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Resource allocation in SDN based 5G cellular networks

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Abstract

The deployment and operation of Fifth Generation (5G) network is expected in 2020. The 5G aim to provide high throughput, reduced latency, increased capacity and a shift from service-orientation to user-orientation in requirements and innovations. The users require an efficient resource allocation and management. The closed infrastructure and ossified services of existing networks lead to complex, inefficient resource allocation and underutilized network resources especially in wireless networks. Different allocation techniques are proposed based on the utility gain of a service provider and user satisfaction. Software Defined Network (SDN) and Network Function Virtualization (NFV) are a hot topic in the wired and wireless network for the network management. SDN based 5G network is another stepping research domain for resource allocation and connectivity in 5G network. In this paper, a survey on state of the art on the 5G integration with the SDN is presented. A comprehensive survey is presented for different integrated architectures of 5G cellular network based on SDN and NFV form part of the paper. Different architectural integration of other wireless technologies such as 3G/4G, LTE, WiMAX etc. are highlighted in term of SDN and network virtualization. Furthermore, the paper focuses on the methods and techniques adopted for resource allocation for SDN based cellular network and elaborate requirements for futuristic 5G networks. It also highlights the role of virtualization and provides an analysis of abstraction for resource allocation in SDN based cellular network. In the end, the potential problems and issues are also comprehended in this article.

Keywords SDN network · 5G · Resource allocation · Bandwidth management

1 Introduction

Current wireless technologies are sprouting IP connectivity to provide a faster Internet connection, multimedia applications and a multitude of services to the end user on their demand. The introduction of the 5G system has increased user demands and data rate demand has raised to 1000-fold. It requires essential management and monitoring, programmability and flexibility to meet the demanded performance and higher data rate at a lower cost. It was approximated that 1.2 billion devices are connected in the third quarter of 2016, and mobile data growth rate is 4000 folds in the last decade [1, 2]. Currently, 4G is providing IP-based services up to 1Gbps with optimized performance. However, billions of connected devices with growing demand and diversity require a high volume of data, low latency, and high throughput. The future 5G technology is anticipated in meeting these requirements and is driving new communication capabilities of high definition and applications in all fields, especially on the Internet of Things (IoT).

5G is anticipated as a unified platform for providing seamless connectivity with a higher data rate of 10 Gb peak data rate, 100 Mb of edge cell data rate, and lower latency. The 5G wireless network is user-centric which require efficient resource allocation for meeting Quality of Services (QoS). However, efficient resource allocation is a major challenge for the increased demand for the 5G cellular network. The wireless network resources are significantly defined in term of the spectrum, power, channel, etc. which need to be allocated according to the user requirement. A cellular network may suffer from spectrum resources scarcity due to the

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immense increase of network users and connected devices. The rigid infrastructure of cellular network statically allocates resources at the backhaul network suffer from many drawbacks [3], which need a change in the existing infrastructure. The 5G focus on the spectrum allocation in a heterogeneous network, accessing high transmission rate and diversity for Multiple-Input Multiple-Output (MIMO).

In a cellular network, changing wireless conditions and limited shared spectrum require fair resource allocation and fair scheduling at the base station. Resources in a cellular network are provided by Base station (BS) which maintain incoming flow queue and schedule them at the time of deployment. This static allocation leads to inefficient resource utilization. For efficient resource allocation, virtual resources are allocated in slices to serve service request. The virtualization of resources at the BS required frequent management due to the frequent changing dynamics of cellular networks. In wireless virtualization, physical resources such as wireless spectrum are shared by providing an abstraction layer of the common physical infrastructure. The virtualization in a wireless network involves a different level of virtualization from the core network to radio spectrum. Moreover, the future 5G cellular network offers differentiated services which need resource isolation and management using wireless slices [4]. However, in the existing research, wireless virtualization solutions are still facing many challenges due to link variability, partial isolation in the wireless slice, the distance between source and destination etc. [5].

The existing networks are closed entities and suffer from network ossification due to the inherent coupling of control plane and data plane. Resource allocation becomes a big challenge in such tightly coupled network. However, SDN provides dynamic resource management by decoupling control plane from data. SDN is primarily used in data centers and provides a centralized orchestration. Recently, SDN based wireless architecture is also proposed to envision the associated benefits of SDN in wireless environments. SDN is also considered as a key enabler for wireless network virtualization due to its decoupling principle of control and data plane and centralized orchestration. In wireless virtualization, flow-based isolation is still lacking. Wireless virtualization also suffers from queue length problem. These factors degrade the overall network performance.

In this research paper, we explore SDN based cellular network more explicitly working around resource allocation in a 5G cellular network. This research is about network virtualization in term of wireless resources in cellular networks. Different flows are classified into isolated flows and resources are allocated according to the assigned scheduling weights. The physical resources are mapped with the virtual slice on the base station. This survey provides a detailed taxonomy of the SDN based solutions for resource allocation in an integrated environment and specifically highlighted the solutions for cellular network resource allocation. To the best of our knowledge, our work is unique because it deals with 5G resource allocation based on SDN virtualization and describes different approaches to meet the demands of different resources.

The rest of the article is organized as follows; Section 2 deals with SDN basic architecture, characteristics and working. In Section 3, some state of the art SDN based virtualization solution in the wired and wireless domain is presented. Section 4 draws some SDN based wireless/ cellular networks architectures. Section 5 will describe different resource allocation proposals at the core level and the base station. In Section 6, we present an analytical review of resource allocation. In Section 7, some simulators for implementation of concepts in SDN are described. Section 8 concludes the work.

2 Software defined networking: architecture and working

SDN is one of the enabling technology for 5G [3]. SDN provides an orchestration of physical network with greater automation and offers agility by decoupling control plane from the forwarding plane. SDN is a layered architecture consisting of the application layer, control plane, and data plane. A generalized architecture of SDN is shown in Fig. 1. It facilitates development and deployment of new applications and services within homogeneous and heterogeneous networks representing a disruptive change in the way networks are architected, built, and operated. The control plane is centralized and programmable endorsing migration of the network functions (e.g., routing, load balancing, security, traffic management, etc.) from dedicated hardware (e.g., routers, switches, and network middleboxes, etc.) to centrally control server called controller. SDN controller provides a centralized and global view of the network and handles network intelligence and states and regulates the entire network states via network policies. Centralized controller ease network configuration and management by defining policies/rules for the forwarding/data plane. The controller may be distributed to enhance the scalability and reliability of the whole network [6, 7]. The data plane participates in packet forwarding according to the flow rules devised by the controller. The communication between controller and data plane is through southbound APIs such as OpenFlow [8] which provides forwarding abstraction and hides underlying hardware details. OpenFlow emerged in response to a research project at Stan-ford University in 2008. The open design and development of OpenFlow are managed by Open Networking Foundation (ONF) [9].

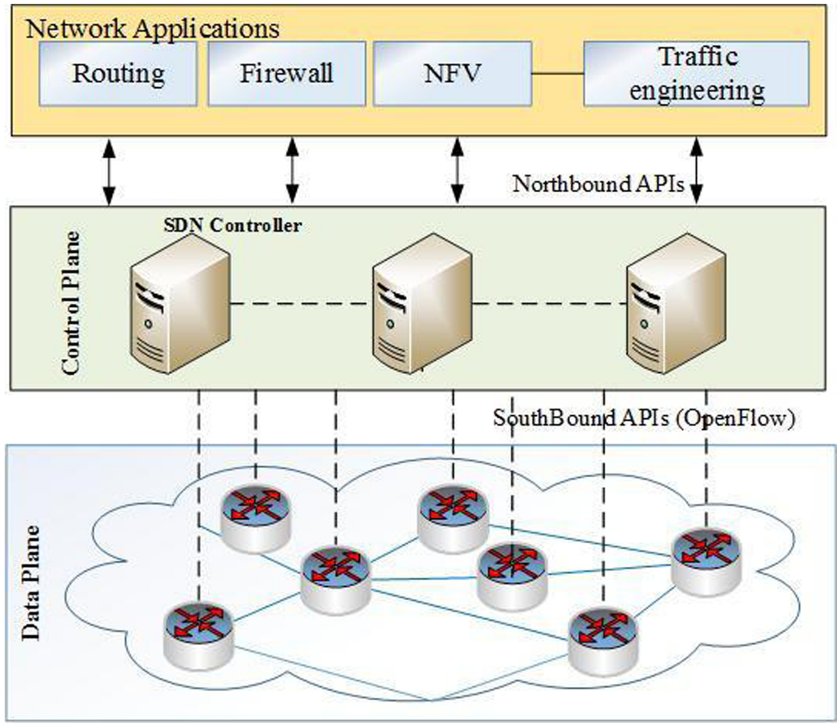

Fig. 1 Generalized SDN architecture

2.1 Communication protocol for SDN

The communication between the control plane and data plane is done through southbound communication protocols. In general, OpenFlow is considered as a de-facto protocol for SDN. OpenFlow implements flow-based control strategy in the flow tables on the SDN-enabled switches in the switching fabric. Flow tables are comprised of three fields, i.e., match field; action field and counter. Furthermore, it can be extended according to the users demand just as a priority, timeout, cookies, metric, etc. There may be multiple tables in regarding this flow; an appropriate action is taken otherwise the packet_in message is sent to the controller. The controller decides and installs flow rules on the OpenFlow switch. The rules are defined according to the application running on the controller or Network Operating System (NOS). Other than Open-Flow, many other communication protocols for the southbound interaction are derived such as OpenFlow Configuration (OF-Config) protocol [10], Open VSwitch Database Protocol (OVSDB) [11], Forwarding and Control Elements Separation (ForCES) [12] etc. The OF-Config protocol manages any Open-Flow enabled switch while OVSDB protocol manages and performs resource allocation in the Open VSwicth [13]. The communication between application layer and controller is via open APIs such as Representational State Transfer (REST) [14], etc. Path Computation Element (PCE) [15, 16] provides traffic engineering using graph representation for a constrained path network. PCE provide path computation in MPLS network by separating network topology from the control and forwarding. Cisco provides programable toolkit Open Network Environment (ONE) Platform Kit (onePK) which extend the network capabilities and configuration automation based the extracted values of the Cisco devices [17]. Table 1 provides a description of communication protocols.

2.2 SDN based solutions and applications

The SDN architecture implementation and implication in integration with other networks are viable; mostly witnessed in datacenters and cloud computing. The most evident deployed example is Google B4 project [18], a shifting of Google datacenters on to SDN-based network for flexible and dynamic management to keep pace with the customer demands since 2012. These solutions aim at providing performance gain and throughput efficiency in datacenters leveraging SDN benefits and defines resource management and monitoring for better network utilization. SDN management potential is also analyzed in wireless and cellular/mobile network. Many SDN-based cellular architectures are proposed in [19–27], etc.,

SDN solutions for datacenters are FlowComb [28], OpenTCP [29], FlowDiff [30], NetGraph [31], LIM [32], BigDataApp [33], UFalloc [34], QueuePusher [35], and ViteNA [36], etc. These solutions aim at providing performance gain and throughput efficiency in datacenters leveraging SDN benefits and defines resource management and monitoring for better network utilization. SDN management potential is also analyzed in wireless and cellular or mobile network. SDN-based application and solutions are shown in Fig. 2.

Table 1 SDN Southbound communication protocols

Communication protocol	Granularity	Description
OpenFlow [8]	Flow	The OpenFlow standardized communication protocol between control and data plane. It is responsible for manipulating flow table in the OpenFlow switches by providing flow level abstraction. OpenFlow needs to change the existing infrastructure by replacing existing switching fabric with OpenFlow enabled switching fabric.
OF-Config [10]	Flow	It is responsible for Configuring OpenFlow switches in an SDN network.
OVSDB [11]	Flow	It provides two-way communication between control plane and data plane and responsible for creating and managing multiple virtual instances of data plane elements
ForCES [12]	Packet	Networking between networking and forwarding elements based on packet-based traffic engineering and don not need to change the existing infrastructure.
PCE [15, 16]	Flow	PCE has a centralized architecture with incomplete network view of the network. It computes path based on network graph.
OnePK [17]	Flow	Cisco OnePK is a toolkit for providing access to the internal function of network entities (routers and switches) and provide APIs for creating and integrating application into Cisco hardware.

Traffic engineering is a most discussed application in the datacenters, and cloud computing for the efficient access of the user demands to keep QoS intact for a huge amount of data. QueuePusher [35], QNox [37], Cloud-MAC [38], ProCel [39] for cellular core network, Plug-n-Serve [40], ALTO [40], OpenQoS [41] for VPN virtualization based QoS in the WLAN, Pronto [42], QoS for SDN [43] for future network and FlowQoS [44]. Bandwidth is not consciously considered during resource allocation in a limited frequency domain of any network service providers [45]. The major focus is the management and allocation of resources in term of limited available spectrum in wireless communication. Bandwidth and resource allocation in the SDN-based network is discussed in [46]. The literature mentioned different SDN-based cellular/mobile and wireless architectures. However, the comprehensive detail of these architectures does not specify the resource/bandwidth allocation in these architectures. These architectures working assumption as traditional bandwidth allocation is largely sufficient in the SDN-based cellular network. These architectures are detailed in next section.

3 SDN based virtualization solutions

The Network Function Virtualization (NFV) [46] is consolidated in SDN to enable multiple tenant and services to share network as per the customer demands and bridge the gap between computing virtualization and networking virtualization and shares common hardware resources. Specifically, NFV is associated with resource management of multiple tenants in the SDN. Different virtualization/hypervisor solutions for SDN are in the market to provide on-demand provisioning of virtual resources sharing a common physical infrastructure. Some of these solutions are FlowVisor [47, 48], Compositional HyperVisor [49], FlowN [50], OpenVirteX [51], IBM SDN VE [52], RadioVisor [24], CellSlice [53], CellVisor [54], AutoVFlow [55], eXtensible Datapath Daemon (xDPd) [56], NVP [57], HyperFlex [58], version-agnostic OpenFlow slicing mechanisms in different SDN context i.e., datacenters, cloud computing, optical networks etc.

FlowVisor [47, 48] is basic virtualization solution for SDN network proposed by R. Sherwood et al. for providing hardware abstraction to facilitate SDN flexible architecture. The physical network hardware is abstracted into a software implementation. FlowVisor provides five kinds of virtualization, i.e., flow space, bandwidth, CPU, topology and Forwarding Information Base (FIB). FlowVisor performs at line rate. Compositional HyperVisor [49] provides platform virtualization for SDN applications and acts as a policy based hypervisor. Compositional HyperVisor aims at reducing policy overhead of the logically separated application. The performance is measured in computation overhead of the composed policy update in case of new rules added, update or deleted.

FlowN [50] provides control plane virtualization for tenant application based on container applications belonging to multiple tenants. FlowN provides topology abstraction for physical network. The flow space is statically assigned to each tenant which limit the number of tenant applications and provide resource isolation for each tenant. Al, Shabibi et al. proposed OpenVirtex [51] which deals with flow space in virtual SDN and provides a mapping between virtual and physical network. OpenVirtex does not deal with control plane or data plane virtualization instead it provides topology virtualization by responding to the Link Layer Discovery Protocol (LLDP) messages. The performance trade-off in OpenVirtex is

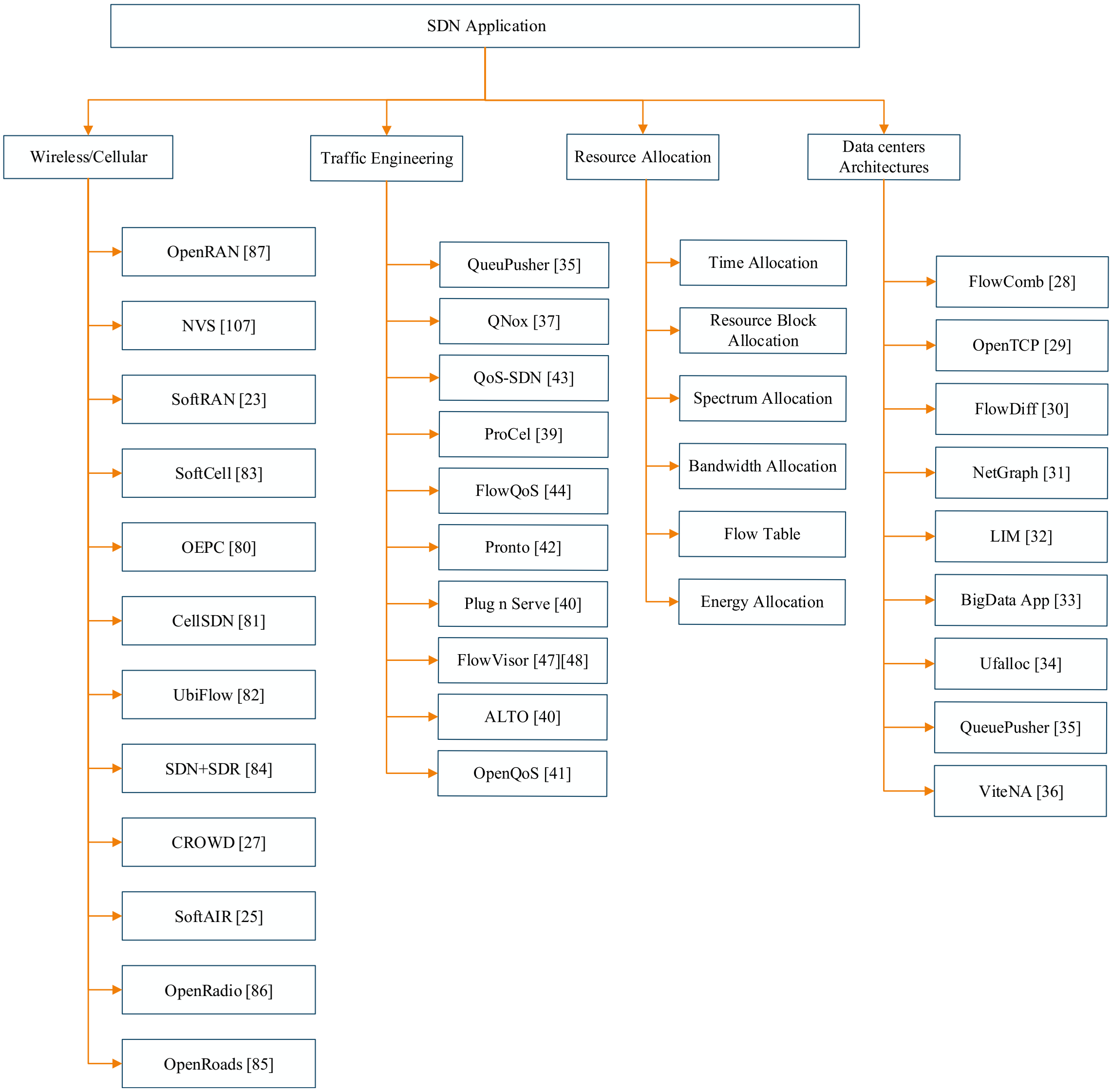

Fig. 2 SDN based solutions and applications for cellular network and datacenters

between added performance and latency. OpenVirtex acts as a proxy between controller and forwarding device and provides topology, address, and control function virtualization.

IBM SDN VE [52] provides a virtual network environment for SDN network using distributed overlay. The underlying network is abstracted as a service or infrastructure and provides network virtualization. IBM VE provides a unified controller for OpenFlow based SDN network and permits communication between multiple virtual entities. The host-based virtualization is provided by virtual network environment and configures control policies.

In [21], Pentikousis et al. proposed a MobileFlow architecture for flow based forwarding in mobile and cellular network based on SDN principle, contributed in software defined mobile architecture. The MobileFlow architecture consist of two major components i.e. MobileFlow Forwarding Engine (MFFE) and MobileFlow Controller (MFC). The MFC provide network abstraction and functionality and interconnect with MFFEs. The MFFEs support GTP tunneling by extending Open VSwitch functionalities.

Gudapiti et al. proposed RadioVisor [24] deal with the radio resources in three dimensions, i.e., space, time and frequency slots. The controller load and radio resource policies are considered for resource allocation between different controllers. RadioVisor provides wireless communication isolation and can allocate same radio resources to multiple radio elements.

R. Kokku et al. proposed CellSlice [53] for the wireless resource virtualization and provide a gateway level solution for cellular network resources slices and does not affect MAC Scheduler. Network virtual substrate is used for downlink slicing. The virtualization is in term of wireless resources in three dimensions, i.e., space, time and frequency and works on the shared spectrum principle. CellSlice indirectly constraint the BS scheduling decisions for the uplink scheduler. CellSlice also ensures inter-slice isolation and radio resource utilization and can remotely control the scheduling decisions.

In CellVisor [54], wireless network resources are sliced. The included resources are radio and BS resources and provide data plane virtualization. The packets from same traffic classification are sliced and use MPLS or VLAN tagging for identifications. CellVisor provides centralized virtualization for a cellular network. AutoVFlow [55] is a distributed hypervisor for SDN central controller and delegates central administration to the distributed administration in a wide area network. The virtual identifier is used to identify virtual MAC address. Administrator handles virtualization for their substrate and share the mapping and send a data packet to their neighbour substrate. Multiple tenant controller interacts with the virtual administrator substrate with OpenFlow interface managing topology and flow space virtualization. eXtensible DataPathDaemon (xDPd) [56] is data plane virtualization solution for physical resource virtualization in SDN. xDPd consists of a virtual agent and virtualization agent orchestrator. The monitoring and configuration are done by the orchestrator whereas a virtual agent is responsible for slicing function and abstract the available resources. NVP [57] abstract the network resource for data centers and these resources are managed by cloud service providers. NVP acts as a distributed controller and manages virtual slice. It provides data plane virtualization in SDN switches. NVP support virtualization of flow table, bandwidth, and queue in the OpenFlow switches.

HyperFlex [58] is proposed for providing resource utilization by virtualizing SDN hypervisor and decompose into functions. HyerFlex executes on SDN network element software proving control plane virtualization. HyperFlex provides a flexible allocation of function virtualization in virtual SDN controller. It provides control plane virtualization that executes in software or in some commodity hardware. HyperFlex also enables to control the incoming packet rate by dropping control channel packets which are not possible in OpenFlow controller to drop control channel packets. It also guaranteed traffic rate using benchmark measurements. However, HyperFlex does not describe abstraction and does not provide virtualization for physical and link resources. The control plane isolation is achieved after having a trade-off between latency and packet loss. The hierarchal distribution of the virtualized solution for SDN is shown in Fig. 3 and description are detailed in SDN-based Cellular Network.

4 SDN-based cellular network

SDN is redefining network architecture and management for wireless and cellular networks, the general architecture of the SDN-based cellular network is shown in Fig. 4. The common architecture of SDN based wireless/cellular network follows a layered architecture as generalized SDN do. In a cellular network, User Equipment (UE) is connected to the eNB (BS) through a front-haul network which grants resources based on the static allocation of resources such as bandwidth, available spectrum, link/channel quality, etc. These BS/eNB depend on the resources granted by the providers gain statically based on the available bandwidth.

The BS/eNB is connected to the Service/Packet Data Gateway (S/P gateway). In an SDN-based cellular network, either eNB or S/P gateways are SDN-enabled, i.e., follow SDN principles of centralized control. In some implementation, Open Virtual Switch (OVS) is implemented on the BS/Access points(AP) [58] to make it OpenFlow enabled. OVS is a software switch that applies a switch virtualization and collects information implemented as software layer on the server. Switch level configuration is stored in the database. It connects and communicates with the outer world using OpenFlow. It provides programmability and capabilities to program and manage the traditional S/P gateway in the cellular network. The OVS exchanges cellular network state information with the edge switch in the SDN-enabled core network.

SDN controller gains global knowledge of the available network and network resources and generates policies/rules for the cellular network based on the collected information. Whenever, new flow enters in the cellular network with some QoS requirements. The controller needs to install a set of new flow entries into switches to change the network forwarding policy. However, there are resource constraints on the network links and switches while updating flow entries and rules in the forwarding tables. SDN controller maintains a global database of the available resources in the network including available bandwidth and resources in the central database of the controller (Table 2).

The resource allocation in an SDN based wireless/cellular network is challenging task due to the changing condition in a wireless network and tight coupling between communicating entities, and it introduces resource management challenges [41]. Many techniques have been adopted for optimizing resource allocation from redefining cellular network architecture to sophisticated channel control algorithm, from heuristic analysis to optimal policing and scheduling. Some of the architectures designed for achieving better network performance is given in section 4.1.

4.1 SDN-based 5G cellular network architectures

The communication link between UE and BS is called as a front-haul network. Different interfaces protocols are established for cellular front-haul for providing ease in communication between different technology constraint devices like CPRI (Common Public Radio Interface) [59] and Open

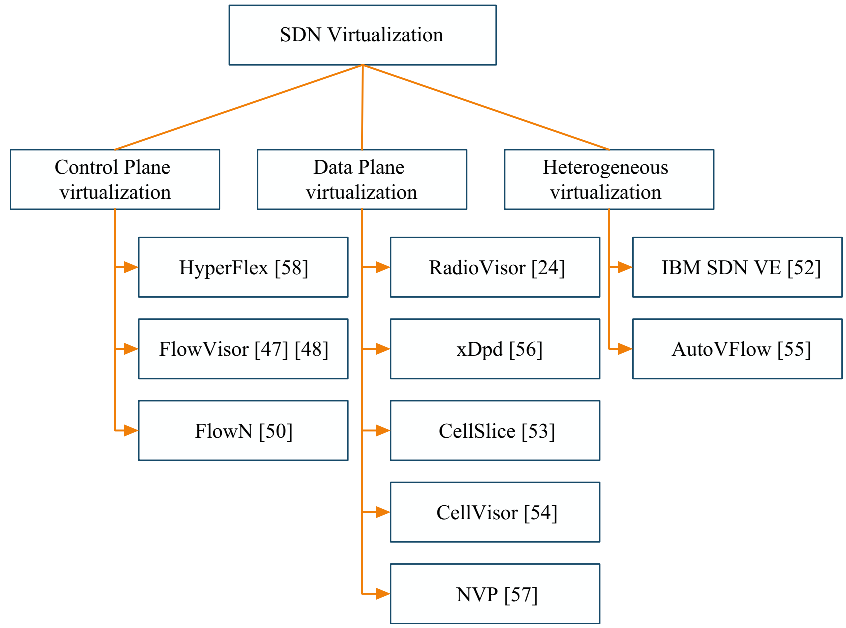

Fig. 3 SDN based virtualization solutions classification

Base Station Architecture Initiative (OBSAI) [60]. Some of the efforts for the packetization of front-haul link communication are made in [61, 62] to increase the transport level efficiency, flexibility, interoperability, etc. in the SDN-based cellular network. The digitization of data and radio is affecting bandwidth expansion in the cellular network. Devices sharing data and information using different technologies require flexible sharing of physical and network resources, whereas the spectrum resources are small as compared to the demand from a number of users. The other requirements are linked distance, energy efficiency, latency, cost, and scalability. Few efforts are made in achieving resource utilization in the futuristic 5G, and to reduce the gap between the radio network and core network, i.e., front-haul network and backhaul network.

5G wireless cellular network is attributed to have immense connectivity and able to provide huge data rate/bandwidth due to use of Millimeter Wave (mmWave) technology which support band between 30GHz to 300GHz [63]. mmWave can provide high access in highly dense network. However, mmWave frequencies suffers from higher prorogation delay, high interference, sensitivity of blockage etc. In [64], Y. Niu et al. presents the idea of Software Defined mmWave mobile

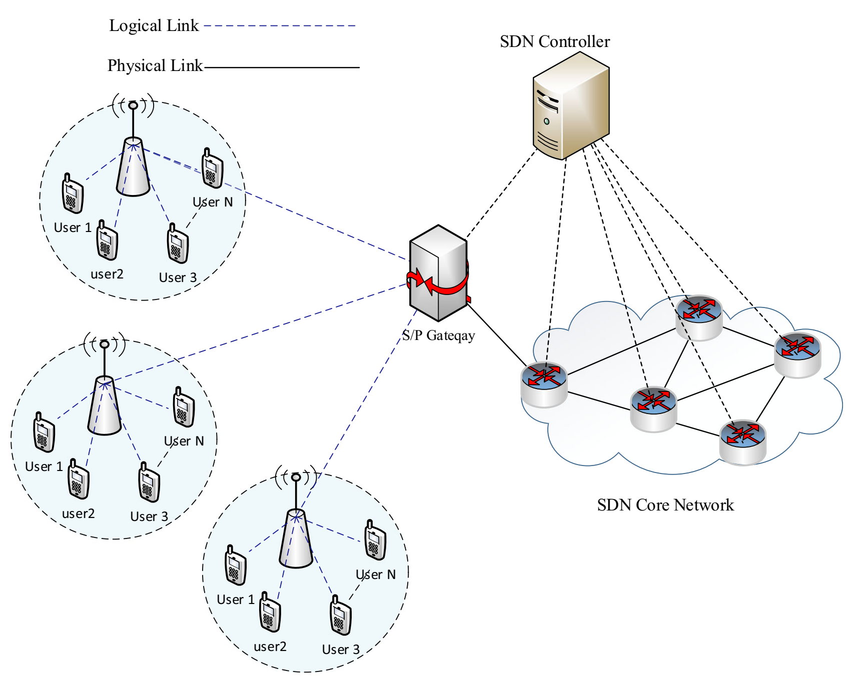

Fig. 4 SDN based cellular network architecture

Table 2 SDN based virtualization solutions

Virtualization Solution	Abstraction	Description
FlowVisor [47, 48]	Data plane abstraction	OpenFlow controller act as a proxy between controller and data plane providing switch virtualization for creating production network slices. OpenFlow acts as a hardware abstraction layer. FlowVisor runs at line rate.
Compositional HyperVisor [49]	Platform abstraction	Policy-based hypervisor manages composite policies for multi-tenant application and reduces policy over-head.
FlowN [50]	Topology abstraction	FlowN provides controller virtualization for isolating different tenant applications. The resources, such as flow space, are statically assigned on per tenant-based with a constant latency overhead.
OpenVirtex [51]	Address and Topology Abstraction	It provides flow space virtualization. Administrator handles virtualization for their substrate and share the mapping and send a data packet to their neighbour substrate.
IBM SDN VE [52]	Network abstraction	This solution provides virtual network environment consisting of a virtual agent and virtual agent orchestration. This agent orchestration enables communication between virtual machines. The network configuration and control policies are orchestrated by virtual agent.
RadioVisor [24]	Space, time, and frequency slots	SDN based virtual solution for cellular network provide isolation of resources in three dimensions.
CellSlice [53]	Gateway solution	It provides radio resources isolation in term of three dimensions, i.e., space, time and frequency. It also ensures isolation for radio resource utilization and inter-slice allocation.
CellVisor [54]	Data plane	An early proposed hypervisor for a cellular network, CellVisor, a virtual solution for traffic isolation using classification. It uses MPLS and VLAN tagging to identify slices.
AutoVFlow [55]	Topology abstraction	AutoFlow provides flow space virtualization of SDN wide area network. Virtual MAC address is identified using the virtual identifier to ensure isolation between slices.
xDpd [56]	Data plane	Physical resources are virtualized abstracting data plane. Virtual functions are used for isolating resources for individual resources.
NVP [57]	Flow space	NVP acts as a distributed controller and manages virtual slices. It provides data plane virtualization in SDN switches.
HyperFlex [58]	Hardware abstraction via software	HyperFlex provides different virtualization function for control plane virtualization. The available physical resources are virtualized. The traffic rate is guaranteed using benchmark measurements.

broadband system under small cell deployment. The integration of SDN and heterogeneous cloud random access network (RAN) are used to introduce cross-layer mobile broadband network. The contribution promises to facilitate spatial reuse, anti-blockage, QoS guarantee, and load balancing in the 5G network leveraging mmWave Wireless Personal Area network (WPAN). The design consideration for SDN based mmWave mobile communication is enhanced capacity, reduced interference, flexible QoS guaranty and spatial reuse of frequency. The central control and local agent coordinate for adaptive change in the mmWave communication. Chen et al. proposed SDN based radio resource management in [65] in 5G mmWave heterogeneous network. The null-space precoding is used to overcome mmWave constraints such as inter-cell interference and SDN controller perform coordination for whole heterogeneous network. The proposed architecture leverage precoding which is multi-stream beamforming techniques to support MIMO and exploits diversity and Radio Resource Management (RRM) in the communication network like in 5G cellular network. The coordinated RRM is achieved by precoding in 5G hetGen network leveraging SDN controller for resource management and MIMO coordination. The network level virtualization is also support as a complementary part of SDN controller. Mathematical model is used to figure out desired benefits.

In [66], Sun et al. propose a general solution for 5G considering different technologies such as NFV integration for mmWave, SDN and SDR etc. It articulates different challenges and requirements for upcoming 5G technologies. Any proposal for an architecture of integrated SDN, NFV and SDR may consider standardization of existing technologies for the backward compatibility and openness of the integrated architecture such as portability, resource management and reduced power consumption etc. The OpenAirInterface (OAI) is presented in [67] as a flexible platform supporting SDN based 5G where radio frequency front end can be extended for mmWave relaying and multiple access. Diverse characteristics for deploying mmWave is studied in [68–70]. Key technologies for 5G including mmWave are discussed in [71]. However, precise deployment devices, spectrum sharing, and configuration require more research and investigations.

The small cell densification is challenging for efficient resource management. The backhaul capacity greatly affected due to large number of users using high frequency bands. mmWave may help due to the available band spectrum. However, mmWave greatly affected by the external phenomenon such as weather condition, high pat loss and blocking conditions. Vestin et al. in [71] investigate SDN for backhaul network capacity utilization leveraging low frequency assist mode. The proposed approach exploits Bidirectional Forwarding Detection (BFD) algorithm which detect link failure and recovery instantly. The rapidly changing behavior of mmWave is addressed by calculating backup path and provides fast failover and changing link quality in small cell backhaul network. The bandwidth allocation depends on the link state. The proposed approach uses probability based linked model to get informed form state change characteristics which are emulated using modified CORE emulator.

Santos et al. in [72] propose SDN based management and operations of small cell where OpenDayLight controller adaptively monitor powering in small cell and minimize the energy cost. The Software Defined Small Cell Radio Access Network (SOCRA) architecture components are optimization module, Packet Handler, Neighborhood Mapper, Path Calculator, and an Orchestrator interface. The forwarding path are configured based on the power allocation.

Amate et al. in [73] proposed SDN based radio over frequency (RoF) in mmWave based 5 g network for increased capacity and connectivity. In this architecture network functionalities are centralized at the edge node of the RoF where central controller manages the allocation of resources in SDN based RoF network. The objective gain is reduced latency and increased throughput. The SDN central controller utilizes Coordinated Multipoint (CoMP) algorithm to enhance control message communication between inter edge nodes. Multiple Remote Radio Heads (RRH) are connected to baseband unit which uses RoF technology for communication. The significant gain of 60% is achieved for RAN network and 36% gain is achieved for edge network using SDN based RoF architecture.

TeraHertz (THz) is a communication band ranges from 300GHz to 3000GHz. THz wavelength, measured in tens and hundreds of micrometres. THz enables very higher data rate as anticipated by the futuristic 5G network. A state of the art survey on TeraNets is provided in [74]. This survey highlights the THz Band device technologies, challenges, some potential solution and defines a roadmap for the THz band technology in the wireless communication. In [75], Cacciapuoti et al. proposed a controlled switching between mmWave and THz bands in a small cell network and provide an admission policy for dynamic switching in small vehicular network. The SDN controller provide admission control for the adaptive switching in the vehicles equipped with THs and mmWave devices and provides Spectrum Switching, vehicle scheduling and capacity modeling as controller components. The effective capacity is measure through mathematical modeling of the available capacity in the network. The outage probability and power consumption at transmitter are key parameters for evaluation. Mumtaz et al. [76] provides a deep insight into the application of THz in the vehicular network and describes limitations of THz and its implication in a vehicular network.

Table 3 summarizes the SDN based mmWave and THz communication in 5G networks.

A cross-layer architecture front-haul and backhaul network is proposed in [77] where SDN centralized controller provides network management using Simple Network Management Protocol (SNMP) and Open Virtual Switch Database (OVSDB) for bandwidth management in a cellular network. The 5G-crosshaul provides different plugins for traditional and other network support and backward compatibility. The 5G-Cosshal orchestration called (XCI) provide network management and communicate with different non-Crosshaul switches such as mmWave switches or legacy switches. Different interfaces are used for communication such as NETCONFIG, REST or NETCONF etc.

The QoS policies are implemented using queuing via OVSDB. LTE network reconfiguration is proposed [78] using SDN based on D2D communication devices and ensures Quality of Experience (QoE) which is measured on the basis of Mean Opinion Score (MOS). Liu et al. [62] proposed an algorithm for multi-tier LTE network reconfiguration for downlink and uplink based on a D2D communication protocol in case of congestion on the nearest eNBs. The parameters used to measure performance are download speed and waiting for the delay because of congestion in the adjacent eNBs. G. Savarese et al. [79] proposed a flexible approach to the reconfiguration and resource allocation in LTE environment when acting as IoT by observing context and connects various types of monitoring terminal devices and the Internet without human interaction. They use context-aware information and geophysical location for their proposed framework architecture for heterogeneous M2M devices over the LTE/4G network with SDN controller and Context-Aware Application (CAA) running over M2M server identifies the failure of certain eNB and informs SDN about the status.

V.G. Nguyen et al. propose an architecture for SDN-based mobile packet core network (OEPC) to realize OpenFlow in the servicing gateway (SGW) and in the packet data gateways (PDW). The GTP-C is replaced with Open-Flow dealing the five basic functions of cellular/LTE network, i.e., initial attachment, user service request, network service request,

Table 3 SDN based mmWave and THz 5G network comparison

Ref.#	Description	Benefits	Limitation
[64]	It provides a cross layer design for SDN defined mmWave mobile communication for optimized load balancing, QoS guaranteed by collecting network state information, control decision computation and control messaging forwarding. The architecture consists of central controller and local agent which support for adaptive change in the network.	Quantitative simulations are used which increase network Throughput by 128%, traffic load is managed by beamforming and smooth handover	The network model is suitable for small network, it does not handle scalability
[65]	The architecture support MIMO through precoding (beam forming) and exploits RRM using SDN based controller and NVF to overcome the low power node in the neighbor and managing resources accordingly.	Numerical results are used for simulating precoding to achieve Spectral efficiency, throughput and power consumption are used to evaluate the performance of the mmWave 5G hetNetwork. The physical constraints are reduced using this technique.	The Complexity of precoding increase the computational cost of the network and scalability will become issue.
[67]	The OAI is an open software platform consist of EUTRAN and EPC for the management of open interface in the cellular network.	Openness of the platform enable different communication network to be softwarized on OAI platform. It supports two different types of emulation by providing physical abstraction and physical layer manipulation. It also serves as a platform for the evaluation of 5G network.	Communication techniques such as beam forming are not supported yet.
[71]	SDN-enabled resiliency mechanisms provide a failover in fast changing environment and can achieve benefits using low frequency	Core emulator is used for wireless link emulation and calculate cumulative delay in the LTE network	Does not support dynamic adjustment of BFD and can suffer from overhead for computing failover paths.
[72]	It provides an SDN based solution for mmWave 5G small cell backhaul network called SOCRA for adaptive power and backhaul forwarding reconfiguration.	Opendaylight controller is used for sending messages and provide a resilient routing infrastructure.	Only theoretical architecture, no proof of evaluation.
[75]	It proposed a SDN framework for supporting switching between THz and mmWave equipped vehicles by dynamic admission policies. The optimal scheduling	Analytical analysis proves the benefits of proposed framework for achieving high capacity using polynomial-time scheduling algorithm which is computationally-feasible.	Poor utilization of high bandwidth due to vehicle backlogging and suffer transfer overhead.

handover, and tracking updates. The performance evaluation is done considering signalling load as a metric and compared it with traditional Evolved Packet Core (EPC) core implementation [80].

CellSDN [81] is a cellular architecture based on SDN in which attribute-based policies are formulated for an individual user in the LTE network and gain fine grain control over the network. Deep packet inspection is used for traffic classification with the help of local cell agent running in each switch on eNB. This local agent in CellSDN can increase scalability by reducing the excessive load on the controller. Controller offloads some of the measurement tasks to the local agent which can perform local control operations. Cluster-based SDN controller architecture for a cellular network is proposed in [66] by M. H. Kabir et al. The cellular area is divided into clusters controlled by a cluster controller where SDN controller provides significant functionalities. Radio access related activities are managed by SDN controller, which reduces the complexity of the BS. Load monitoring and session control are done through the controller's head in the clustered area. The cluster head controllers communicate with each other via controller services.

Wu et al. propose a UbiFlow framework which provides the integration of the SDN and the IoT [82]. UbiFlow provides an efficient flow control and mobility management in urban multi-networks using SDN distributed controllers. In UbiFlow architecture, IoT network is partitioned into small net-work chunks/clusters in which each partition is controlled by a physically distributed SDN controller. The IoT devices in each partition may be connected to the different Access Points (APs) for various data requests. These distributed controllers coordinate to provide flow scheduling, mobility management, optimized access point selection, reliable and scalable control order. UbiFlow also guaranteed fault tolerance and load balancing for multi-network IoT. The per-device flow management and optimized access point selection are based on the multi-network capacity performed by the SDN controller, which partition the network using network calculus in the UbiFlow architecture.

SoftRAN [23] uses SDN principle in 4G LTE network. A centralized control plane abstracts the whole RAN into the geographical area. This geographical area acts as a big base station where many radio elements, i.e., physical base stations are deployed under the control of a centralized controller; which manages radio resource allocation in the big base station. The resources are allocated in a three-dimension grid of space, time, and frequency. The interaction between controller and radio element is done through APIs. Radio element backups the information in the control plane. Radio element takes some of its decision based on local information to manage the delay between controller and radio-element. In SoftRAN, global network decisions are taken by the controller and local resource management is done by the radio element.

SoftCell [83] incorporates SDN in the cellular core network and provides fine-grained policies for an LTE network. The contributing components in SoftCell architecture are i). controller, ii). access switches, iii). core switches and iv). middle-boxes. The controller defines policies and implements through switch level rules through middle-boxes. Traffic classification is done on the access switches. Every access switch has a local agent which caches each UE profile. In this way, local agent control packet classification in access switch which results in controller work reduction. The controller has a global view and defined rules on the match fields, i.e., policy tag, hierarchical IP address and UE identifiers. The location and policies are embedded into packet header to avoid reclassification of the traffic. Core switches connect to the Internet through gateways fine-grained policies ensure through multi-dimensional aggregation and packet classification in asymmetric topology. Data plane over-head is reduced by placing critical functionalities at the low bandwidth access edge, and multi-dimensional aggregation of forwarding rules helps in reducing bandwidth consumption.

An integration of SDN and Software Defined Radio (SDR) in the 5G network is proposed in [84] called Hybrid SDN/SDR architecture. The proposed architecture is cross layer combination of SDN and SDR for exploiting frequency spectrum and link information in the 5G network. Network environment consists of the spectrum and bandwidth perception in SDR layer while SDN controller can detect channel usage in the network. The cross-layer controller has used request frequency spread spectrum and is the decision maker and review flow traffic. This architecture also manages user authorization in the cross-layer controller and grants access to a better band. The process of cross-layer communication between SDR and SDN starts with scanning spectrum holes.

A comprehensive architecture, SoftAir proposed by Akyildiz et al. [25], provide a detailed and in-depth integration framework for SDN principles in 5G network. SoftAir exploits cloudification and network virtualization of a resilient network. The architecture provides mobility aware load balancing and efficient resources allocation through virtualization. The network architecture is based on software-defined switches and BSs which can be dynamically programmed. The aggregated control is provided by NFV creating multiple virtual networks with independent protocols and resource allocation algorithms. Data plane comprises of SD-RAN and SD-core network nodes, which are OpenFlow-enabled. Data plane monitoring is done through OpenFlow and Common Public Radio Interface (CPRI). All management policies are defined at central control plane, which enables cloud orchestration. Traffic management module in control plane selects an optimal path in mobility aware context. QoS applications are carried out through distributed traffic classification module in the control plane. Overall, SoftAir presents a detailed and complete architecture of 5G cellular network management based on SDN and provides end-to-end QoS guaranty.

H.-A. Ahmad et al. proposed CROWD [27] with two tier-SDN hierarchy of two controllers, i.e., local controller and regional controller, which cover the MAC layer configuration and backhaul management in the overlapping wireless network like WLAN and LTE. The logical decisions are represented as state full algorithmic operation. CROWD provides a dynamic solution for provisioning of resources and dynamic reconfiguration of the densNet backhaul network.

OpenRoad by K. K. Yap et al. in [85] for removing structural barriers between innovation and closed wireless capacity. The OpenRoads project envisioned future cellular demand and proposed an SDN based wireless architecture pro-viding handover performance and mobility management in different wireless networks and focusing on user requirements and involvement. OpenRoads provides backward compatibility and separate mobility manager for its customers. OpenRoads provides envisioned OpenFlow Wireless.

The re-engineering of wireless cellular network in the core network called OpenRadio is proposed in [86]. OpenRadio uses modular abstraction for control plane operations in the cellular network supporting different technologies. OpenRadio focuses more on the programmability for processing and decision and provides mechanism for managing inter-cell interference.

M. Yang et al. proposed OpenRAN, a software defined architecture for RAN via virtualization [87]. OpenRAN consists of wireless spectrum resource pool (WSRP), cloud computing resource pool (CCRP) and SDN controller. J. Liu et al. [88] propose a QoS guaranteed resource allocation scheme based on the content caching into the resource allocation parameters and measure the impact of backhaul latency in the user data rate in the downlink scenario of an SDN-enabled RAN. Radio resources are virtualized into the resource pool. Taylor expansion is used to simplify the mixed-Integer nonlinear programming and then converted into the convex problem and optimized the solution using the sub-gradient method.

D. Zhang et al. [89] propose a double auction mechanism based on virtualization in the SDN-based cellular network and provide resource allocation for multiple flows for different Infrastructure Providers (InPs) and Mobile Virtual Network Operators (MVNOs). The double auction provides fairness among InPs and MVNOs and allocates physical resources. and each InP and MVNO bid for the resource available in the virtualized service pools. However, individual user QoS is not considered. The user satisfaction is the responsibility of MVNOs.

R. Trivisonno et al. presented a plastic architecture for the service generation performance and functional requirements using SDN principles of decoupled control and data plane [90]. The architecture consists of three control planes (C-Plane) and clean slate data plane (D-Plane) to provide a unified architecture. The control and management are either centralized or distributed depending on the network dynamism. The edge controller is responsible for the network access control, mobility, packet routing, security and connection management, QoS and radio resource management functions. The edge controller is distributed over the cloud computing. Descriptive details of SDN based cellular architecture is presented in Table 4.

5 Resource allocation in SDN based 5G cellular networks

In the wireless scenario, more specifically in 5G networks, wireless channels suffer from time variation and randomness which require dynamic resource/bandwidth allocation instead of deterministic allocation. In SDN-based cellular architectures, bandwidth allocation techniques are either addressing one level of bandwidth allocation, either is core network (SDN-enabled switch) or in the backhaul network. However, in SDN-based cellular architecture, an end-to-end QoS is possible if there exist specific mechanisms for bandwidth allocation based on user demands with the high dynamics of networking.

5.1 Resource allocation solutions for Core network and datacenter

Resource allocation and bandwidth management in datacenters are crucial in sharing due to the multiple tenant requirement. The tenants must gain utility in contrast to user satisfaction. Many techniques are adapted to use to increase their utility gain. However, user satisfaction is also important to consider. Different optimization and resource allocation strategies are adopted to gain performance improvement and user satisfaction. Some of SDN based allocation and management techniques are discussed in this section.

5.1.1 Game theoretic models for resource allocation

F. Xu et al. in [34], proposed UFalloc, an application level bandwidth guarantees for fairness performance in the datacenter network. The proposed work is based on the utility level max-min fairness of bandwidth allocation. UFalloc presents an application level strict utility max-min fair allocation algorithm and a non-linear model for the trade-o between utility and fair allocation among the datacenters. Even though utility max-min fair allocation algorithm maintains a fair share of bandwidth, however, there is computational overhead.

T. Feng et al. [91] present bandwidth allocation as a price-based joint allocation model and a fair allocation algorithm of bandwidth and flow table for multiple control applications in SDN. It proposed Virtual Forwarding Space (VFS) and flow scheduling policy based on the proportional fair allocation of link bandwidth to manage network resource including link bandwidth and flow tables capacity.

Guo et al. proposed Falloc [92], a distributed algorithm for datacenter bandwidth allocation using a bargaining game approach to achieve the asymmetric Nash bargaining solution. Falloc provides an application level bandwidth allocation for VMs in datacenters and achieves fairness among them using utility function. S. Tomovic et al. proposed a hard QoS for SDN-based architectures by hard-coded bandwidth rate reservation and admission control. The incoming flow requests its required bandwidth and controller are determining the shortest path according to the demanded bandwidth. This demand acts as a constraint on the QoS. If the constraint is not fulfilled, i.e., demanded bandwidth path is not available then this flow request is dropped. The queue is used to guarantee bandwidth in the OpenFlow switch [93].

Zhang et al. [89] proposed a double auction mechanism for multi-flow transmission game theoretic model for bandwidth allocation in the multi-tenant network is proposed in [94]. The controller acts as a bidder, and FlowVisor acts as an auctioneer. Resources are granted to the auctioneers when controller reached to Nash Equilibrium. Admission control and per-flow bandwidth guarantee and end-to-end QoS are provided in [43] for the future Internet. In the architecture, single Autonomous

System (AS) is controlled by a single controller which implements QoS using OVSDB or Of-Con g and adds a failure recovery system in their architecture. QoS and non-QoS flow are installed on the switch and directed by two different queues on the OpenFlow switch. However, in this architecture bandwidth guaranteed and virtualization is not addressed.

5.1.2 Optimization based resource allocation

D. Caixinha et al. [36], presented ViTeNA architecture for the embedding of the virtual machine in the datacenters. ViteNA guarantees the bandwidth allocation and network performance in a work conservative network. Open VSwitch manager creates new queues upon receiving the new request and allocate bandwidth as per request, which guarantees the required bandwidth in the multi-tenant network. Virtualization/hypervisor manages inter-service and intra-service. A virtual network pair is assigned on receiving the request. ViteNA follows incremental consolidation of each request and reduces performance degradation due to a burst of control message communication. ViteNA uses QueuePusher [35] for the creation of queues in the OpenVSwitch.

J. Hao et al. [95] proposed a flow-level bandwidth provisioning using Combined Input Cross-point Queued (CICQ) switches (FBP) in an SDN-based wired network. However, for a cellular network, it is largely incapable of dealing dynamic changes in the bandwidth requirement due to the huge influx of new applications and services offered by the operators and service providers. The queue-length based solution in the wireless cellular network is considered as CICQ in [95]. The flow-level bandwidth allocation algorithm is proposed to overcome the switch scheduling problem for multiple instances of fair queuing in the OpenFlow-based network.

In [96], a network resource policy VLM+ is proposed for the SDN-based cellular network. VLM+ evaluate three policies i.e., Full Sharing, Full Split, and Russian Dolls. VLM+ define QoS classes and share available bandwidth on the per link basis. The Russian Dolls preserve fairness in bandwidth allocation. The fairness, convergence, and scalability of three network resource management model for three different classes, conversational, gaming and best effort services are evaluated to fulfil different operators need. However, VLM+ support links slicing instead of network slicing.

In [97], A. Leivadeas et al. proposed the placement of network virtualization function for the efficient resource allocation in an SDN enabled cloud. SDN based virtualization provides service chaining, and service-oriented traffic steering. The computing and network resources are shared, and NFV is migrated according to the dynamic requirements. The network is formulated using Mixed Integer Programming (MIP). SDN controller is responsible for collecting and updating network status and resources to the resource optimizer. Link Utilization in the datacenter as a simple network with policy and no policy is tested in [98]. Unfortunately, the delay in the LAN is excessively high due to the communication of TCP/IP between the controller and the datacenter. They use best effort bandwidth allocation model for the available bandwidth on the link. Whenever a new flow arrives at the controller, the available link is used first to increase the link utilization.

Link utilization using flow space in SDN data plane is discussed in [99] and solve the flow sequence update in the flow table for achieving optimized bandwidth. Maximum performance of link is optimized using minimizing maximum link utilization algorithm. The heuristic algorithm used is based on LP relaxation and polynomial time algorithm which computes link capacity and then update the flow table accordingly. Link optimization for the bandwidth maximization and allocation in an SDN is studied in [100] and maximizing the energy efficiency and link utilization. Enhancement in the Cuckoo search algorithm is used to solve the NP-complete problem of flow allocation by maximizing bandwidth and reducing energy in the SDN network.

QoS aware virtualization, routing and flow allocation in multi-tenant applications is discussed in [101]. Geographical perspective, i.e. subnet diameter and path delay or packet loss, and flow arrival rate is considered for a congested link and traffic aware resource allocation is provided in the SDN network. Multi-objective optimization based QoS aware Virtualization-enabled Routing (QVR) algorithm is used for computing bandwidth virtualization and end-to-end QoS guarantee. The authors proposed a fine grain virtualization and develop a routing algorithm for providing complete isolation and flow resources allocation.

5.2 Resource allocation solutions for wireless network

In a traditional wireless cellular network, resources are allocated pre-planned, i.e., at the time of deployment which is a static allocation and can lead to an inefficient allocation of resources. Some of the work done in resource allocation in SDN based cellular network provides dynamic resource allocation. In softAir [25], bandwidth monitoring is proposed using two level of virtualization, i.e., at network-level virtualization, consisting of network hypervisor, and on the lower level virtualization composed of the wireless hypervisor and switch hypervisor. Switch hypervisor is based on OpenFlow and focus on bandwidth partitioning in single SD-switch and aims at providing predefined bandwidth for any specific traffic flow. FlowVisor provides isolation among slices and employs leaky bucket for bandwidth provisioning. However, this does not support flow and queue for this they proposed queue based Generalized Processing System (Q-GPS). It proposes to publish/subscribe message for flow guaranty.

Bandwidth allocation and resource management using virtual machines in the RAN is proposed in [102]. The

Aggregated bandwidth is mapped on the physical machine for service chaining in an optimal way. In [103], rate based allocation in LTE network using SDN and utility maximizing model. The resources function decomposition for the allocation of bandwidth is achieved by a concave utility function. The unique optimal between allocated bandwidth and price is calculated using Lagrange multipliers for the heterogeneous network. The QoS queues, i.e., M/M/1 queue and M/D/1 queue are used as queuing model at the P-GW and at the controller. Different queue model results in large delay due to different arrival rate at the BS and at the controller.

A. Farshin et al. [104] proposed resource allocation using dynamic SDN controller allocation in an SDN based cloud assisted 5G network. They use PSO based chaotic Grey Wolf Optimizer algorithm for dynamic controller allocation. The authors proposed M/M/c queueing model in the multi-core SDN based mobile network and Erlang -C formula is used to calculate arriving packet probability and response time of the controller. The utility function is inverse proportional to the response time, i.e., increase in response time, utility function will decrease and vice versa. Utilization function is increased using the quadratic function at a slow rate. The authors also consider fair switches distribution for load balancing in the controller. However, resource allocation is not considered with respect to the controller allocation and network utilization.

G. Bartoli et al. [105] proposed a solution for bridging the gap between physical layer resources and network resources using Artificial Intelligence (AI). The idea to jointly optimize the backhaul traffic distribution and cell association. This cross-layer proposal mitigates the difference between data rate in each and backhaul capacity considering user satisfaction in term of data rate and energy consumption by the activated devices. SDN based virtualization is considered in the backhaul network and responsible for taking routing decision based on bandwidth demand. Load balancing association is performed to produce maximum rate request. The proposal for virtualized SDN-based EPC for the cellular network [3] to share resources among Mobile Network Operators (MNO) and backhaul service providers. The time variation and user equipment (UE) is considered for dynamic allocation of resources. Multiple optimization techniques are considered for different scenarios such as max-min fairness and ate guarantee.

Multiple Access Radio Scheduling (MARS) [103] scheme proposed for bandwidth allocation considering bandwidth, QoS requirements, and network statistics. The per-packet scheduling based on Round-Trip Time (RTT) and bandwidth is computed on the sender side. End-to-end delay is considered as QoS parameters. In [106], X. An et al. proposed an end-to-end slicing for a plastic architecture with separate control and data plane. An end-to-end slice is selected by using device triggered network control mechanism. The slicing concept is used only in the core network.

R. Kuko et al. [107] proposed Network Virtualization Substrate (NVS) for WiMAX network for slicing downlink and uplink bandwidth and provide resource allocation, isolation, and customization. The architecture comprises of two different scheduler for proving (i) slice scheduling and (ii)fl flow scheduling. The bandwidth and resource reservation is guaranteed using per slice base using FlowVisor as slice manager.

The subscriber mobility is addressed in [54] which is considered as initial SDN-based cellular architecture. The application payload is reduced by compression. Radio Resource Management Module (RRM) takes part in the resource allocation of BSs. The resource allocation to multiple slices is done by extending FlowVisor which is SDN de-facto virtualization hypervisor.

In [108], X. Duan et al. proposed data offloading optimization in a congested heterogeneous network. The offloading of data is done using WiFi network. The spectrum shortage is alleviated by leveraging this offloading of a congested network to dense WiFi network. The primary and secondary bandwidth is allocated to cellular and WiFi network respectively.

A primitive study on the fair resource allocation in the wireless network is presented in [99] describing queue length based resource allocation. User-level fairness model (UFair) for the future network is present in [109] for HTTP adaptive streaming (HAS). In this model, the user level independence is proposed leveraging OpenFlow controller and adaptive algorithm despite the fact the major resource allocation assumes that all participants require an equal amount of resources in the network. This work assumes the utility max-min [97], and utility proportional fairness [34, 91] work for the allocation of user QoE and fairness. K-T. Bagci et al. [107] proposed a flow-path computation by queue allocation under per-flow service-level constraints. The proposed model provides high QoE for high-quality video streaming over the SDN network and maximizing ISP revenue under per-flow.

Small cell resource allocation suffers from bottleneck due to the static allocation in a cellular network. The uplink bandwidth allocation for the traffic from uplink to eNB is static. A large number of small cells in a geographical area produce a large volume of aggregated traffic at the eNB which can create an uplink bottleneck between eNB and operator gateway. The Uplink bandwidth allocation is considered in [110] by introducing smart gateway (Sm-GW) and SDN orchestrator between eNB and P/S-GW of the cellular network for the optimized resource allocation. The introduction of Sm-GW aggregates small cell connections and provides uplink bit rate optimization. However, this paper lack in providing QoS for a different type of traffic. The small cell BS station is usually low powered and contains small size buffer requiring an efficient scheduler and traffic management for the downlink traffic from the backhaul network to the BS. Small cell traffic scheduling and interference management for the downlink bit rate are explored in [111] using H-controller to manage the queue length in the BS. The flow controller regulates the traffic flow keeping track of all wireless channel condition. The S. Lakshminarayana et al. formulate queue-length evolution as a linear dynamic system and develop a queue length controller.

Dynamic spectrum allocation in dense deployment is addressed in [112] proposing Harmonized SDN-enabled Approach (HSA) for harmonizing network wide policies and provide dynamic spectrum management. SDN controller

Table 4 SDN based cellular architectures

Solution	Technology	Description	Limitations
MobileFlow [21]	Mobile carrier network	An initial architecture for the integration of flow based forwarding in carrier grade network consisting of MFFEs and MFC.	QoS parameters are not drawn and scalability as required in 5G in not doubted.
SoftRAN [23]	RAN	SoftRAN provides support for resource management, mobility, and traffic offloading from a big base station consisting of a centralized controller and local agent at eNBs.	No concrete solution, virtualization is not clear, centralized control plane and interaction between the core network and RAN are not defined.
CROWD [27]	Dense Network	CROWD provides MAC layer configuration and backhaul management in heterogeneous SDN based network. Offers a dynamic solution for provisioning of resources and dynamic reconfiguration.	Many challenges remain unaddressed, e.g. optimal data transmission in the core network and QoS provisioning.
CellSDN [81]	LTE	CellSDN provides attribute-based policies for cellular SDN and gains fine grain control over the LTE networks.	No proof of concept and evaluation of the proposed scheme, vague traffic engineering handling using MPLS/VLAN tags etc.
SDN_D2D [78]	5G	The architecture is based on the SDN based cellular network for D2D communication and provides quality enhancement algorithm for d2d communication in 5G cellular context for DL and UL transmission.	Queue length allocation and management is not considered.
OEPC [80]	Mobile Network	OEPC realizes OpenFlow in the SGW and in the PDW.	It does not support GTP processing at the underlying network.
Ubiflow [82]	Mobile IoT	An architecture to provide an efficient flow control, mobility management, flow scheduling, optimized access point selection, reliable and scalable control order.	Flow scheduling towards backbone network is not addressed.
SoftCell [83]	LTE	SoftCell introduces modification in the core network consisting of a logically centralized controller, local agent SD-RAN (BS). Dynamic traffic offloading, efficient routing, minimizing the state in core network are key characteristics of SoftCell.	Fine grain service policies are missing in SoftCell.
OpenRoads [85]	WiFi/WiMAX	OpenRoads provides an open interface architecture for slicing and virtualization of wireless network and provides a high-level abstraction for dynamic spectrum and power allocation.	No support for the cellular network only implemented for Wi-Fi and WiMAX mobile network, optimized traffic steering.
Openradio [86]	Wireless network	In OpenRadio, multiple networks can act as a single network and extend in the mobile network defined by declarative and modular programmable interface. OpenRadio provides spectrum management.	It does not support RAN controller.
OpenRAN [87]	Heterogeneous Wireless Networks	It provides an architecture for Radio Access network consisting WRSP and CCRP. It supports for wireless spectrum virtualization as virtual BS.	The complete set of operations are not identified, and it does not support OpenFlow.
SDN/SDR [84]	5G	It provides the management of spectrum allocation and network management in a 5G network and enable Power saving and optimization in resources allocation	Complex Cross-layer controller and security issues are not handled.
SofAIR [25]	5G	SoftAir provides an architecture for network function cloudification and network virtualization for 5G networks. It aims at dealing mobility aware control traffic balancing, resource efficient network visualization.	Many research questions are remaining to investigate like queue-length allocation in the wireless hypervisor, the level of network granularity, etc.

defines fine grain operational policies for a distributed network, and BS implements the established policies. Kang et al. [113] proposed a price based heterogeneous fair resource allocation algorithm. The bandwidth prices are updated by using the gradient projection method and Utility maximization is considered as metric for radio resources allocation in two dimensions, i.e., time and frequency.

Dynamic resource allocation in SDN based cellular network is conserved using diverse approaches such as optimization, fair scheduling or using different optimal policing. Resource slicing is used in the cellular network; however wireless virtualization is still challenging due to the changing conditions in network dynamics. Descriptive analysis of resource allocation in SDN based cellular network is presented in Tables 4 and 5.

6 Analytical review of existing literature

The SDN architectures efficiently address bandwidth allocation in datacenters using some utility function and propose architectures as a game theoretic model based on utility gain or present some satisfactory bandwidth allocation policy based on the revenue and interest generated by the InPs. They mostly use SDN virtualization for providing multi-tenancy and resource allocation. However, the common assumption in unlimited bandwidth that can be allocated as per the demand of the customer. In fact, bandwidth is a limited resource that needs to be optimized in a constrained manner (Table 6).

Generally, traditional network engineering uses MPLS for traffic classification and static resource allocation in a greedy fashion by assigning priorities to ingress and egress port traffic and lack network fair share in a wide network. Hence, the resultant outcome is not bandwidth efficient. To overcome this limitation, SDN-based control and data plane virtualization are considered as in [35, 36, 54–56, 82, 84, 90, 92, 97, 102, 108]. However, they consider the static allocation of bandwidth in a fair allocation manner. SDN FlowVisor uses a leaky bucket which is not optimal in the case of large traffic burst and performance degrade.

In a traditional cellular network, resources are allocated statically, and there is a lack of central coordination with turns into the underutilized allocation of resources [104]. Moreover, resources in the wireless cellular net-work are more limited in term of spectrum and bandwidth. The wireless virtualization tools and techniques are not matured. Many significant challenges are remaining like isolation, control signalling,

Table 5 Resource allocation and bandwidth management in SDN-based data centers using game theoretic models

Ref.	Virtualization	Bandwidth Allocation	Contribution	Limitations
[34]	Utility max-min fairness among applications by adjusting VM.	Max-min fair allocation, non-linear model.	Application level strict utility max-min fair allocation algorithm in the datacenters	It is for SDN-based datacenters to allocate bandwidth to the different cloud application.
[91]	Virtual forwarding space (VFS) for data plane	A price-based joint allocation model of network resource and proportional fair bandwidth allocation.	Proportional fair bandwidth allocation policy and reduce global delay and accelerate packet forwarding	Unlimited bandwidth is considered in fair allocation even though bandwidth is not unlimited.
[95]	Network level virtualizati-on.	Application-layer bandwidth sharing protocol based on weighted bargaining Nash equilibrium.	Dynamic traffic among VMS in datacenters and VM-based fairness and allocation residual bandwidth in proportional fairness.	The allocation is in the datacenter on the VM basis and considered homogeneous network.
[93]	No Virtualizati-on	Automatic bandwidth guarantees for priority flow.	QoS framework for OpenFlow/SDN environment in while controller monitor and perform route calculation and reservation. Best effort traffic information is used for resource utilization.	The maximum rate for the queue is specified and QoS to stay within the maximum rate. Not Scalable.
[94]	FlowVisor	Auction-based resource allocation as a non-cooperative game theory, where FlowVisor act as auctioneer and NC as bidder	Resource allocation in the context of link bandwidth and flow table in multi-tenant SDN network.	Heterogeneity missing.

Table 6 Resource allocation and bandwidth management in SDN-based cellular network

Ref.	Virtualization	Bandwidth allocation	Contribution	Limitation
SDN-based shared EPS [3]	Virtualized architecture core and backhaul network	systematic modelling of virtual core and backhaul elements	Different optimization techniques are used as per service class like MMF and RG QoS-unaware: RR, BET, MT and PF.	Devised for LTE networks
SoftAir [25]	FlowVisor and wireless hypervisor	FlowVisor is responsible for network bandwidth allocation and wireless hypervisor responsible for wireless resources allocation.	A detail and Comprehensive architecture for SDN-based 5G network dealing mobility aware control traffic balancing, resource efficient network visualization.	Many research questions are remaining to investigate like queue-length allocation in the wireless hypervisor, the level of network granularity, etc.
QueuePusher [35]	OpenFlow virtualization	A queue management extension to OpenFlow controllers was defined, supporting the OVSDB standard.	Management of traffic control queues in OpenVSwitch in datacenters.	Queue creation may not be supported by all hardware.
5G -Crosshaul [77]	Control plane based virtualization	Prioritization and timing	Redesigning of transport network by integrating front-haul and backhaul network for the cellular 5G network.	Physical interference model used which include complexity.
D2D communica-tion Algorithm [78]	No virtualization	Quality enhancement algorithm for D2D communication in 5G cellular context for DL and UL transmission.	SDN based cellular network for D2D communication.	User means of statisfaction is key parameter but optimization and policing are not defined and slod this solution does not consider scalabililty and huge data traffic in UL and DL traffic communication.
Context-Aware SDN based cellular Network [79]	OpenFlow virtualization	Static and SDN-based bandwidth allocation for LTE cellular network and M2M devices	An architectural framework for context-aware cellular network based on SDN.	Only theoretical architectural proposal and does not support proof of concept.
CellVisor [54]	CellVisor extended from FlowVisor for cellular resource allocation.	Bandwidth allocation is left for CellVisor extended version of FlowVisor.	Urban scale deployment of IoT and heterogeneous network.	FlowVisor does not support dynamic allocation of bandwidth.
SoftRAN [23]	No virtualization instead considers base station in a region as big base station	Static backhauls bandwidth allocation to the remote radio heads.	Framework for centralizing base station in a geographical region as big base station controller by centralized controller.	A centralized controller is not responsible for allocating resources it only has information for handing send by the Big base station.
CellSDN [81]	CellSDN provide initial SDN based architecture for LTE cellular network	Resources are allocated statically by separating flow management form traffic management in the LTE network	It provides an initial architecture for LTE network based on SDN principle where control of traffic management and flow management is separated by providing a prototype controller based on Floodlight	It provides only theoretical architecture for SDN based TE network but no proof of concept and traffic engineering and fine grain policiing is missing.
SoftCell [83]	FlowVisor but not separate wireless virtualization.	Multi-dimensional aggregation of forwarding rules.	Minimize the size of the forwarding tables by aggregating traffic along multiple dimensions	Lacking fine-grained policies in the core network only.
Double Auction Mechanism based on	Flow level virtualization and wireless virtualization	The MVNOS and InPs bid gradually according to their own utility function. Flows are assigned resources based on the data rate	SDN-based wireless virtual resource allocation framework with diverse QoS requirements.	Static allocation of resources based on utility gain in InPs and MVNOS and real simulation is a mission.

Table 6 (continued)

Ref.	Virtualization	Bandwidth allocation	Contribution	Limitation
virtualization [89]				
MARS [103]	No specific virtualization, it uses OpenFlow virtualization	Multiple tables for mapping of aggregation bandwidth and throughput reduction are considered leveraging relative RTT for the scheduling on incoming flows.	MARS is a multi-access radio scheduling scheme based in RTT to reduce the end-to-end delay in the cellular network.	This scheme is need a change in the hardware for mapping multiple incoming flows which will increase the network expenditure
[104, 105]	Data plane virtualization.	Dynamic allocation of controller using chaotic population-based metaheuristic mode	PSO based chaotic Grey Wolf Optimizer algorithm for controller allocation. M/M/C model for multi-core Cell association at the physical layer and optimization at the backhaul layer	• Lack of dynamic resource allocation • Bandwidth is not considered
QoS guaranteed resource allocation [88]	OpenFlow Virtualization but not separate wireless virtualization.	Resource allocation in a cellular network.	Measure the impact of backhaul latency on user data rate.	Wireless virtualization is not considered.
SDN-based resource allocation in LTE network [113]	No virtualization	Price based heterogeneous fair resource allocation algorithm. The bandwidth prices are updated by using the gradient projection method. And Utility maximization radio resources in two dimensions, i.e., time and frequency.	Lagrange multipliers M/M/1 for core and M/D/1 for wireless	• Do not support virtualization, • Single SDN controller domain. • Heterogeneity of resource allocation is not supported • Control messaging overhead Only consider access link capacity and neglect core link utilization
Sm-GWs [110]	No Virtualization	sm-GW and SDN orchestrator between eNB and P/S-GW of the cellular network for the optimized resource allocation.	Maximize the utility by scheduling of resources in small cell cellular network and provide adaptive scheduling in the small cell network.	No virtualization and QoS for different parameters can also be investigated
[106]	Virtualization in the end to end cellular network.	Resource allocation and utilization in an elastic manner based on user demand.	SDN based elastic architecture for 5G with different use cases for M2M and V2V communication.	Does not specify the bandwidth allocation on the dynamic demands.
[110]	No virtualization specified.	Adaptive allocation of resources from uplink to eNB based on the demand.	Insertion of smart gateway between eNB and s/p gateway which are SDN controller enabled and resources are allocated based on demand cellular network.	QoS is not considered.

resource discovery and allocation, mobility management, network management and operation, and security [114]. SDN-based cellular architecture, comparatively new one, [24, 25, 54, 56, 79] etc. have different requirements from SDN tradition virtualization management. In cellular /mobile/wireless network, wireless medium is of broadcast nature and consumes more traffic resources (bandwidth and time). The isolation of these spectrums (resource) cannot be handled by the SDN virtualization technique. Another factor, the existing wireless virtualization solution does not focus on the queue-length based solution, though some work focuses on per-flow queue management as in [103] in the WiMAX wireless network and put tags on each arriving packet on per-flow-basis and allocate queue. However, this solution does not support full virtualization of a heterogeneous network.

A brief architecture with virtualization details for the core network, providing backhaul access, and wireless domain, proving cellular access is proposed in [25]. Ian. F. Akhildiz et al. proposed to an architecture for 5G cellular network based on SDN consisting of the hierarchy of virtualization. Despite the strong theoretical framework of SDN based 5G cellular network architecture, practical implication and results are not evident as a proof of concept.

From Table 7, we can analyze that the dynamic resource allocation and wireless virtualization in SDN based cellular network are less considered in the research, even if the studies are focusing optimization and policy framework. Moreover, wireless virtualization relies on the network virtualization which has completely different set of requirements. The SDN network virtualization work for flow level slicing while in wireless virtualization, physical level resources are needed to be virtualized for efficient and dynamic resource allocation.

6.1 Complexity analysis

SDN based 5G cellular network is in its infancy, and most of the research is in the context of building a flexible architecture to incorporate the expected demands and flexibility. The resource allocation in SDN based cellular network is immensely complex due to the dynamism of the changing requirements of the customer and increased versatility of user need. Resource allocation algorithms follow static distribution and utilization in the cellular network which itself is an NP-complete problem. Many research focuses on the resources allocation considering utility gain of the mobile operators and satisfaction of the user need which introduced intricacy.

Table 7 Dynamic resource allocation comparison based on optimization and policing scheme in SDN-based cellular networks

Reference	Infrastructure/ Architecture	Optimization	Policing	Virtualization		Dynamic resource allocation
				Flow level virtualization	Wireless virtualization	
SDN-based shared EPS [3]	✓	✓		✓		
SoftRAN [23]	✓	✓		✓		✓
SoftAIR [25]	✓	✓		✓	✓	
CROWD [27]	✓	✓				
CellVisor [54]	✓		✓			
5G -Crosshual [77]	✓			✓		
D2D communication Algorithm [78]	✓		✓	✓		
Context-Aware SDN based cellular Network [79]	✓			✓		
CellSDN [81]	✓		✓	✓		
UbiFlow [82]	✓	✓	✓			
SoftCell [83]	✓		✓	✓		
QoS guaranteed resource allocation scheme [88]		✓			✓	
Double Auction Mechanism based on virtualization [89]		✓			✓	✓
Falloc [92]		✓		✓		✓
MARS [103]	✓		✓			
SDN-based resource allocation in LTE network [113]		✓				✓
Sm-GWs [110]	✓	✓				
Synergistic spectrum 5G HetNets [112]	✓		✓			

inefficient resource allocation. Some research work focuses on reducing complexity using low complexity algorithm in conjunction with Taylor extension [85]. The mobility also affects the efficient resource utilization as in Ubiflow as it takes O(|AP||MD| log(MD)) [82]. UFalloc [34] takes O(|K|) for a constant number of applications. The high complexity incurred during resource allocation is addressed by introducing shadow price in [89] which illustrate marginal utility adjustment to gain performance of InP and MNOs.

The existing work for resource allocation in SDN based cellular network shows diversity and dynamism in the evaluation, considering different paradigm in varied direction. Table 8. shows the diversity in evaluating resource allocation such as throughput, utility, fairness, data rate, arrival rate and hit ratio etc. to analyze the performance gain in allocating resources to the users or the utility gain to the mobile operator. The existing works shows that the using SDN paradigm in 5G cellular network can achieve higher throughput and low latency compared to existing network architectures. The centralized control and management in SDN provide assistance in fast innovation in the rapidly changing network requirements.

7 Simulation and implementation

Simulation is of great importance due to the provision of flexibility in implementation in cost-effective manner. There are many simulators for testing the implementation of new ideas and evaluating the performance output. For SDN, many simulators facilitate researchers for implementation. Mininet has commonly used software for academic simulation at small scale. It provides an easy installation and configuration of SDN network and provides flexibility. However, Mininet does not support wireless radio module and hence cannot be targeted for this research. NS2, NS3, MATLAB, LIANA simulator and OPNET provide support for SDN based cellular network. A general comparison of SDN simulator is given

Table 8 Existing literature performance parameter comparison

Reference	Evaluation Parameters	Result
SDN-based shared EPS [3]	Fairness	41%
SoftRAN [23]	N/A	
SoftAIR [25]	Delay reduction	73%
	Traffic latency	–
	Classification	> 90
D2D communication Algorithm [78]	SNIR, Data rate	–
UbiFlow [82]	Jitter	<69.95% for audio and < 49.72% for video
	Data rate	7.24 Mbps
	Throughput	42.24%
	Delay	62.07%
	Transmission Delay	0.4 s
SoftCell [83]	UE arrival rate	99.99 percentile
	Hit ratio	80%
QoS guaranteed resource allocation scheme [88]	Throughput	5Mbps
Double Auction Mechanism based on virtualization [89]	Convergence rate (in step size)	0.15
MARS [103]	Reordering Throughput	1.3Mbps
	End-to-end delay	21,458 ms
SDN-based resource allocation in LTE network [113]	Fairness	10Mbps fairly allocated
	Throughput	45Mbps
	Delay	Maximum for an arrival rate of 4000 otherwise less changing
	Convergence (in step size)	Within 1000 iteration
Sm-GWs [110]	Low traffic state probability	70%
	High traffic state probability	30%
	Fair Throughput	140Mbps
	Uplink Transmission bit rate	50Mbps

in Table 9. providing a descriptive detail of available tools for simulation and implementation of SDN cellular networks.

8 Requirements for resource allocation in SDN based 5G cellular network

SDN-based cellular networks face many challenges such as link isolation, channel estimation, radio spectrum fluctuation and scarcity of available bandwidth, etc. These challenges pose data rate limitation on the user requirements [115]. The requirements and implementation of dynamic resource allocation are still vague [5] and need restructuring resource allocation and dynamic management. In a traditional cellular network, bandwidth is allocated statically on the availability of bandwidth. The general solutions for the allocation of bandwidth are Round Robin (RR), Round Trip Time (RTT) [[103], Leaky bucket [116] etc.

However, in SDN paradigm, flow table entries need to be updated dynamically on the flow basis. Flows are defined based on some different granularities, such as a set of packets which have one or more common features, e.g., source IP address, destination IP address or source MAC address, etc. So, there is a frequent change in the definition of rules/policies in the data plane for fast forwarding of data. For the change in the flow table, network updates are frequently required. These updates are sent to the controller, which result in a huge bandwidth consumption while transmitting control information. Due to the static allocation of resource, cellular equipment may suffer from bandwidth scarcity. It may cause a bottleneck in the network and reduces performance and efficiency when many updates are required. Flow-level bandwidth provisioning solutions suffer from several drawbacks, including high implementation complexity, poor performance guarantees, and inefficiency to process variable length packets.

In a cellular network, the wireless hypervisor does not consider queue length based solutions while SDN follows flow-based traffic engineering which results in a huge disparity between flow management and queue-based resource allocation of incoming flow request. The wireless network virtualization is still immature and facing many issues regarding isolation, mobility management, resource allocation, network management and monitoring [114]. The network virtualization is a heavily used to share physical resources for multiple network slices however, wireless virtualization still need an intense research to isolated wireless physical resources like radio resources, interference management and power consumption in heavily connected scenario and extensively changing network dynamic. The fronthaul and backhaul resource also need to isolate for the provision of high data rate over a same physical network. The radio resource virtualization need to be provided at the edge or at the base station or access point to better have visibility of network partitioning and resource management.

9 Conclusion

5G network is a hot trend in the research with the motivation of achieving high performance in term of higher capacity, greater throughput, lower latency and provision of last mile connectivity. These attributes require fair resource allocation and network management. SDN and NFV facilitate network administrator to provide automatized network management and efficient resource allocation and provision. However, the cellular network still suffers from static resource allocation due to multiple factors such as limited physical resources and huge connectivity. This article highlights the requirement for the resource allocation in a 5G cellular network. Resource allocation requires a dynamic and optimized resource policy leveraging virtualization and SDN for achieving fair and

Table 9 Simulation tools for SDN cellular network implementation

Simulator	Environment	Programming Language	License	Remarks
Mininet	LINUX	Python	Open source	Mininet is initial emulator tool for SDN and supports small-scale simulation.
NS2	LINUX	C++/OTCL	Open source	Discrete Event simulator mainly support wired network routing and management functionality, also support for SDN and wireless network.
NS3	LINUX/UNIX	C++/Python	Open source	NS3 provides support for SDN and wireless network as well.
MATLAB	Windows/LINUX	MATLAB script	Commercial	MATLAB is very efficient in performance evaluation and support SDN and wireless and sensor network
OMNET++	Windows	C++	Open source	OMNET++ provides support for SDN and wireless and evaluate complex communication and system performance
OPNET	Windows	Proto C	Commercial	Provide high-level Performance management of communication protocols. SDN can be realized in OPNET.

efficient resource allocation. We are working on addressing dynamic resource allocation in a cellular network by efficiently slicing physical resources at the BS and scheduling from the centralized controller.

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