised on a portal and dropped into a customer's service chain. Network carriers may also offer IDPS solutions as per residential case shown above where SDN and NFV can provides a platform for tackling the DDoS attacks that have been directed at a given customer. Such an approach would allow classifiers to be installed which will identify suspect flows at the edge of the network and re-direct them to DPI platforms where network traffic can be scrubbed. However, the network traffic flows with no suspect of attacks can be passed through to the enterprize using the normal network path. SDN in future network services is envisaged to provides a dynamic tool for combatting such attacks through a controller such as open daylight which has an integrated elements of this capability.

VIII. CONCLUSION

The current growth of user demands for real-time experiences has led the MNOs to have the look on new ways for services delivery at a lower cost. WNV has emerged as a possible approach to making network equipment more open, which allows the MNOs to become more flexible, and easily adapt to the innovations. Through network resources sharing WNV can reduces both CAPEX, and OPEX. WNV together with the closely complimenting fields of SDN and C-RAN gives a bright future of communication systems.

In this paper, we introduced WNV, described its features and contribution for the future systems as well proposing an architectural framework based on SDN. We have noted that the flexibility, interoperability, integrated management, orchestration, and service automation of WNV, led to many communication stakeholders to investigate on the WNV as a solution for their current and future network challenges. However, for the time being there is no a well defined WNV standards. It is, therefore, important, and urgent for the respective bodies to come out with specifications and standards so as to spear up the new innovations.

The requirements and opportunities for the future cellular networks technologies are identified. An in-depth review of the concepts of SDN, C-RAN, their features, relationship with WNV, and architectures have been discussed. Also, the challenges and research issues that will be essential to the success of the WNV which need to be addressed in bridging the gaps for future networks communication improvements is given. Finally, we provided several promising candidates of future network services for residential, and business customers.

In general this research area still in infant stages, it is argued that research organizations and individuals to focus on integrating these complementing technologies into a single powerful system. These technologies have promising solutions to the current and future challenges in mobile communication systems.

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