VNET: Towards End-to-End Network Cloudification

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***Abstract*—To address the needs for future network services, existing network architecture should evolve significantly to provide a higher level of flexibility, resilience and quality of service. This challenge was also the one of computing which has found with "virtualization" a breakthrough approach to bring a high flexibility in existing computing architecture which makes today the success of cloud computing. The next obvious following step is therefore to "*cloudify*" the networks. We introduce the VNET project, which proposes to study some of the most complex network cloudification problems from a global point of view i.e at radio access networks and the core networks to the service hosting data centers. It will identify the challenges and address the problems related to the visualization of RAN (Radio Access Networks), the problems of service composition and dependability related to the deployment of SDN and NFV, and finally the design a NaaS platform with the associated tools to allow the specification, validation, deployment and management of on-demand end-to-end services. In addition, the project will address the manageability of this "*cloudified*" architecture using autonomic concepts based on the MAPE framework.**

***Index Terms*—Software Defined Network, Network Functions Virtualization, Access Point, Virtualization, Resources Allocation, Optimization**

I. Introduction

Cloud solutions such as computing and storage services witnessed a wide adoption. In fact, the cloud offered highly elastic environments with auto-configuration and auto-adaptability capabilities. However, the cloud is limited actually to the infrastructure, platform, and software as a service models. The natural following step is to "*cloudify*" also the networks to provide an end-to-end solution and add the Network as a Service (NaaS) model. In recent years, Software Defined Networks (SDN) started to emerge. The latter concept focuses on virtualizing the control functions of network equipment and has lead to a new research field named "Network Functions Virtualization" (NFV). NFV promises to make networks work based on the same scale-based, cheap, general purpose hardware used in current cloud infrastructure. While these ideas look obvious and appealing, they are far from being easy to realize. Most of the obstacles to make them reality are yet to be understood and solved.

The VNET project addresses separately the different segments of the problem and then integrate the solutions in a holistic framework. VNET's first goal is to begin a long term collaboration between France, Chile, Brazil, and Uruguay around technological and scientific solutions for next generation networks. Structured in four themes, in VNET we will study the end-to-end "network cloudification". In particular, we will study the virtualization of radio access networks and related interference management problems in the context of random access networks. We will also study the challenges related to service composition and dependability issues using SDN and NFV using heuristics, such as Greedy Randomized Adaptive Search Procedures (GRASP), Simulated Annealing, Genetic algorithms and Local Search. We will study as well the concept of NaaS and design a platform with the associated tools that will allow the specification, validation, deployment and management of on-demand, end-to-end compound networking and computing services. Finally, we will study the applicability of the MAPE (monitor, analysis, planning, execution) framework to *cloudified* networks management.

This paper is organized as follows. In section II, we present related works. Section III presents a scenario illustration of the targeted problem. In section VII, we present the VNET deployment platform MOSt-VNET. Section V and VI explain different virtualization objectives with the MOSt-VNET deployment platform. Finally, the work is concluded in section VIII.

II. Related Works

Industry and academia have made a great effort to improve the communication technologies of computer networks. Several technologies were interesting during specific periods of time. We can mention, for instance, trends such as Differentiated Services (DiffServ), Grid Computing, Next Generation Networks (NGN), P2P Networks, and Cloud Computing. Now the academic community and big companies, such as HP, Cisco, Alcatel, Ericsson, and IBM are mainly focused around two paradigms: Software Defined Networking (SDN) and Network Function Virtualization (NFV) [1].

SDN is a paradigm that breaks this integration between control plane and data plane from switches. The main idea is to remove the control plane from each switch and put it in an external and centralized entity that enables a new programmability approach allowing decision-making based on global (network) status. With this, SDN makes possible the

creation of a network infrastructure able to adapt according to future network demands in a simple way. Thus, SDN aims to redefine the network infrastructure.

Network Function Virtualization (NFV) is a novel technology that employs virtualization to implement network devices in virtual entities deployed on commodity hardware. According to [2] NFV projects usually have three main purposes. First, NFV aims at reducing the costs of purchasing physical, dedicated, and expensive network equipment. Second, it allows new services to become available to users in short deployment cycles. Third, NFV aims to reduce the overall management cost required for a large number of heterogeneous network equipments. They are usually implemented taking advantage of SDN (Software Defined Networks). Using NFV technology it is possible to create, deploy and manage middle boxes in a fraction of the time it takes when specific hardware and software platforms are required. In this way, in the project context, NFV allows create new instances of virtual baseband as needed. SDN makes it possible connecting those instances to the radios that need them.

The objective of many of the SDN proposals is to decouple management from hardware and technology and be able to give an homogeneous interface to control an heterogeneous network. The objective of virtualization in the RAN is to enable infrastructure and spectrum sharing. Some of the existent work, in this field are specific to cellular networks (SoftRAN [3], SoftCell [4], C-RAN [5], [6]) and some specific to Wifi (Odin [7], [8], MAClets [9], Empower [10], AeroFlux [11], [12], VirtualWiFi). Many of these works tackle the virtualization problem from different perspectives. For example, most of them apply the SDN ideas in different ways for wireless networks. Many works have focused in abstracting wireless technology and allowing programmability, however, most of them do not consider the problem of isolation and coexistence of virtual networks over a shared infrastructure.

The integration of these technologies in a network will permit to introduce great flexibility but at the same time numerous challenges in terms of reliability, performances and so on that will be addressed by the VNET project.

III. Considered Scenario

”Network cloudification” and the capacity to provide network service as cloud services (Network As A Service) are a major objective for Telco and IT Industrial but also for the research community because many aspects are still not solved. The virtualization of network function aims to allow the deployment of services related to network function that are traditionally part of the control plan of network devices (Virtual Network Appliance) into a cloud infrastructure. A virtualized control plan or orchestration plan ensures the configuration of the virtual infrastructure including the network and uses dedicated cloud services that emulate network function such as IP routing, Firewall, CDN (Content Delivery Network) or any function of the cellular network such as EPC (Evolved Packet Core), etc.

Nowadays, from the cloud components applications point of view, applications are usually deployed in a distributed environment with multiple components running in parallel and taking care of different tasks of the application. Thus, dynamic reconfigurability makes impractical the existence of a centralized knowledge of the whole application architecture where reconfiguration decisions can be taken. Nevertheless, in a distributed environment with cloud ”intelligence” and the separations of concerns provided by SDN/NFV, the MAPE framework seems suitable for solving the problem of *cloudified* networks. As depicted in Figure 1, each application will be completely isolated from other applications and having its own visible network. Network elements can be virtualized or physical network components. Furthermore, network components can vary between routers, switches, and access points.

Moreover, Internet of Things (IoT) elements can be added to the application, hence empowering deployed applications with real world data. Our main objective in this project is to turn into reality a cloud infrastructure to provide network functions as cloud services and to allow their composition with any other computing services available in the cloud, or connected object in the real world.

IV. Core Network Virtualization

When considering the use of network equipment (e.g. routers, servers and links) through network virtualization technologies, there is a risk of failure involved (either hardware or software). Obviously risks are inherent to physical infrastructure because its hardware is prone to failure so does the respective software infrastructure. Currently, network infrastructures tend to have more software components with the use of SDN and NFV. One big obstacles in this trend is the system availability. In general, software are much more error-prone than hardware components. Hence, it is necessary to take into account attributes of dependability in order to mitigate faults. Ignoring this matter may cause a high rate of failures in virtual requests, causing a low quality of service and even more causing poor Quality of Experience to the end users.

In the VNE project, the aim is to address challenges related to service composition, resilience and dependability issues using SDN and NFV in the project context. Some heuristics like Greedy Randomized Adaptive Search Procedures (GRASP), Simulated Annealing (SA), Genetic algorithms and Local Search will be analyzed in different scenarios. When possible, techniques based on exact methods (e.g. Linear Programming) can be used as well. The aim is also to propose innovative techniques for faults recovery in a time frame that is in line with the services constraints.

V. Access Point Virtualization

New architectural and design approaches for Radio Access Networks have appeared with the introduction of network virtualization in the wireless domain. One of these approaches splits the wireless network infrastructure into isolated virtual

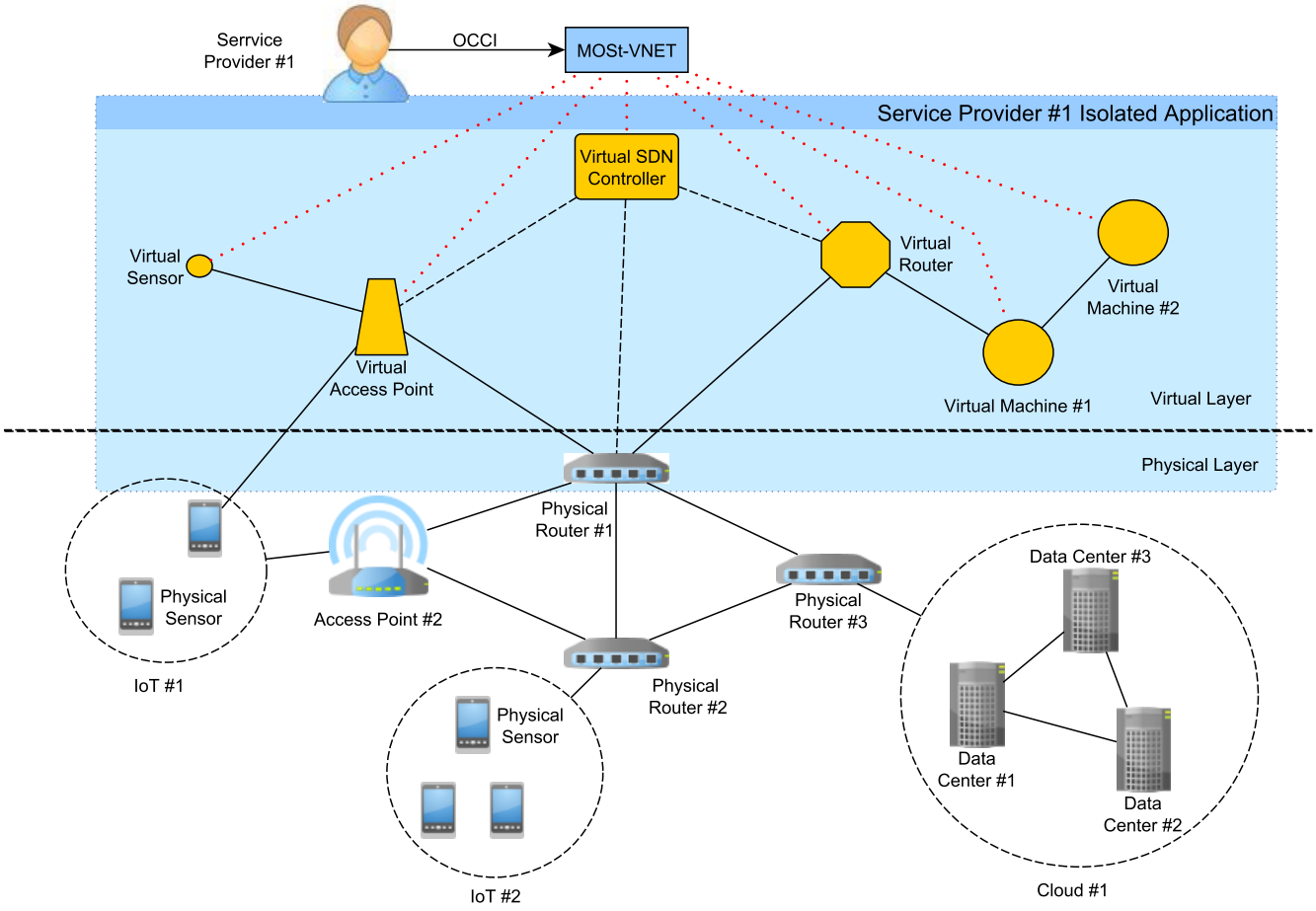


Figure 1. VNET Project Scenario.

slices under their own management, requirements and characteristics.

The concept of slicing in the context of network virtualization is multifaceted. In the most general definition, a slice can be considered as a group of flows belonging to different final users (mobile clients of the wireless network in our case). Then, a slice supports flows of multiple final users, but at the same time, a final user can participate in multiple slices. A flow (stream of packets) is an atomic entity in this approach, it can have specific QoS requirements and is a member of only one slice. For example, a flow in an IP network could be defined by the tuple composed by source and destination IP addresses and ports. Furthermore, a slice can be defined as a subset of network resources allocated to a tenant (virtual operator or service provider), with complete control over those resources. An important aspect of the slicing design approach is the delivery of customization and programmability tools to the tenant. Examples of slices can be: all the flows whose source or destination is a given type of device such as sensors; or all the flows from a VoIP service; or, all the flows with source or destination the final user of a given operator. Depending on the specification of a slice, a final user can participate on different slices but, slices are always independent between each other.

Despite the advances in wireless virtualization, not concluding results for the resource allocation and isolation of wireless slices have been reported. Because of the dynamism and shared nature of the wireless medium, the assignment of physical resources to slices has proven to be difficult. Even more, guaranteeing that the traffic on one slice will not affect the traffic on the rest of the slices is also a complex task. Our plan is to study the problem of slicing in wireless heterogeneous networks and propose techniques and mechanisms to achieve an efficient resource allocation and isolation of wireless slices. To accomplish this plan we are formalizing the problem in the two current predominant wireless technologies LTE and WiFi, review existent solutions, and design, develop and evaluate new mechanisms with the aim of providing resource allocation with efficiency and isolation. In summary, our objective is to propose a mechanism which can overtake the shortcomings of existent solutions and achieve an efficient use of wireless resources in a sliced network using the concepts of network virtualization as a framework but with the aim set at the low-

level problems caused by the unpredictable dynamics of a radio link.

The main goal of this part of the work is to design and develop techniques and mechanisms to achieve an efficient resource allocation and isolation of slices in the context of heterogeneous wireless access networks. For achieving this goal the focus will be given to the problem of dynamic resource allocation and mainly to the enforcement and control task. However, for the design of a comprehensive dynamic resource allocation mechanism some previous objectives have to be accomplished, so we are also considering some aspects of the embedding problem. Our work is two-fold: we are modelling of resources and requests and, studying the dynamics of resource allocation. The former implies (i) to study the possibilities of a unified model for wireless resources which can abstract the representation of resources from the specific technology, (ii) to define abstract and high-level model for the slices" requests of wireless resources and, (iii) to design a mapping from high-level models to low-level resource allocations. Coping with the rource allocation dynamics means (i) to design and develop decision mechanisms for the dynamic allocation of wireless resources to slices, (ii) to design and develop enforcement and control mechanisms for the dynamic allocation of wireless resources to slices and, (iii) to focus the design, development and evaluation of the proposed mechanisms in terms of efficiency, quality of service guarantees and isolation.

VI. IoT Virtualization

Traditionally, sensor networks were application specific, hence the organization willing to deploy an application using sensor networks needed to own, configure, and deploy the sensor network. Furthermore, organization needed to spend money maintaining their sensor networks. However, converging the cloud computing and the Internet of Things allowed to decouple applications and sensor networks by virtualizing the sensors layer. The abstraction layer added between applications and sensors hid the complexity and heterogeneity of sensors from applications, and enabled the sharing of these sensors between multiple applications. We notice several approaches in the literature to address sensor network virtualization as seen in Figure **??**: (a) node level virtualization [15], (b) sensors networks virtualization [15], and (c) virtual sensors [16].

Node level virtualization consists of executing a thread on the sensor node. Each thread belongs to an application and relays information gathered by the sensor node this application. Network level virtualization creates overlay networks on top of the sensor networks creating a logical sensor network for each application. Virtual sensors technique relies on the abstract representations of sensors within an IoT middleware. An IoT middleware uses wrappers to instantiate virtual sensors which connect to the physical sensor and retrieve sensed information. The middleware manages then the retrieved data and relay it to appropriate applications.

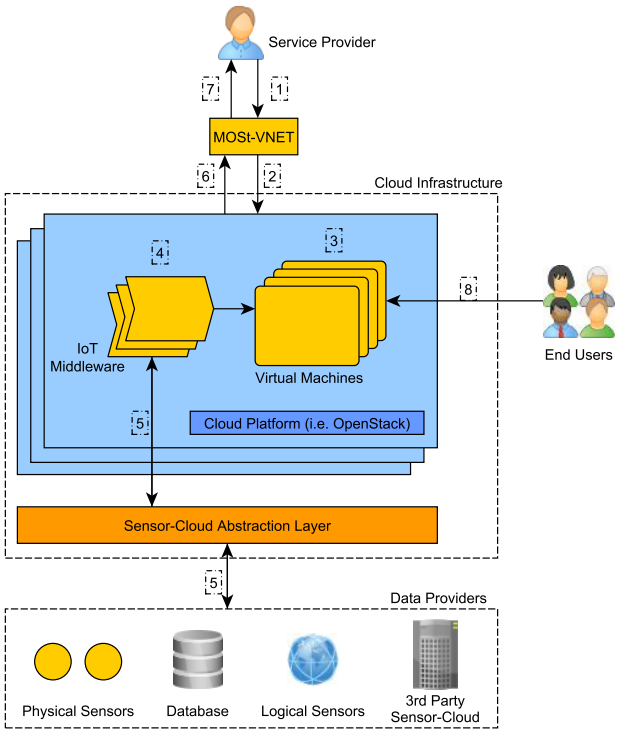


Figure 2. MOSt-VNET in a Cloud Computing and Internet of Things context.

The main goal of this part as illustrated in Figure 2 is to integrate IoT with MOSt-VNET. Therefore allowing the provisioning of sensors and deploying appropriate services to interface with selected sensors. Figure 2 depicts using middlewares as a mean to interface with data sources.

VII. VNET Deployment Platform MOSt-VNET

In such environment, a placement algorithm is needed to identify optimally the host node for each service, network components, or virtual sensor. Moreover, the components need to be deployed in a complex environment consisting of several types of physical nodes such as cloud data centers, switches, routers, access points, connected objects, etc.

In order to calculate the optimal provisioning plan of a complex service request in a multi-site cloud infrastructure, a solution called Multi-site Orchestration System (MOSt) was proposed in [13], [14]. MOSt permits to find the best placement of the complex service request onto a networked multi-site cloud infrastructure. The complex service represents a set of service components to instantiate (i.e. database service, portal service, etc.) and the links between these components. MOSt relies on a placement algorithm called IGM (Iterative Graph Mapping) described in [14].

MOSt is however limited to deploying services in cloud infrastructure. Furthermore, the used algorithm doesn't take into consideration the network components or connected objects used by the deployed services. MOSt uses the *OCCI* specifications in order to describe the infrastructure resources

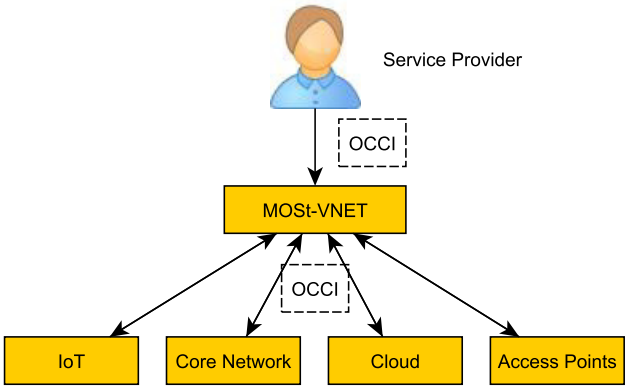


Figure 3. MOSt-VNET deployment platform.

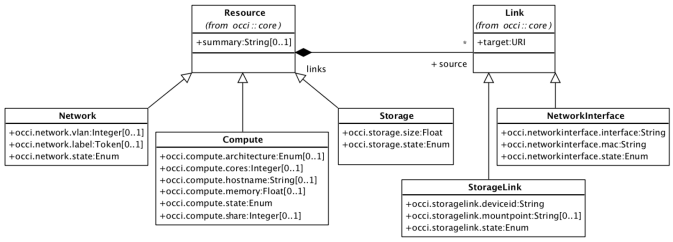


Figure 4. OCCI infrastructure specifications.

shown in Figure 4. These specifications only consider virtual machines deployment at the infrastructure level. The *OCCI* specifications were extended to include service level objectives on each allocated resource and the platform as a service deployment. However, network and Internet of Things components are not defined yet.

Therefore we thrive in this project to extend MOSt by adding network and Internet of Things aspects. We refer to this extension as MOSt-VNET as illustrated in Figure 3. Existing specifications need to be extended to add network and Internet of Things resources, and autonomic placement mechanisms must be conceived to deploy defined applications in complex infrastructures.

VIII. Conclusion

The VNET project aims to deploy an end to end network solution in the cloud on demand which might use connected objects from the real world. Such autonomous deployment with self-configuration and self adaptability in the cloud is not addressed yet in the literature to the best of our knowledge. Many challenges remain to address in order to reach this vision.

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References

[1] B. Han, V. Gopalakrishnan, L. Ji, and S. Lee, "Network function virtualization: Challenges and opportunities for innovations," *IEEE Communications Magazine*, vol. 53, no. 2, pp. 90–97, Feb 2015.

[2] E. Haleplidis, D. Joachimpillai, J. H. Salim, D. Lopez, J. Martin, K. Pentikousis, S. Denazis, and O. Koufopavlou, "Forces applicability to sdn-enhanced nfv," in *2014 Third European Workshop on Software Defined Networks*, Sept 2014, pp. 43–48.

[3] 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*, ser. HotSDN '13. New York, NY, USA: ACM, 2013, pp. 25–30.

[4] 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*, ser. CoNEXT '13. New York, NY, USA: ACM, 2013, pp. 163–174.

[5] C. Mobile, "C-ran: the road towards green ran," *White Paper, ver*, vol. 2, 2011.

[6] M. Hadzialic, B. Dosenovic, M. Dzaferagic, and J. Musovic, "Cloud-ran: Innovative radio access network architecture," in *ELMAR, 2013 55th International Symposium*, Sept 2013, pp. 115–120.

[7] L. Suresh, J. Schulz-Zander, R. Merz, A. Feldmann, and T. Vazao, "Towards programmable enterprise wlans with odin," in *Proceedings of the First Workshop on Hot Topics in Software Defined Networks*, ser. HotSDN '12. New York, NY, USA: ACM, 2012, pp. 115–120.

[8] J. Schulz-Zander, L. Suresh, N. Sarrar, A. Feldmann, T. Hühn, and R. Merz, "Programmatic orchestration of wifi networks," in *Proceedings of the 2014 USENIX Conference on USENIX Annual Technical Conference*, ser. USENIX ATC'14. Berkeley, CA, USA: USENIX Association, 2014, pp. 347–358.

[9] G. Bianchi, P. Gallo, D. Garlisi, F. Giuliano, F. Gringoli, and I. Tinnirello, "Maclets: Active mac protocols over hard-coded devices," in *Proceedings of the 8th International Conference on Emerging Networking Experiments and Technologies*, ser. CoNEXT '12. New York, NY, USA: ACM, 2012, pp. 229–240.

[10] R. Riggio, M. K. Marina, J. Schulz-Zander, S. Kuklinski, and T. Rasheed, "Programming abstractions for software-defined wireless networks," *IEEE Transactions on Network and Service Management*, vol. 12, no. 2, pp. 146–162, June 2015.

[11] J. Schulz-Zander, N. Sarrar, and S. Schmid, "Towards a scalable and near-sighted control plane architecture for wifi sdns," in *Proceedings of the Third Workshop on Hot Topics in Software Defined Networking*, ser. HotSDN '14. New York, NY, USA: ACM, 2014, pp. 217–218.

[12] ——, "Aeroflux: A near-sighted controller architecture for software-defined wireless networks," in *Presented as part of the Open Networking Summit 2014 (ONS 2014)*. Santa Clara, CA: USENIX, 2014.

[13] K.-T. Tran and N. Agoulmine, "Adaptive and cost-effective service placement," in *Global Telecommunications Conference (GLOBECOM 2011), 2011 IEEE*, Dec 2011, pp. 1–6.

[14] K.-T. Tran, N. Agoulmine, and Y. Iraqi, "Cost-effective complex service mapping in cloud infrastructures," in *Network Operations and Management Symposium (NOMS), 2012 IEEE*, April 2012, pp. 1–8.

[15] I. Khan, F. Belqasmi, R. Glitho, N. Crespi, M. Morrow, and P. Polakos, "Wireless Sensor Network Virtualization: A Survey," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 1, pp. 553–576, jan 2016.

[16] S. Madria, V. Kumar, and R. Dalvi, "Sensor Cloud: A Cloud of Virtual Sensors," *IEEE Software*, vol. 31, no. 2, pp. 70–77, mar 2014.