5G cellular network integration with SDN: Challenges, issues and beyond

Conference Paper · March 2017

DOI: 10.1109/C-CODE.2017.7918900

2 authors:

Sahrish Khan
COMSATS University Islamabad

Munam Ali Shah
COMSATS University Islamabad

5G Cellular Network Integration with SDN: Challenges, Issues and Beyond

Sahrish Khan Tayyaba
Department of Computer Science
COMSATS Institute of Information Technology
Islamabad, Pakistan
sahrish.aiou@gmail.com

Munam Ali Shah
Department of Computer Science
COMSATS Institute of Information Technology
Islamabad, Pakistan
mshah@comsats.edu.pk

Abstract— **The tremendous growth in communication technology is shaping a hyper–connected network where billions or connected devices are producing a huge volume of data. Cellular and mobile network is a major contributor towards this technology shift and require new architectural paradigm to provide low latency, high performance in a resource constrained environment. 5G technology deployment with fully IP-based connectivity is anticipated by 2020. However, there is no standard established for 5G technology and many efforts are being made to establish a unified 5G stander. In this context, variant technology such as Software Defined Network (SDN) and Network Function virtualization (NFV) are the best candidate. SDN dissociate control plane from data plane and network management is done on the centralized control plane. In this paper, a survey on state of the art on the 5G integration with the SDN is presented. A comprehensive review is presented for the different integrated architectures of 5G wireless network and the generalized solutions over the period 2010-2016. This comparative analysis of the existing solutions of SDN-based cellular network (5G) implementations provides an easy and concise view of the emerging trends by 2020.**

Keywords—Software Defined Network; 5G; cellular networks; Integrated Cellular SDN;

I. INTRODUCTION

The tremendous growth in the technology and connectivity is shaping a hyper-connected world of million and billions of devices connected and communicating with each other. The current wireless technologies such as 3G/4G are sprouting IP connectivity and aims in providing faster internet connection, multimedia application and multitude of services with increased performance, flexible deployment and low cost implications. However, the services demand and traffic patterns diversity is growing with a fast stride that exponential growth in mobile data is witnessed to grow 4000 fold in last ten years [1] and 150 million subscription in the first quarter of 2016 making it 1.2 billion connected devices at the third quarter of 2016 [2].

Based on these enumerations of fast development in the connection/subscription and connected devices, current deployed 3G/4G wireless network do not sufficiently meet the demand of diversity, low latency and high performance which is anticipated in 5G wireless system/mobile network. The 5G basically provide a user centric connectivity where multiple applications are accessed at faster pace, at higher capacity and at 1ms latency. The 5G is considered an important tool for realizing Internet of Thing (IoT) paradigm connecting billions of devices as it is capable of supporting machine-to-machine (M2M) communication at low cost and low battery consumption guarantying high quality of services (QoS). However, the standardization efforts for 5G are still under its infancy and complete realization of 5G is forecasted in 2021 in South Korea, Japan, China and the US [2].

The implementation and deployment of 5G wireless systems require re-engineering in the design of existing communication and network technologies. This is because the farsighted flexibility and cost efficiency for the management of billions of connected devices is not possible with existing 3G/4G architecture. Moreover, existing spectrum is insufficient to fulfill the expected gain and performance requirements in M2M communication, vehicular connectivity, smart cities and industrial automation as expected from 5G mobile system in term of IoT. For this reason, 5G is investigating both in the academia and in the industry and many potential enabling technologies are parameterized. Such enabling technologies include Software Defined Networks (SDNs) and Network Function Virtualization (NFV).

The SDN is redefining network architecture by separating control plane from data plane and providing support for heterogeneous network interplay with rapid evolution and dynamism using programmable planes. While, NFV provides freedom from the underlying complexity and resource allocation for multiple user seamlessly connected to the network. SDN integration with cellular network foster the innovation at higher pace and flexibility in the deployment lead to shorter access of new IP based services.

However, the complexity of 5G and cellular network protocol and implementation require abstraction which is still an open issue in the cellular network. Therefore, different existing architecture for cellular network in context of SDN is envisioned and advocate that SDN based cellular architecture can reshape the cellular communication in IP connectivity This paper highlight different studies which provide SDN based solution for cellular based IoT technologies more specifically, implementation of 5G in SDN context. We survey the literature over the period 2010-2016, by focusing the attention on different cellular architecture leveraging SDN control plane independence. The organization of this paper is as follows:

Section II describes the architecture for SDN and SDN enabled cellular networks. Based on study, different architectural characteristics of 5G technology is highlighted. Section IV provides a detail review of the existing solution, providing comparative analytics of the existing integration solutions. Section V conclude the study.

II. SDN AND SDN ENABLED WIRELESS WORLD

SDN is recently emerged network paradigm where dis-association of control plane from data plane provides vendor independence and operator sovereignty for network programmability and providing support for heterogeneous network. SDN is generally associated with network routing and act as an orchestrator for network level management. SDN control plane is logically centralized entity having global view of the entire network; network management and configuration is performed on the control plane. The underlying switching network (data plane) is abstracted from applications and user services. The most witnessed application of SDN are viable in data center and cloud computing [3][4][5][6].

A. SDN Architecture and protocol

In SDN, control plane is decoupled from forwarding plane and communication between two planes is done through APIs e.g. OpenFlow[7]. SDN is basically a layer architecture consist of three layers (1). Data plane layer, (2). Control plane/controller layer, and 3). Application layer. Data plane consist of dumb forwarding devices i.e. router & switches which only forward data on the controller instructions. Controller acts as a brain and manage network by having global view of the network. The customer needs are abstracted over application layer which are communicated to the controller via Northbound APIs e.g. RESTfull API. The controller manages whole network and possess a global view of the network. All applications/programs run above the controller. Many controllers are in the market from its inception such as OpenDaylight [8], Floodlight [9], NoX/POX [10], etc. SDN controller define rule for the incoming flows from the data plane. SDN layers communicate with each other via open APIs called Northbound Interface (NI) API and Southbound Interface (SI) API.

The SDN controller provides programmability and flexible management for flow forwarding state in the data plane by having a global view of the network. SDN can facilitate high data transmission, spectral efficiency, resource allocation and network management for the IoT devices for fulfilling growing need of the customer demands. Many controller application are also envision for cellular network such as self-organizing networking (SON) application [11]running on the centralized controller. SON provide performance gain in RAN network by optimization achieved through SON algorithm on the control plane.

1) SDN enaled wireless network

SDN benefits are also realized for wireless connectivity and an integrated SDN based wireless network SDWN emerged in [12]. The management of wireless network is assisted by the centralized SDN controller in a cost-effective manner and fine grain channelization is achieved at high data rate and low latency using SDN centralized controller architecture. Baseband virtualization is used for spectrum management in SDWN. Architecture for managing wireless data plane is presented in [13] for decoupling of MAC protocol from the data plane. Management of data plane is done through declarative and modular programming interface and refactoring wireless protocols (WIFI, LTE). A software abstraction layer is used to program the PHY and MAC layer of the wireless data plane. Mobileflow [14] present an architecture in which operator model the carrier grade flow based forwarding for mobile network and present and test bed implementation. Bernardos et. al in [15] present SDWN architecture for multiple Radio Access Network (Multi-RAN) and core network for deploying new services and introduce programmability to enhance RAN and core switches (L2 and L3 switches in core network). Core controller provides functions such as authentication, authorization and QoS services provisioning. A general architecture for mobile wireless based on SDN is shown in Fig.1.

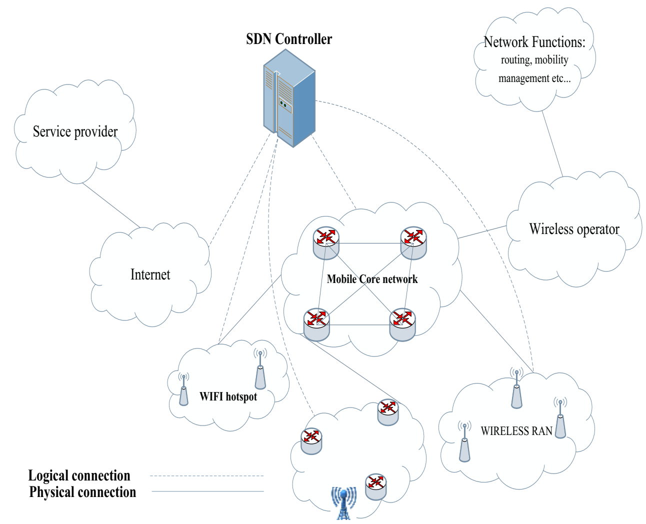

Fig. 1. SDN based Mobile wireless network architecture.

2) SDN based Cellular network architecture

The evaluation of cellular network from first generation (1G) to the upcoming 5th generation (5G) are aiming in QoS provisioning for hyper-connected network wirelessly connected over a long range of network domains. The basic ingredient of cellular network is wireless access network with variant spectrum and forming a heterogeneous network consisting of multiple domains like Wi-Fi, LTE, WiMAX and 3G/4G network. The other direction of this technology shift is 4G and 5G network that are user driven instead of operator driven i.e. the need for services requirements and demands are divergent and require evolvability and flexibility in the implementation and deployment of these new networks. The hyper connected M2M modules in the 5G network require integration of already existing technologies as well as new emerging scenarios. These intersecting technologies expose many challenges to provide a convergent network. 5G technologies comprise of user terminal and divergent set of autonomous networks and RAN technologies. These RAN technologies (distinct network) are connected to the outer IP world with IP link controlled by the control system policy server. A general architecture for cellular network is shown in Fig. 2.

B. *Architectural characteristics of 5G*

The future vision of 5G network technologies are based on some assumption like higher data volume, higher data rate for each user, low latency, higher number of connected devices, 1ms latency and low battery consumption[16]. The heterogeneous network management in 5G is also an important deal for a converged network.

1) *5G Data rate and Volume*

The anticipated data rate is 30.6exabytes produced by mobile data traffic with an average connection speed of 3Mbps up till 2017 [1]. This data rate is 1000 times higher than the existing traffic volume and 100 times greater of data rate. For this reason, the capacity management in the 5G network is looking for re-engineering in the PHY technologies and spectrum efficiency. The spectrum efficiency for dense network is addressed in [17] in which self-organizing network utilizes ultra-dense network capacity by including macro eNB and low power eNB in a dense network. This reduces the path loss between user and BS and network capacity enhanced.

In 5G, if a single centralized controller handles all the incoming traffic, there is an obvious reduction in the performance. To reduce the load on the centralized controller, the load on the P-GW should also be reduced. In this context, Qin et al presented an architecture MINA that can also be part of 5G technology based on SDN management. In [18], Qin *et al*. enhanced the idea of Multi-network controller architecture (MINA) for heterogeneous IoT network based on SDN controller for a multi-network environment such as network accessing Wi-Fi, WiMAX, LTE, ZigBee and other cellular network. MINA is basically a middleware whose working principle is self-observing. SDN principle helps in flow matching and management. MINA follows SDN like layered architecture which reduces the semantic gap between IoT and task definitions in multi-network environment. This architecture aims flow scheduling and management. The architecture is modeled using Genetic algorithm and network calculus. Flow shares the same node resources and network is optimized for this resource sharing in this architecture.

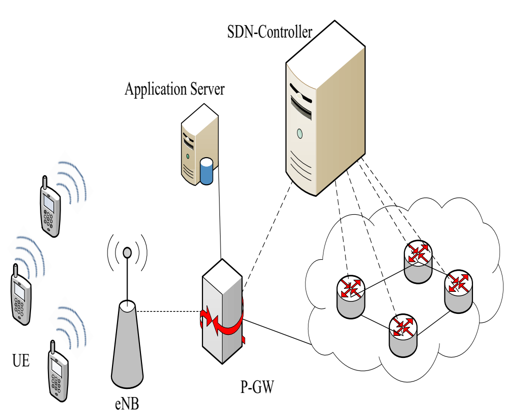

Fig. 2. SDN based cellular network

2) *Reduced latency in 5G*

An important characteristic of 5G technology is reduced latency called 1ms latency especially in M2M connectivity. The devices in 5G technologies are capable of cashing local content e.g. content cashing in EPC and eNB reduce the response time in the 5G network. However, the limited storage cashing capacity in eNB is not capable of enough content caching and refreshes frequently which reduces the cache hit ratio compared to miss ratio and overall latency increased in the network.

3) *Improved energy efficiency*

M2M communication is generalized as energy constrained devices. Hence to get higher and longer life time of energy constrained network, energy consumption optimization is required. Sleep/awake mechanism and scheduling can be used for unutilized channels are nodes to support energy conservation [19]. W. Wang et al. presented an SDN based algorithm “Energy Consumed Uniformly Connected K-Neighborhood” (EC-CKN) called as SDN-ECCKN. In this architecture, a controller node calculates the overall energy of WSN. SDN-ECCKN helps in retaining energy of each node and minimizes the broadcast messages from the individual node.

4) *Key Features of 5G Architecture*

To summarize the key benefits of 5G mobile network, it should satisfy the following requirement of highly connected devices capable of providing higher data rate and low latency and flexible and programmable architecture. The programmability of 5G technology/cellular network can be achieved by utilizing the concept of SDN and NFV. So, for much architecture are established or under review for leveraging SDN control plane programmability in 5G cellular network which are discussed in section III.

III. Cellular Network Integration in SDN

With the increasing complexity and aggregated tele-communication technologies, cross functionality in cellular network is hard to obtain the desired result and need to physically intervening in radio technologies. By providing software based radio manipulation, distinct management flexibility can uplift network performance.

A. *SDN based Cellular network Architecture*

The first proposal for SDN based cellular network was presented by Li. Erran et. al in [20]. They name it as CellSDN, in which attribute based policies are formulated for individual user in the LTE network and gain fine grain control over the network. In CellSDN, local agents on each switch perform deep packet inspection and reduce excessive load on the controller.

Radio Access Network (RAN) individually handle network as a collection of base station in which cross functionality is hard to obtain due to Distributed coordination algorithms. By providing software-based radio manipulation, distinct management flexibility can uplift network performance.

SoftRAN is proposed by S. Tomovic *et al*. in [21], uses SDN principle in 4G LTE network. A centralized control plane abstracts the whole RAN into geographical area. A big base station with centralized controller perform resource allocation in a grid of three dimension i.e. space, time, and frequency slots. The controller decides to allocate resource in the domain of frequency, time and space slot. Radio elements/BS takes some local decision to manage the delay.

SoftCell [22], incorporate SDN in cellular core network and provide a fine grained policies for LTE network. In SoftCell architecture, traffic classification is done on the access switches instead of gateway. Every access switch has a local agent which caches each UE profile to control packet classification is access switch. Controller assigns policy tag, hierarchical IP address and UE identifiers and embeds into packet header to avoid reclassification of traffic.

SDN and SDR integrated architecture for 5G network is proposed in [23], called Hybrid SDN/SDR architecture . The architecture is cross layer combination of SDN and SDR for exploiting frequency spectrum and link information in 5G network. The cross-layer controller is used to request frequency spread spectrum and make decision for flow traffic. This architecture also manages user authorization in the cross-layer controller and grant access to a better band.

SoftAir [24], by Ian F. Akyildiz *et al*. proposed the 5G network exploiting virtualization for a resilient network. SoftAir provide mobility aware load balancing and resource efficient allocation through virtualization. The aggregated control is provided by NFV creating multiple virtual networks with independent protocols and resource allocation algorithms. SD-RAN and SD-core network nodes are OpenFlow enabled and monitored through OpenFlow and Common Public Radio Interface (CPRI). All management policies are defined at controller and provide end-to-end QoS guaranty.

In SDN&R [25], a an integrated management of cellular network is proposed. SDR is used to maintain radio status information in the control plane implemented on a base station (BS). The OpenFlow enabled control plane performs radio allocation on the BS and cognitive edges (CE). The packet processing is done on the controller connected to BS via a secure channel. This architecture is detail footprint of SDN integration in a cellular network for managing resources in IoT network.

B. SDN based Cellular network Management

The configuration, reconfiguration, resource allocation and even the pattern of inter communication become extremely difficult. SDN play a vital role in the management of such heterogeneous network.

Di. WU *et al*. in [26], presents UbiFlow which provide an efficient flow control and mobility management in urban multi-networks using SDN distributed controllers. In UbiFlow architecture, IoT network is partitioned into small network chunks/cluster, controlled by a physically distributed SDN controller. The IoT devices in each partition may be connected to different access point for different data requests. MINA performs per-device flow management and optimization of access.

M. Boussard *et al*. [27], proposed SDN based control and management framework for IoT devices in a smart environment. The management framework, called as "Software-Defined LANs (SD-LAN)", organize devices and group in the order of requesting services from the user. This framework uses Universal Plug and Play (UPnP) and Simple Service Discovery Protocol (SSDP) for discovering new device in the SD-LAN network and create a virtual topology for service requirement.

Ali-Ahmad et. Al. proposed CROWD in [28], which cover the MAC layer configuration, backhaul management in the overlapping wireless network like WLAN and LTE.

Security aspect in wireless mobile network is very little discussed in research [29]. Aaron Yi Ding *et. Al.* proposed a secure architecture for wireless mobile network based on a security agent on controller and a security layer for mobile wireless link.

Jararweh *et al*. in [30] proposed a framework model for SDN based IoT management and control. The data is collected from the sensor board and aggregated on the IoT Bridge. Then collected data is send to SDSec controller for security checking. Access is provided only to an authorized device by using authentication and authorization. Rules are defined based on collected data for routing and controlling policies by the SDN controller and stored into SDStore module of the framework.

IV. DISCUSSION AND OPEN ISSUES

SDN paradigm can be applied on different layers of cellular network. However, wireless SDN is still in its infancy and many issues are still un-handled. The low-cost devices are resource constrained requiring duty cycle enabled communication to reserve resources, long coverage communication using multiple hop communication and data aggregation and manipulate cross layer optimization. However, the existing solution is not fully integrated in SDN and a comprehensive architecture and framework is not established so far. Few efforts are really admirable such as SoftRAN, SoftAir, openRoad, mobileFlow etc., where a complete framework for IoT devices is presented giving resource allocation strategies, operating system for SDN based cellular network management and architectures. A comparison of selected studies is given in Table. 1.

The SDN controller should be capable of handling node mobility, self-configuration, and flow management for dense network. Control traffic in any network consumes bandwidth and hence degrades the spectral efficiency in the cellular network. The low latency i.e. 1ms latency in 5G network require routing and flow management using in-network processing which is still not clear which flow should be externally handle by centralized controller and which flow should be processed on eNB or local controller. Also, SDN centralized control plane may suffer from denial of services attack and man in middle attack. Due to huge amount of data produced in IoT cellular network, data privacy is a critical issue. Efficient design of SDN based cellular network is hard to achieve due to the immense complexity of hyper connected devices.

V. CONCLUSION

5G is an upcoming goal in 2020 communication providing new norms of connectivity and communication enabling smart ecosystem. It is changing the way of thinking about the communication in object exists in our surroundings and improving the quality of life. However, standards for 5G are still not established and significant research is carried out to establish a unified 5G architecture which can support high connectivity and huge volume produced by the cellular network. A cellular network lacks programmability, agility, security and data management due to huge amount of connected devices and data produced.

To meet the need of customer requirement, it is highly anticipated to use programmability and centralized control. In this paper, we have reviewed the existing solution of cellular network integration in SDN control plane.

In this work, key characteristics of 5G network and efforts made to achieve high data rate in a cellular network is discussed. In the last, it is concluded that SDN can flexibly change the cellular network shape and gain success in reshaping the cellular architecture to meet the desired features for 5G cellular network.

TABLE 1. THE COMPARISON OF EXISTING CELLULAR IOT SDN SOLUTIONS

Architecture	Resource Management	Interface API	Purpose	Virtualization	Control/data plane decoupling	Traffic engineering	Scalability	Benefit	Limitation
openRadio [12]	Spectrum management	Declarative and modular programmable interface	Multiple network can act as a single network and extend in mobile network	No virtualization	Wireless data plane	Operator define rules for traffic stream	Low	Evolvability, remotely programmable, network optimization	RAN controller is not Software defined
OpenRoad	Dynamic spectrum and power allocation	Openflow wireless interface	An open interface architecture for slicing and virtualization of wireless network and provide high level abstraction	Big base station	Data plane and control plane separation as in openflow network	Big base station acts a controller and perform	Medium	Reduce jitter in the wireless domain, flexibility for deploying mobile service, hide underlying execution of process	No support for cellular network only implemented for Wi-Fi and WiMAX mobile network, optimized traffic steering
MobileFlow [14]	Mobility management	Openflow	Flow based forwarding in a mobile network	Control plane and data plane virtualization,	Control and forwarding plane	Control plane steer user traffic throughout the mobile network	Medium	carrier-grade flow-based forwarding, on demand network creation	Multiple control of controllers is not defined, RAN integration into SDN controller
SoftRAN [21]	Resource management, mobility support, traffic off loading	Controller API/ Femto API	To overcome the tightly bounded co-ordination in resource management	Big base station	Centralized controller and local agent at eNBs , slicing forming big base station	Load balancing Interference management/ SD Radio access network	Low	Radio resource management, mobility support, Traffic offloading, Reduced delay	No concrete solution, virtualization is not clear, centralized control plane and interaction between core network and RAN is not defined
Hybrid SDN-SDR [23]	Spectrum management	Openflow based devices	For the management of spectrum allocation and network management in a 5G network	No virtualization	Centralized controller	Spectrum resource management and network resource management	Low	Power saving and optimization	Cross layer controller, security
SoftCell [22]	Fine grain policies management.	OpenFlow API	Modification in the core network	Minimum virtualization	Logical centralized controller, local agent SD-RAN (BS)	MPLS and slandered routing as in OpenFlow	High	Dynamic traffic offloading, efficient routing, minimizing the state in core network	Fine grain service policies
SoftAir [24]	Distributed traffic classification, network management	OpenFlow & CPRI	network function cloudification and network virtualization	Fine grain virtualization	SD-BS, SD-switch, BS-clustering	Collaborative processing, scheduling and mobility management	High	Flexible platform for fully & partial centralized architecture	Security issue not addressed
CellSDN [20]	Mobility management and policy control	NOS	virtualization	Basic support for virtualization	Centralized control plane, local control agent ate BS	MPLS traffic labeling or VLAN tags	Low	Seamless mobility management and fine grain control due Local agent	No proof of concept and evaluation of the proposed scheme, vague traffic engineering handling using MPLS/VLAN tags
CROWD [28]	MAC layer reconfiguration, dynamic backhaul reconfiguration, and connectivity management	CROWD Regional and Local controller	Efficient operation of DenseNet in context of wireless network based on SDN	No virtualization	Control and data plane separation with two-tier SDN controller hierarchy	Access point cooperation, Access Selection, Load Balancing, D2D Offloading	Low	dynamic reconfigurability of the network elements	Does not provide security for centralized two level of controller hierarchy

References

[1] "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020 White Paper," *Cisco*. [Online].

[2] W. OBILE, "Ericsson Mobility Report."

[3] S. Sezer *et al.*, "Are we ready for SDN? Implementation challenges for software-defined networks," *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 36–43, Jul. 2013.

[4] F. Hu, Q. Hao, and K. Bao, "A Survey on Software-Defined Network and OpenFlow: From Concept to Implementation," *IEEE Commun. Surv. Tutor.*, vol. 16, no. 4, pp. 2181–2206, Fourthquarter 2014.

[5] D. Kreutz, F. M. Ramos, P. E. Verissimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig, "Software-defined networking: A comprehensive survey," *Proc. IEEE*, vol. 103, no. 1, pp. 14–76, 2015.

[6] B. A. A. Nunes, M. Mendonca, X.-N. Nguyen, K. Obraczka, and T. Turletti, "A survey of software-defined networking: Past, present, and future of programmable networks," *IEEE Commun. Surv. Tutor.*, vol. 16, no. 3, pp. 1617–1634, 2014.

[7] W. Braun and M. Menth, "Software-Defined Networking using OpenFlow: Protocols, applications and architectural design choices," *Future Internet*, vol. 6, no. 2, pp. 302–336, 2014.

[8] J. Medved, R. Varga, A. Tkacik, and K. Gray, "Opendaylight: Towards a model-driven sdn controller architecture," in *Proceeding of IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks 2014*, 2014.

[9] S. Floodlight, "OpenFlow Controller," *Web Httpsgithub Comfloodlightfloodlight*.

[10] N. Gude *et al.*, "NOX: Towards an Operating System for Networks," *SIGCOMM Comput Commun Rev*, vol. 38, no. 3, pp. 105–110, Jul. 2008.

[11] M. Y. Arslan, K. Sundaresan, and S. Rangarajan, "Software-defined networking in cellular radio access networks: potential and challenges," *IEEE Commun. Mag.*, vol. 53, no. 1, pp. 150–156, Jan. 2015.

[12] W. Wang, Y. Chen, Q. Zhang, and T. Jiang, "A software-defined wireless networking enabled spectrum management architecture," *IEEE Commun. Mag.*, vol. 54, no. 1, pp. 33–39, Jan. 2016.

[13] M. Bansal, J. Mehlman, S. Katti, and P. Levis, "Openradio: a programmable wireless dataplane," in *Proceedings of the first workshop on Hot topics in software defined networks*, 2012, pp. 109–114.

[14] K. Pentikousis, Y. Wang, and W. Hu, "Mobileflow: Toward software-defined mobile networks," *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 44–53, Jul. 2013.

[15] C. J. Bernardos *et al.*, "An architecture for software defined wireless networking," *IEEE Wirel. Commun.*, vol. 21, no. 3, pp. 52–61, Jun. 2014.

[16] J. Zhang, W. Xie, and F. Yang, "An architecture for 5G mobile network based on SDN and NFV," in *6th International Conference on Wireless, Mobile and Multi-Media (ICWMMN 2015)*, 2015, pp. 87–92.

[17] N. Bhushan *et al.*, "Network densification: the dominant theme for wireless evolution into 5G," *IEEE Commun.* Mag., vol. 52, no. 2, pp. 82–89, Feb. 2014.

[18] Z. Qin, G. Denker, C. Giannelli, P. Bellavista, and N. Venkatasubramanian, "A Software Defined Networking architecture for the Internet-of-Things," in *2014 IEEE Network Operations and Management Symposium (NOMS)*, 2014, pp. 1–9.

[19] Y. Wang, H. Chen, X. Wu, and L. Shu, "An energy-efficient SDN based sleep scheduling algorithm for WSNs," *J. Netw. Comput. Appl.*, vol. 59, pp. 39–45, 2016.

[20] L. Erran, L. Z. Morley, and M. J. Rexford, "Cellsdn: software-defined cellular networks," 2012.

[21] A. Gudipati, D. Perry, L. E. Li, and S. Katti, "SoftRAN: Software defined radio access network," in *Proceedings of the second ACM SIGCOMM workshop on Hot topics in software defined networking*, 2013, pp. 25–30.

[22] X. Jin, L. E. Li, L. Vanbever, and J. Rexford, "SoftCell: Scalable and Flexible Cellular Core Network Architecture," in *Proceedings of the Ninth ACM Conference on Emerging Networking Experiments and Technologies*, New York, NY, USA, 2013, pp. 163–174.

[23] H. H. Cho, C. F. Lai, T. K. Shih, and H. C. Chao, "Integration of SDR and SDN for 5G," *IEEE Access*, vol. 2, pp. 1196–1204, 2014.

[24] I. F. Akyildiz, P. Wang, and S.-C. Lin, "SoftAir: A software defined networking architecture for 5G wireless systems," *Comput. Netw.*, vol. 85, pp. 1–18, 2015.

[25] S. Namal, I. Ahmad, S. Saud, M. Jokinen, and A. Gurtov, "Implementation of OpenFlow based cognitive radio network architecture: SDN&R," *Wirelesss Network.*, vol. 22, no. 2, pp. 663–677, 2016.

[26] D. Wu, D. I. Arkhipov, E. Asmare, Z. Qin, and J. A. McCann, "UbiFlow: Mobility management in urban-scale software defined IoT," in *2015 IEEE Conference on Computer Communications (INFOCOM)*, 2015, pp. 208–216.

[27] M. Boussard *et al.*, "Software-Defined LANs for Interconnected Smart Environment," in *Tele-traffic Congress (ITC 27), 2015 27th International*, 2015, pp. 219–227.

[28] H. Ali-Ahmad *et al.*, "CROWD: an SDN approach for DenseNets," in *Software Defined Networks (EWSDN), 2013 Second European Workshop on*, 2013, pp. 25–31.

[29] A. Y. Ding, J. Crowcroft, S. Tarkoma, and H. Flinck, "Software defined networking for security enhancement in wireless mobile networks," *Comput. Netw.*, vol. 66, pp. 94–101, 2014.

[30] Y. Jararweh, M. Al-Ayyoub, A. Darabseh, E. Benkhelifa, M. Vouk, and A. Rindos, "SDIoT: a software defined based internet of things framework," *J. Ambient Intell. Humaniz. Comput.*, vol. 6, no. 4, pp. 453–461, 2015.