Edge Computing Enabling the Internet of Things

Ola Salman   Imad Elhajj   Ayman Kayssi   Ali Chehab
Electrical and Computer Engineering Department
American University of Beirut
Beirut 1107 2020, Lebanon
{oms15, ie05, ayman, chehab}@mail.aub.edu

Abstract— **Mobile Edge Computing (MEC), a new concept that emerged about a year ago, integrating the IT and the Telecom worlds will have a great impact on the openness of the Telecom market. Furthermore, the virtualization revolution that has enabled the Cloud computing success will benefit the Telecom domain, which in turn will be able to support the IaaS (Infrastructure as a Service). The main objective of MEC solution is the export of some Cloud capabilities to the user's proximity decreasing the latency, augmenting the available bandwidth and decreasing the load on the core network.**

On the other hand, the Internet of Things (IoT), the Internet of the future, has benefited from the proliferation in the mobile phones' usage. Many mobile applications have been developed to connect a world of things (wearables, home automation systems, sensors, RFID tags etc.) to the Internet. Even if it is not a complete solution for a scalable IoT architecture but the time sensitive IoT applications (e-healthcare, real time monitoring, etc.) will profit from the MEC architecture. Furthermore, IoT can extend this paradigm to other areas (e.g. Vehicular Ad-hoc NETworks) with the use of Software Defined Network (SDN) orchestration to cope with the challenges hindering the IoT real deployment, as we will illustrate in this paper.

Keywords— MEC, SDN, IoT, Fog computing, Cloud computing, NFV.

I. INTRODUCTION

By the end of 2015, there will be more than 7 billion mobile cellular subscriptions corresponding to a penetration rate of 97%, up from 738 million in 2000 according to the last ITU report [1]. This reflects the fact that the use of mobile phones and tablets has exceeded that of computers and laptops. In addition, the intensive and ubiquitous use of mobile phones is accompanied with an evolution in the mobile network architecture (2G/3G/4G/5G) and an explosive growth of demand for high bandwidth services (e.g. Video on Demand) due to the "big bang" of social networking and entertainment applications.

Despite the evolution of both the nano-technological components and the storage capabilities of portal devices, they still do not have the computing power and battery life that allow them to perform effectively, which calls for Cloud computing involvement [2]. Thus, the centralization of data in the core of mobile networks makes this solution bandwidth intensive in addition to introducing high latency.

Therefore, pushing some of the computing functions to the network edges (MEC) has been proposed recently in the mobile communications domain. Based on ETSI definition, MEC provides IT and Cloud computing capabilities within the Radio Access Network (RAN) in close proximity to mobile subscribers. Located at the base station or at the Radio Network Controller, it also provides access to real-time radio and network information such as subscriber location or cell load that can be exploited by applications and services to offer context-related services. The RAN edge offers a service environment characterized by proximity, ultra-low latency, high-bandwidth, as well as real-time access to radio network information and location awareness. *"MEC will enable operators to open their Radio Access Network (RAN) edge to authorized third parties, allowing them to flexibly and rapidly deploy innovative applications and services. We can look forward to a myriad of new use cases across multiple sectors as well as the many benefits that will result from increased collaboration between the different players in the value-chain,"* says Nurit Sprecher, Convener of the ETSI's Industry Specification Group.

On the other hand, the Internet has recently experienced an explosion in the number of connected devices adding a new networking dimension ("anything" connectivity) to the Internet of the future. An estimate from Cisco portrays that 50 billion things will be connected to the Internet by 2020 [3]. This will lead to an unexpected amount of generated data. Thus, the IoT "Big Data" will be about four Vs: **V**elocity, **V**ariety, **V**olume, and **V**alue [4]. Hence, we will have many different models of generated data at different rates resulting in different volumes of data that will be stored, analyzed and used by IoT applications. Consequently, considering advanced data management technologies will be essential.

Cisco introduced recently the concept of *Fog computing* to enable applications on billions of connected devices in the IoT, to run directly at the network edge [5]. Data, computing, storage, and application services to end-users are provided by both Cloud and Fog. Distinctly, Fog is characterized by its proximity to end users, its dense geographical distribution, and its support for mobility, which provide low latency, location awareness, improved QoS, and heterogeneity support. The Fog computing paradigm is well-positioned for real-time big data

978-1-5090-0366-2/15/$31.00 ©2015 IEEE

analytics. It also supports densely distributed data collection points, and provides advantages in entertainment, advertising, personal computing and other applications. Essentially, Fog devices could be interconnected, and each of them linked to the Cloud [6]. Therefore, Fog is an Edge Computing and Micro Datacenter (MDC) paradigm, suitable for IoTs [7]. MEC is a special case of Fog computing specific to mobile networks [8].

However, managing such a network of distributed edges, maintaining connectivity and providing services especially in the IoT domain, is not easy. Emerging technologies, such as SDN& NFV (SDNv2), can be used to enable flexible management of the network environment. The employment of these technologies can ease the implementation and management of the distributed edges, increase network scalability and reduce costs. Many Fog computing related tasks, such as resource allocation, VM migration, traffic monitoring, application-aware control and programmable interfaces will benefit from the introduction of these new facilities. In this paper, we will try to fuse these three concepts: Fog (MEC as special case), SDN and NFV, to show how we can achieve better MEC employment in the mobile networks and how we can extend this solution to enable the IoT wide deployment.

The rest of this paper is organized as follows: In section II, we survey related works. The evolution of the mobile networks and the integration of new technologies such NFV, SDN, and Fog computing will be discussed in section III. In section IV, we show how we can extend the Software Defined Mobile Edge Computing (SD-MEC) which is the proposed solution to enable a wide deployment for IoT. Finally, we conclude in section V.

II. RELATED WORK

On September 26, 2014, ETSI formed a new Industry Specification Group (ISG), to allow the creation of industry specifications for MEC. Nokia Networks, Intel, Vodafone, IBM, Huawei and NTT DOCOMO have founded the initiative. Hence, the white paper [9] authored by the founders of the MEC ISG, introduces the concept of MEC and the related market drivers. It discusses also the business, consumer and technical value/benefits offered by this technology, the enablers, the requirements and challenges for MEC as well as the objectives of the MEC initiative. Additionally, this white paper presents the high-level architectural blueprint of MEC as well as a number of use cases where MEC seems to have an important value. Active Device Location Tracking is one of the use cases that enables real-time measurement-based tracking of active terminal equipment, which is totally independent of the Global Positioning System (GPS) functionality when GPS coverage is not available. Distributed content and Domain Name System (DNS) caching is another use case that benefits from the proximity of connected subscribers to create an improved experience, as well as providing relief to other parts of the cellular network (e.g. core and transport).

Besides, MECs are meant to be used in high mobility environments and hence their efficient management must be considered for the real MEC deployment. In this context, a dynamic service migration scheme for MECs was proposed in [10]. To make the problem legible, there was a reduction of the general problem into a Markov Distance Problem (MDP) that only considers an important parameter, namely the distance between the user and the service. The authors showed that the distance-based MDP is a good approximation to scenarios where the users move in a 2-D space, which is confirmed by analytical and numerical evaluations and by simulations with real-world traces of taxis in San Francisco. Although they assumed that MECs are co-located with base stations, the proposed approach is not restricted to such cases and can easily incorporate other scenarios as long as the costs are geographically dependent. The results showed an efficient solution to service migration in MECs and the approaches used could be extended to a range of other problems that share similar properties.

Bringing the Cloud to the edge was the goal of the work done in [11]. The authors presented a model of a hybrid Cloud architecture they referred to as the *Edge Cloud*, which is designed to deliver low-latency, bandwidth-efficient and resilient end user services with a global footprint. The *Edge Cloud* is meant to extend the Cloud all the way to the end user by leveraging compute and storage nodes at the edge. By interconnecting edge networks with data center networks, this model enables latency-sensitive computation and volatile storage at the edge nodes while hosting heavy-duty processing and database components in the data center nodes. This will provide two essential benefits: the latency particular reduction for users far from the data center and the bandwidth reduction between edge and core provided by allowing the preprocessing at the edge. Finally, application resiliency is provided in two ways. In case the edge resources become temporarily unavailable, edge components of an application can fall back to the more reliable data center Cloud. Conversely, if an edge component can provide an application's basic functionality by itself, the application can continue to function even without data center components. An instantiation of this paradigm on the OpenStack Cloud management platform with OpenStack extensions and a quantitative evaluation of two Edge Applications: 3D indoor localization and video surveillance were performed at the end of the paper.

Extending this concept to a more general use case, the IoT, Aazam et al. [7] proposed a model of Fog-based micro datacenters co-located with smart gateways for pricing and resource estimation for IoT. An implementation using CloudSim showed the effectiveness of the proposed model. However, the model focuses only on the data plane not considering the fact that these distributed nodes have to be managed. Therefore, applying the SDN and NFV paradigms will be beneficial in this case.

In this context, an ICN based edge-cloud service framework leveraging NFV and SDN technologies was proposed in [12]. The paper discusses the power of NFV and SDN to enable agile infrastructure and resource management for operators. The authors tried to figure out the relationship between MEC (Fog computing more generally), IoT, NFV and SDN trends.

For an environment similar to mobile networks specifically, the vehicular one, a Fog SDN enabled (FSDN) vehicular network architecture was proposed in [13]. The architecture is composed of:

1. **SDN Controller** carrying the global intelligence that controls all the network behaviors of the entire SDN-based VANET system; it also acts as Fog Orchestration and Resource Management.
2. **SDN Wireless Nodes** such as the vehicles acting as end-users as well as forwarding elements, equipped with On-Board Unit (OBU) and operating OpenFlow constituting the Data Plane elements.
3. **SDN Road-Side-Units** run OpenFlow and they are controlled by the SDN Controller being a Fog device.
4. **SDN Road-Side-Unit Controller (RSUC)** which is a Fog device OpenFlow-enabled and controlled by SDN Controller; it is responsible for forwarding, storing local road system information and performing emergency services.
5. **Cellular Base Station (BS)** not simply carrying voice calls and conveying data, but it is more sophisticated; it is OpenFlow enabled and capable of delivering Fog services. Similar to RSUC, BS presents also a local intelligence and it is a Fog device under the control of the SDN controller.

To the best of our knowledge, there is no work in the literature on IoT architecture that employs the SDN paradigm while extending the MEC concept to provide Software-Defined Fog-enabled IoT gateways (SDF-Gateways). In this paper, we will try to combine these concepts in a global IoT architecture, which presents high management capability inherited from the SDN concept; and low latency, heterogeneity abstraction, support of mobility and other characteristics inherited from the Fog computing paradigm.

III. MOBILE NETWORKS EVOLUTION

A. *Cloud Computing Integration*

The Cloud computing paradigm has invaded the IT market in the last decade. It is a model for enabling ubiquitous, convenient, and on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) contributing essentially in reducing Operating Expenditure (OPEX) in the networking and IT domains [14]. Thus, most of mobile phone applications are based on Cloud services. Furthermore, rather than residing on Cloud-based applications, the mobile phone evolution will call for further operations of Cloud computing at different levels. One of the most innovative applications of Cloud paradigm in the mobile communication world is at the RAN level. Thus, the Cloud-RAN (C-RAN) presenting an introduction of the centralized RAN, i.e. consists of partitioning base stations into a baseband unit (BBU) and a remote radio head component. Therefore, due to the physical detaching of the baseband processing from the radio frequency processing, it is now possible to have those two operations installed at different locations. This will procure several benefits including a more effective interference coordination, reduced operational complexity and simplified site acquisition.

Fog computing is another captivating notion that has to be taken into consideration for the evolution of mobile networks. MEC, a sub-category of Fog computing, has certain advantages such as improving the services' quality perceived by mobile users and it will equally serve in saving bandwidth cost and energy consumption inside the Internet and the mobile networks. Therefore, Fog computing proves to be a scalable and durable solution to enable the assembling of Cloud-based Internet and mobile computing [15].

Virtualized C-RAN and MEC are the two fundamental industry trends that aim to apply the Cloud paradigm to the telecom domain. Their implementation will trigger developments that will generate a different class of services, applications and mobile user experience. Intelligent service hubs will be created out from the antecedent mobile base stations to meet expectations of delivering highly personalized services and machine-to-machine communication directly from the very edge of the network while administering the best possible performance in mobile networks.

B. *SDN and NFV Integration*

Recently, there is a lot of work trying to apply the SDN paradigm to the mobile network domain (e.g. Software defined cellular [16], SoftRAN [17], and SoftCell [18]). SDN is a new networking trend aiming to separate the control and data planes. This separation provides high level of abstraction for management functions and hides the increased complexity in the network management domain [19]. Management at different levels is needed as shown in the MEC platform architecture presented in the white paper in [9]. Thus, applying the SDN paradigm to manage the MEC nodes will enhance the effectiveness of this new concept.

Network virtualization in the data center and the wide-area network became a mainstream trend in 2014. Network Functions Virtualization's (NFV) core responsibility is porting network functions to virtual environments to facilitate the migration from proprietary appliance-based archetypes to a standard hardware and Cloud-based infrastructure. The recurring debates over the network's adaptation to support the highly virtualized computing and storage infrastructure in data centers has permitted network solution vendors to avail from this current state via working on approaches to deliver the ace network visualization solution according to their assumptions. This trend has correspondingly reached the mobile network infrastructure industry, which has started to create value from virtualization technology. Virtualizing functions of the evolved packet core has truly reached an advanced state; however, the virtualization of the radio access network is still in its infancy.

Hence, a massive adoption and exploitation of MEC, SDN, NFV, and services virtualization will make the mobile network operating system (OS) feasible [20]. Figure 1 shows how these technologies can be exploited to achieve a robust mobile network architecture. Having a distributed set of MECs at different access points will allow the local-based services and applications the capability of running without the need to access the core network. This will decrease the overload and the signaling between the access and the core planes making this network less prone to failure. At the same time, the user will experience a high quality of service (low latency and high bandwidth). Additionally, the SD-MECs, being managed by the controller, will hide the complexity of the management and allow the deployment of new services thanks to the integration of the SDN & NFV concepts. Thus, The SD-EPC is out of scope of the discussion in this paper; it is already considered in previous works.

Essentially, this architecture will allow a cellular operator to rapidly deploy new services for different business segments that drive new revenue streams and differentiate subscriber experience, thanks to the SDN integration. Thus, applications that are aware of the local context in which they operate will drive the creation of new service categories with enriched and personalized offerings. Application and service hosting at the edge of cellular networks will reduce the volume of signaling offloaded to the core network, as well as reducing OPEX for the cellular operator as compared to hosting applications and services within the core. MEC will give the cellular operator the ability to recognize revenue based on the application server resource usage, in terms of storage, network bandwidth, CPU utilization, etc. for each application or service deployed by a third party.

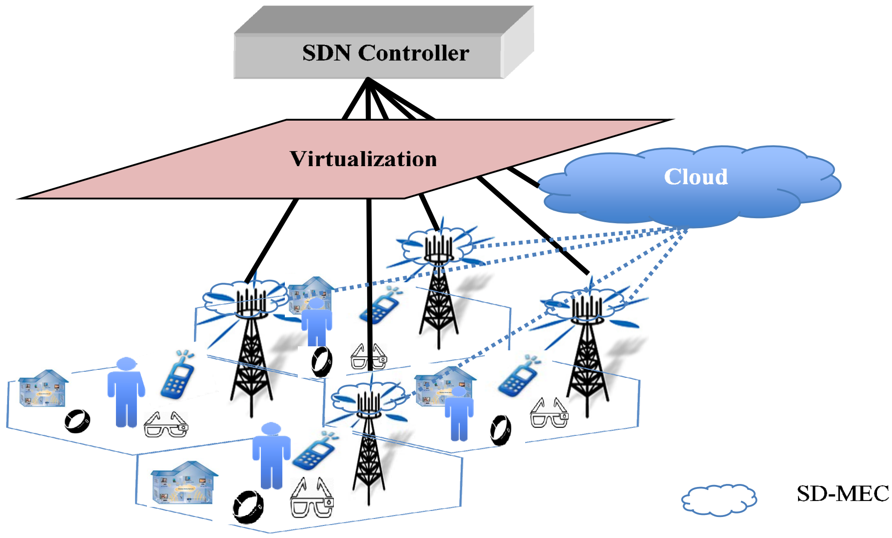

Figure 1: SD-MEC architecture

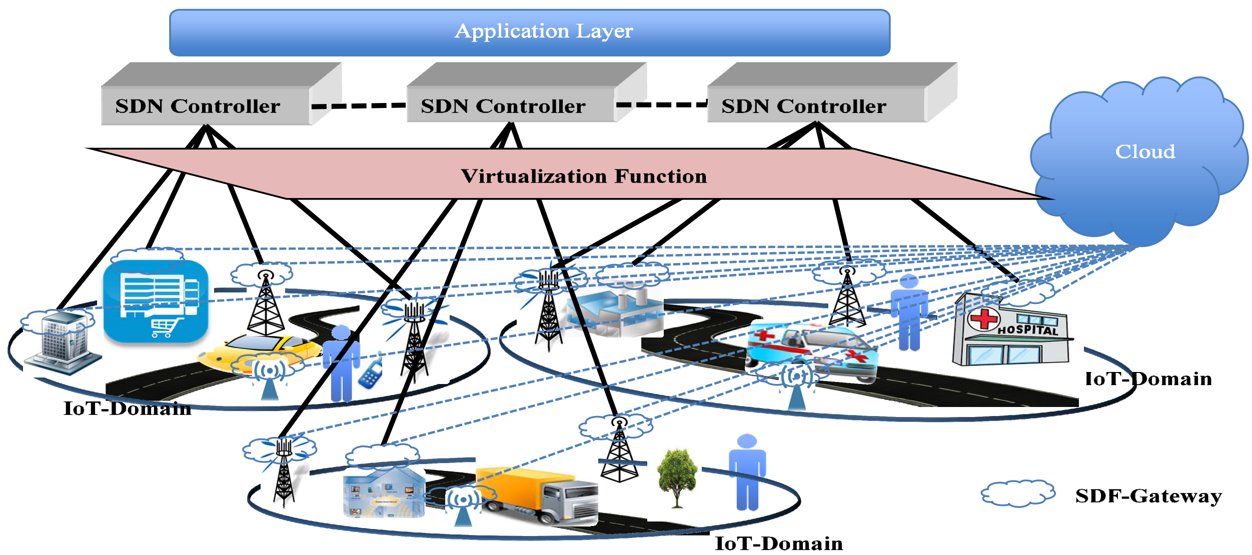

Figure 2: IoT domain-based architecture relying on SDF-Gateways

Familiar programming models, relevant tool chains and Software development kits (SDKs) are key elements to allow the development of new applications for the new MEC environment. Thus, SDN, NFV and Cloud computing are key constituents for providing the Software-Defined Infrastructure (SDI) in the mobile network domain [21].

IV. ENABLING IOT WITH SDF-GATEWAYS

The "Internet of Things" will welcome the MEC capabilities, promising better performance and more efficient service implementation. Thus, several studies have considered the importance of Fog computing for the IoT real deployment [5, 7, 22]. As we mentioned before, "Big Data" management is one of the challenges that hinder the IoT wide deployment. Therefore, Fog computing will open broad research issues on network management, traffic engineering, big data and novel service delivery. However, there are other challenges such as the heterogeneity of connected things, the privacy and security concerns, and the scalability of this network of networks. In order to extend the previous scheme of SD-MEC in the mobile network, we propose a new architecture for IoT to overcome the cited challenges. Mainly, this architecture [23] is composed of four layers as shown in Figure 2:

1. ***The Device Layer***, where different types of identification and communication technologies are used (RFID, EPC, uCode, NFC, BLE, QR, 3G/LTE, Zigbee, Z-Wave, Wifi, etc.), allows the communication of things with the different access points (indoor and outdoor) such as base stations, local Wi-Fi access points, etc.
2. ***The Network Layer*** is responsible for receiving the data from the device layer and connecting vertical silos networks. Thus, the most important components in this layer are the SDF-Gateways. These gateways have to ensure the interoperability between the different communication protocols and the communication between heterogeneous network islands. Routing access control (firewall), en/de-capsulation of the packets, translation of the addresses (NAT), enabling data storage (Fog computing), providing traffic prioritization (QoS) and forwarding packets are the main functions of these gateways. The southbound interface of these gateways will be very specific for each type of network allowing these gateways to communicate with things belonging to different technologies. Essentially, today's IoT gateways present problems as stated in [24]; currently, a separate physical router or smartphone application must be provided in order to enable gateway services for each type of IoT device deployed. Thus, we believe that the SDF-Gateways will offer good solutions for most of today's gateway problems. Currently, the limitations of OpenFlow capabilities and the OF switches which support mainly Ethernet connections lead to the idea of more elaborated gateways having the core of an SDN switch with advanced capabilities and options managed through the SDN controller using specific management protocols (NetConf) and an extended OpenFlow protocol (e.g. adding new actions for packets en/de-capsulation). Thus, multiple gateways implementing intelligence for objects and applications issued from diverse application domains will be deployed. With the proliferation of objects and gateways, there will surely be a strong need to manage and control these gateways from the network & IT infrastructure. Thus, SDN-OF offers a simple and scalable solution for this problem. Many schemes, that provide data and communication protocols interoperability, have been proposed to be deployed on the IoT gateways; and oneM2M seems to be the most mature one at this stage as shown in the comparison done in [25]. Thus, the integration of such protocols at the gateway level allows handling the connectivity between different things connected to these gateways and the horizontal interconnectivity between different vertical silos of IoT applications.
3. ***The Control Layer*** is where the network orchestration and most of the computations are done. The main functions of this layer are collecting the topology data, computing the forwarding rules by running some routing algorithms, implementing scheduling algorithms and defining security rules. Essentially, the connection to the gateways is done through the southbound interface; an extension of OpenFlow will be needed and the configuration of the SDF-Gateways can be done through specific management protocols (e.g. NetConf and Yang, OF-Config). The application layer communicates with this controller through the northbound interface (e.g. REST). However, the centralization of the control may pose scalability limitations. Therefore, we have to implement a distributed scheme (East/West-bound interfaces) to cope with this issue; Thus, Onix [26], ONOS [27], and OpenDaylight [28] are examples of controllers representing distributed scheme capabilities. Additionally, a virtualization layer is added (e.g. FlowVisor, OpenVirtex, etc.) to ensure fine-grained flow services. As shown in the literature and in the previous section, associating NFV with SDN is an opportunity for the infrastructure operator. In addition, third parties have access to infrastructure services upon which they can build their own solutions. The infrastructure services can indeed be exposed to numerous third party actors such as application developers, service providers, or even IoT virtual operators. Essentially, the centralization of the control will have an impact on the security enhancement in this architecture.
4. ***The Application Layer*** is where the softwarization reveals its usefulness. Several functions relying on the information provided by the control layer can be implemented there and can be added dynamically. Another benefit of having central control is the ability of deploying the same applications on different SDF-Gateways. This architecture allows the applications to be run on different devices benefiting from having

shared data semantics. We will be able to retrieve our cars, for example, using our phones in certain local gateway domain without having to access the Cloud for retrieving location data. This and other innovative applications will benefit from this data layer managed in an optimal way and located at the network edges.

V. Conclusion

The IT and Telecom worlds have experienced real conceptual transformations in the last few years. Cloud, NFV, and SDN are at the base of these changes. The MEC concept, recently coming out, aims at applying Fog computing (Cloud at the edge) to the mobile network domain. Moreover, MEC will have a real impact on the way Telecom operators deploy new services since they will benefit from NFV and more generally the combination of SDN & NFV (SDNv2). Either way, the IoT, which is highly associated with the mobile network, will benefit from extending the MEC core concept to other areas (VANET, WSN, etc.). In this paper, we have tried to shed light on these new trends and we have drawn our vision of the Internet of the future. This work is not comprehensive one; more technical and elaborative implementations are needed to ensure the effectiveness of the proposed schemes.

VI. Acknowledgment

This research is funded by TELUS Corp. Canada.

References

[1] ITU, ICT Facts & Figures, The world in 2015 [Online]. Available at:http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx.

[2] G.A. Lewis, "'Mobile computing at the edge (keynote)," In *Proceedings of the 1st International Conference on Mobile Software Engineering and Systems*, pp. 69-70. ACM, 2014.

[3] D. Evans, "The Internet of Things How the Next Evolution of the Internet Is Changing Everything," April 2011.

[4] I.A.T. Hashem, I. Yaqoob, N.B. Anuar, S. Mokhtar, A. Gani and S.U. Khan, "The rise of "big data" on cloud computing: review and open research issues," *Inf Syst*, vol. 47, pp. 98-115.

[5] F. Bonomi, R. Milito, J. Zhu, S. Addepalli, "Fog computing and its role in the internet of things", *MCC workshop on Mobile cloud computing*, August 2012.

[6] I. Stojmenovic, "Fog computing: A cloud to the ground support for smart things and machine-to-machine networks," *Telecommunication Networks and Applications Conference (ATNAC), 2014 Australasian*, pp. 117-122.

[7] M. Aazam and Eui-Nam Huh, "Fog Computing Micro Datacenter Based Dynamic Resource Estimation and Pricing Model for IoT," *Advanced Information Networking and Applications (AINA), 2015 IEEE 29th International Conference on*, pp. 687-694.

[8] S. Yi, C. Li and Q. Li, "A Survey of Fog Computing: Concepts, Applications and Issues,", pp. 37-42.

[9] M. Patel, J. Joubert, J.R. Ramos, N. Sprecher, S. Abeta and A. Neal, *Mobile-edge computing, Introductory Technical White Paper, 2014*.

[10] Shiqiang Wang, R. Urgaonkar, M. Zafer, Ting He, K. Chan and K.K. Leung, "Dynamic service migration in mobile edge-clouds," *IFIP Networking Conference (IFIP Networking), 2015*, pp. 1-9.

[11] Hyunseok Chang, A. Hari, S. Mukherjee and T.V. Lakshman, "Bringing the cloud to the edge," *Computer Communications Workshops (INFOCOM WKSHPS), 2014 IEEE Conference on*, pp. 346-351.

[12] R. Ravindran, Xuan Liu, A. Chakraborti, Xinwen Zhang and Guoqiang Wang, "Towards software defined ICN based edge-cloud services," *Cloud Networking (CloudNet), 2013 IEEE 2nd International Conference on*, pp. 227-235.

[13] N.B. Truong, Gyu Myoung Lee and Y. Ghamri-Doudane, "Software defined networking-based vehicular Adhoc Network with Fog Computing," *Integrated Network Management (IM), 2015 IFIP/IEEE International Symposium on*, pp. 1202-1207.

[14] J. Costa-Requena, J.L. Santos, V.F. Guasch, K. Ahokas, G. Premsankar, S. Luukkainen, O.L. Perez, M.U. Itzazelaia, I. Ahmad, M. Liyanage, M. Ylianttila and E.M. de Oca, "SDN and NFV integration in generalized mobile network architecture," *Networks and Communications (EuCNC), 2015 European Conference on*, pp. 154-158.

[15] T.H. Luan, L. Gao, Z. Li, Y. Xiang and L. Sun, "Fog Computing: Focusing on Mobile Users at the Edge," *arXiv preprint arXiv: 1502.01815*.

[16] A. Bradai, K. Singh, T. Ahmed and T. Rasheed, "Cellular software defined networking: a framework," *Communications Magazine, IEEE*, vol. 53, no. 6, pp. 36-43.

[17] 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*, pp. 25-30. ACM, 2013.

[18] 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*, CoNEXT'13, pp. 163-174.

[19] Hyojoon Kim and N. Feamster, "Improving network management with software defined networking," *Communications Magazine, IEEE*, vol. 51, no. 2, pp. 114-119.

[20] D. Soldani and A. Manzalini, "Horizon 2020 and Beyond: On the 5G Operating System for a True Digital Society," *Vehicular Technology Magazine, IEEE*, vol. 10, no. 1, pp. 32-42.

[21] S. Koizumi and M. Fujiwaka, "SDN + cloud integrated control with statistical analysis and discrete event simulation," *Information Networking (ICOIN), 2015 International Conference on*, pp. 289-294.

[22] M. Yannuzzi, R. Milito, R. Serral-Gracia, D. Montero and M. Nemirovsky, "Key ingredients in an IoT recipe: Fog Computing, Cloud computing, and more Fog Computing," *Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2014 IEEE 19th International Workshop on*, pp. 325-329.

[23] O. Salman, I. Elhajj, A. Kayssi, A. Chehab, "An Architecture for the Internet of Things with Decentralized Data and Centralized Control," *Second International Workshop on Internet of Things, Systems, Management and Security (IoTSMS), Marrakech Morocco, 17-20 November 2015*.

[24] T. Zachariah, N. Klugman, B. Campbell, J. Adkins, N. Jackson and P. Dutta, "The Internet of Things Has a Gateway Problem," In *Proceedings of the 16th International Workshop on Mobile Computing Systems and Applications*, HotMobile'15, pp. 27-32.

[25] Al-Fuqaha, A. Khreishah, M. Guizani, A. Rayes and M. Mohammadi, "'Toward better horizontal integration among IoT services," Communications Magazine, IEEE, vol. 53, no. 9, pp. 72-79.

[26] T. Koponen, M. Casado, N. Gude, J. Stribling, L. Poutievski, M. Zhu, R. Ramanathan, Y. Iwata, H. Inoue, T. Hama and S. Shenker, "Onix: A Distributed Control Platform for Large-scale Production Networks,", pp. 1-6.

[27] P. Berde, M. Gerola, J. Hart, Y. Higuchi, M. Kobayashi, T. Koide, B. Lantz, B. O'Connor, P. Radoslavov, W. Snow and G. Parulkar, "ONOS: Towards an Open, Distributed SDN OS,", pp. 1-6.

[28] J. Medved, A. Tkacik, R. Varga and K. Gray, "OpenDaylight: Towards a Model-Driven SDN Controller architecture," *A World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014 IEEE 15th International Symposium on*, pp. 1-6.