SEED, A Server Platform for the Edge of the Network

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***Abstract*—Software defined Network – Network Function Virtualization (SDN-NFV) has been the catalyst of most of the researches in the networking and telecommunication domain during the latest years and it is supposed to have important deployment in the early next ones. However, there is no common understanding why it is so important and why it is the winning solution for the next generation networks. This paper describes, from an infrastructure point of view, the challenges to understand what SDN-NFV deployment into the Radio Access Network (RAN) really means. Our approach identifies how the Server at the Edge (SEED) of the network should look like. The paper describes the meaning of moving SDN-NFV into the RAN (conceptually different than moving the RAN into the cloud) and identifies the key function enablers for meeting the operation agility request from Radio Access. Resources and meters handling as critical characterization to empower the Self Organizing Network (SON) concept without unacceptable performance cost are also described. The paper aims to emphasize the enablers of the new business model needed in the SEED more than being an exhaustive description of single components.**

Keywords-SDN-NFV; C-Mobile OS; operational agility, new business case.

I. INTRODUCTION

Today, the Telecom realm is facing an epic moment, a technology step that will drive the evolution of the networked system in the future and, at the end of the day, the End User services and life style. Although it has become common knowledge, it is important to recall what is behind the SDN-NFV fortune in order to clearly identify some design rules that should drive the design in the area.

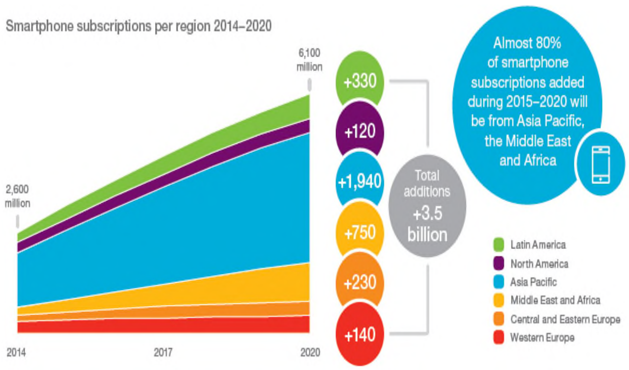

Figure 1. Smartphone penetration behind the growth of DATA ARPU (source: Ericsson)

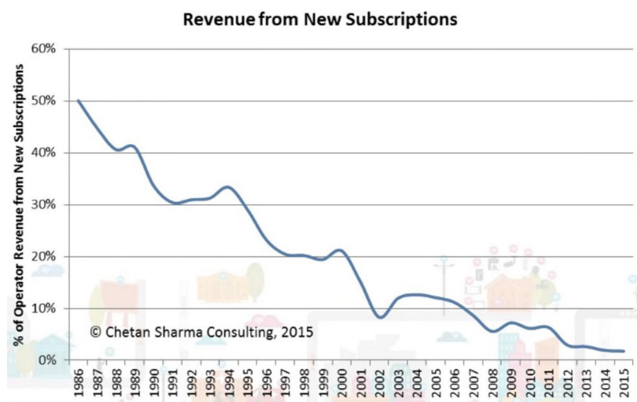

Figure 2. The revenue from new subscription trend (source Chetan Sharma Consulting [2])

In the last years, Telecom operators have seen an exponential growth of data traffic and, at the same time, a significant income reduction from the "golden eggs goose" voice and Short Message Service (SMS). Concurrently, thesmartphone penetration is continuously increasing (see Figure 1), changing the user's usage style of connectivity [1] [3]. Today, it is a common condition for all operators to have most of their Average Revenue Per User (ARPU) coming from data traffic and indeed voice and SMS is often offered at a very cheap price in order to attract new customers and increase revenue from data traffic. The trend is not supposed to change in the next years: Ericsson prediction shows that, by 2021, there will be 28 billion connected devices around the world [1]. 5G technology is just the answer to such a tremendous demand of connectivity for data traffic [3].

Saying so, one could start thinking that the operators might have better income from increased network capability, but the picture is not complete: the majority of mobile users are not prepared to spend too much for using their smartphones and it is not a case that the revenue from new subscriber dropped down dramatically in the last years, as reported in Figure 2. Such a condition results in a significant reduction of operator margin in a way that some pessimistic vision [4] is predicting a possible "end of profitability" condition for their business. Even in a more optimistic prediction, it is however a fact that the current business model is not really sustainable and operators need a direction where their margins can start to increase again [5].

A common understanding is that SDN-NFV is a key to reduce Operating expenses (Opex) and Capital expenditures (Capex) and then increase operator's margin. But, it looks like

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that statement is without a strong background vision, or at least, not able to give the right clue of the operators' strategy. Just to avoid any misunderstanding, SDN-NFV architecture will reduce Opex and Capex, but it is not actually that huge of an incentive for the operators' business. In fact, Opex and Capex have been reduced during the latest years, mostly thanks to the cost reduction of technology, and the real truth is that today total cost and revenue are so close that one can hardly imagine a new golden era thanks only to Opex and Capex reduction. It seems enough for surviving in the Telecom market battlefield, but surely not enough to justify a new infrastructure investment by the operators. Eventually, let us consider the life cycle of a new Telecom technology: the delivery rate between a technology step (from 2G to 3G, from 3G to 4G and so on) has an aggressive pace, in most of the case "forcing" operators to make a new infrastructure investment. But reduced revenue and delivery interval is concurrently reducing the business case window, so operators are not actually too keen to join a new technology in such conditions and for sure they are looking at any new investment very carefully. So, what are the actual operators' needs then?

So far, their effort has been focused on a market where improvement of capacity and quality of the connectivity has been enough. But the richest market today is fully in the hands of the over-the-top content (OTT) media delivery companies (Google, Facebook, Netflix, etc.). A real shift of operators' business is the key to enter into such a rich market. Eventually, that will be a win-win condition, since OTT is perfectly aware that reducing the end-to-end (E2E) data contents latency will improve their business. They are also aware that accessing User Metadata (very well known by Telecom operators) will increase even more such a market thanks to new business cases. Those considerations are behind the successful story of the SDN-NFV. The architecture has been designed in order to feed that win- win condition. At the same time, reducing Opex and Capex creates a more green-power environment and allowing an easy deployment of a new technology in a shorter, safer and comfortable new way. The "core" promise of SDN-NFV is to guarantee a new "business environment" where Telecom operators are a stakeholder in the creation of new flexible services.

This paper explores how RAN is integrated into the SDN-NFV architecture in Section 2. Section 3 introduces the SEED as architecture element, which is further described in detail in Section 4. We end with conclusions in Section 5 and future works in Section 6.

II. SDN-NFV AND THE C-RAN

The European Telecommunications Standards Institute (ETSI) has set regulations and indications in order to design and define SDN-NFV architecture [7][8], but some parts are left for others to design. One of those parts is the so called Network Function Virtualization Infrastructure (NFVI), where the Radio Network vendors could play their significant role, in this way, both contributing to the SDN-NFV best deployment and improving their own business. The first discriminating condition to succeed in this challenge is their ability to integrate the traditional IT world with the Telecom one (as explicitly required by the new business case), that is, their ability to provide full SDN-NFV architecture up to the edge of the network: into the RAN. ETSI group defined the deployment of the SDN-NFV for the mobile network in their Use Cases study report [6]. According to that scenario, the current base station is actually split into two main objects: the Remote Radio Header (RRH), that is antenna and eventually the basic Layer 1, and the virtualized Baseband Unit (vBBU) as a service housed in a specific server implementing Layer 2 and Layer 3 of mobile protocols. Then, from an infrastructure point of view, the challenge is to understand what SDN-NFV deployment into the RAN really means, identifying how the server at the edge of the network should look like. The questions that initially need to be answered are: what are the characterizations and technologies that must be considered as key components of the server itself, which hardware characteristics are matching the requirements, which functions are clearly new components (services) of the platform housed into the server@edge (SEED) and which ones need more attention and effort to remove possible obstacles and limitations?

It is a long journey where the infrastructure designers must remember the real needs behind the SDN-NFV. Moreover, the operators' expectations have to be fulfilled and also a more complete understanding of other opportunities like footprint and energy consumption. For these reasons, it is worth to start considering the SDN-NFV deployment scenario from a system level view and then refer to it while defining services and functions. This paper wants to focus on the SEED concept, identifying its characterization to cope with the radio function requirements. In fact, the starting point of this paper is that it could be very difficult to move the RAN into the cloud and more suitable to port SDN-NFV into the RAN. This will give all the benefits of SDN-NFV described in the introduction and, concurrently, will answer the specific requirements needed at the edge of the network. The reference deployment model has

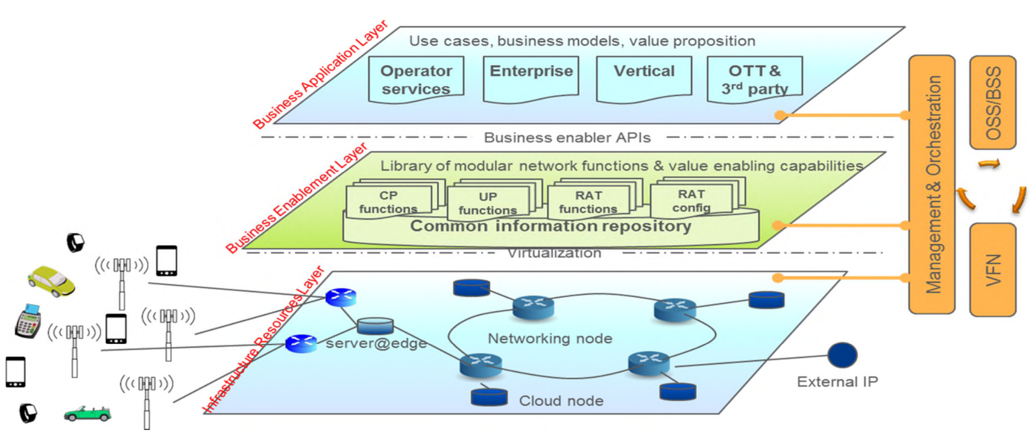

Figure 3. SDN-NFV layered architecture

been described [9][10] and ETSI made some progress in the same area [7] introducing the so called Mobile-Edge Computing (MEC) server. It offers application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the mobile network.

In this paper, the MEC server is considered the starting point of any investigation of the SEED definition and characterization. Another aspect is to consider SDN-NFV as an overall system solution, an end-to-end solution from that perspective to avoid not fulfilling the fundamental requirements.

SDN-NFV architecture is built over three layers [11], as logically shown in Figure 3:

- Business Application Layer – where the enterprise business value model is defined
- Business Enablement Layer – where the enabling and capabilities value are defined
- Infrastructure Resources Layer – where the resources needed by the value are defined

In the next decades, enterprises will increasingly make their specific applications available on mobile devices. The next wave of mobile communication is to mobilize and automate industries and industry processes. This is widely referred to as machine-type communication (MTC) and the Internet of Things (IoT). OTT players will move to deliver more and more applications that require higher quality, lower latency, and other service enhancing capabilities). The SDN-NFV layered vision is the most useful to understand the service oriented approach supported by the architecture itself. Deployment over the network, functions blocks and their reference points have been the main focus of the ETSI group. There are also some concepts on the splitting of the current Base Station in RRH and vBBU and what it actually means for the current implementation of the Base Station Controller (BSC). As an example, one can refer to the LTE protocol deployment in order to figure out pros and cons while moving LTE function from RRH to the vBBU. The deployment of Radio Technology between RRH and BBU could be done in several ways, mostly deciding the point in the protocol chain where the split is done and so defining the interface typology between RRH and BBU. Depending on the decision taken, one can face different types of issues or constraints. An ETSI-based vBBU implementation, for example, is able to guarantee the highest service flexibility possible, so the highest level of operational agility (indeed very useful for Telecom Infrastructure providers as well, since deployment of a new technology could be handled in the same product handling shape of a new service deployment), but it is challenged by very aggressive latency time requirement. On the other hand, a "smooth" porting of the existing BSC solutions into the cloud could be attractive in term of legacy software or reduced latency time that would simply the first deployment, but it fails to answer the strong request of operation agility, because, in this case, the protocol splitting is done on the highest protocol layer only. In a similar way, splitting BSC between RRH and BBU could have important impacts by means of Fronthaul and Backhaul capacity demand [12]. The successful story of SDN-NFV deployment is passing by an infrastructure that matches all demands: there is nothing more important than the operational agility in the business behind the SDN-NFV and this simple consideration is driving the decision to where one should focus their effort: define and design an infrastructure for the SEED that cope with the latency time requirement. As already mentioned before, that is not a new concept indeed. It is in the ETSI studies while talking about the so called MEC Server [7]. What remains to be done is identifying the technical characterization of the C-mobile platform, the SEED, in order to handle the MEC server as needed. It is worth to mention that all network function should be handled as service, according to the layer architecture described in Figure 3. In SDN-NFV network, the deployment is based on Service Availability Concept: shortly, Radio Access must be a function deployed on the Business Enablement Layer and published in order to be used as component in a service chain at the Business Application Layer. The service chains capability [13] is considered a key accelerator of the SDN-NFV usage, since it is introducing a high level of operational agility, already mentioned as mandatory requirement. Note how the service chain is also a mindset in ETSI use case description of the BS [6] and it is at the very fundamental of SDN-NFV architecture description [14][15].

III. SEED, A SDN-NFV SYSTEM ELEMENT

SEED is the C-mobile platform for the MEC server, by definition the server at the edge of the network. It is designed to allow a unique and logical centralized network controller spread from end user to the data center. The characterization of the SEED could only be done with that picture in mind and the aim to never violate the operational agility. This concept is fully aligned with the ETSI group SDN-NFV use case about mobile network implementation [6]. From a high level functions point of view, the MEC server should be able to host: computing capability (for mobiles, as well as for generic services), connectivity (with external network, as well as with the radio interface), and storage, one of the value enabler resource for new business case. The above set of different capabilities is defining the SEED as described in Figure 4, duplicated by redundancy in order to have high reliability condition.

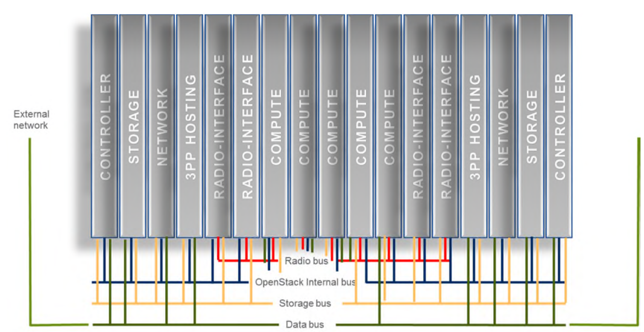

Figure 4. The SEED structured for function capabilities

The number of those capabilities for the SEED will define its size, which is a pure dimensioning calculation. The solution is fully aligned to the most common cloud platform (ref. User's Guide indication [16][17]). A bit more could be added about connectivity. In order to avoid unwanted disturbances in traffic bandwidth availability, Virtual Machine's (VMs) data, storage, network and radio buses should be kept independent from each other. To comply with the idea of SEED we need to look on a lower level than macro functions, try to figure out how the C-mobile platform looks like. Next, we will clarify some misunderstandings around some concepts that are normally pointed out while talking about SDN-NFV. The virtualization layer is not an option. Virtualization is the core of the SDN-NFV architecture and there is no alternative to conform to such architecture. All resources must be virtualized, with no exception. Functions are virtualized, and every single physical resource is virtualized as well. A downsize of the virtualization range is against the operational agility characterization that has been already mentioned previously as the key incitement for the business model behind the SDN-NFV [18]. Downsizing the virtualization means to downsize the operational agility, which affects the business capacity of the operators and eventually misses the expectation they have for the new business opportunity. Applications are services and handled as services into the new architecture. That means there is no software deployment as traditionally intended, but instances of service as VMs (or containers) deployed over the architecture and connected in a service chain to deploy a network value. One of the most common buzz words around SDN-NFV is Common Off The Shelf hardware (COTS), most of the time, used as an enabler to reduce Opex and Capex. Hardware evolution is always ongoing. Vendors are fighting their own war and they are fully aware of the needs/requirements coming from the next mobile generation world. So, why should we get stuck on COTS that most likely will be obsolete in a (short) while? Thinking about our main ideas of the implementation for the best SEED, we should identify the requirements of the hardware platform in order to achieve our optimal architecture. This means that the available COTS could not match our requirements. What hardware characteristics and performance will match our requirements is defining the next generation of COTS. What we actually need (and that is not only a design decision for software) is a suitable hardware in order to:

- Remove the latency obstacles to strengthen the operational agility, even thanks to ad hoc hardware assisted functions and accelerations;
- Improve connectivity;
- Design secure Quality of Service (QoS) resource usage for Service Level Agreement (SLA) handling;

IV. STRUCTURING THE SEED

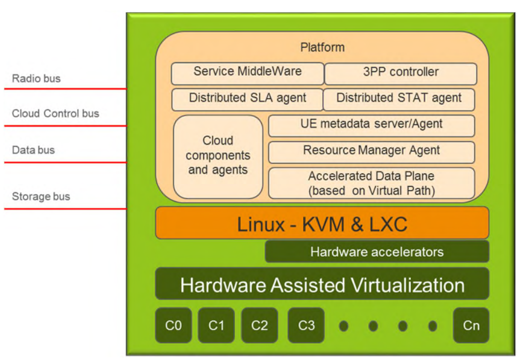

Figure 5. Main objects housed in SEED boards

Looking at the state of the art, Intel architecture seems to have better performance and virtualization features than other architectures: the management of virtualized objects requests less capability and introduce less latency in the system using Intel solution. Moreover, SDN-NFV implementation is strongly supported by the Open Software Community and by de facto a lot of functions and features in SDN-NFV are designed on Intel architecture first and then eventually ported on other targets. Though, power consumption needs to be considered, especially while referring to the edge of the network where power consumption is really a big issue and where other hardware architectures seem to be more efficient in the power consumption domain. Figure 5 is summarizing the main objects housed in SEED board, where differences are described in the next paragraphs.

A. Compute Platform for the Edge

The compute platform for the edge shall be based on 64-bits Linux Operating system (OS). Both hardware and software support the virtualization layer and this is pointing to a very specific set of needed features: reduce the cache pollution (e.g., Huge Page or Rapid Virtualization Indexing (RVI), depending on hardware architecture), support multi-core system, guarantee low power consumption, full set of hardware and software feature in order to speed up VM context switch, Virtual Interrupt Handling, hardware assisted trace & debug capability in a virtualized environment and virtual path. Both Kernel-based Virtual Machine (KVM) and Linux Containers (LXC) should be supported: for the reasons mentioned above, it seems a good choice to have a C-mobile platform able to handle both, but having VM's and container's concurrently in a service chain is introducing a level of complexity. The OpenSoftware Cloud components and agents are obviously there (OpenStack, OpenDayLight, ONOS, M-CORD and whatever is requested by the Management And Orchestration – MANO - of the system). Accelerated Data Plane in User Space (vSwitch, fastpath, direct interrupt delivery, etc.) is needed in order to design efficient connectivity solution. A Resource Manager Agent is needed and must be able to handle the resources reference point as described in the SDN-NFV architecture. Distributed SLA and STAT agents are needed and they shall interwork, not only to each other but to higher hierarchical SLA and STAT objects in the architecture. That is done in order to handle the available resources in a dynamic way and providing the support for Self Organizing Network (SON) capability. The hierarchical approach for meters and resources handling, as described in Figure 6, is crucial to avoid massive signaling. Moreover, the local resource-meters agents can apply the right taxonomy to create the resources relationship between different logical layers, from physical resources usage up to QoS. Important characteristic is the User Equipment (UE) metadata Server, as the service available in the SEED to publish the UE metadata and control the access/usage of them and the Third Party Product (3PP)-bridge controller. It will provide "close-to-UE" service capability to enterprises and other 'vertical' services. External connectivity to Radio bus, Cloud control internal bus (Management plane), data bus (data plane) and Storage bus (caching service) are available for the compute board.

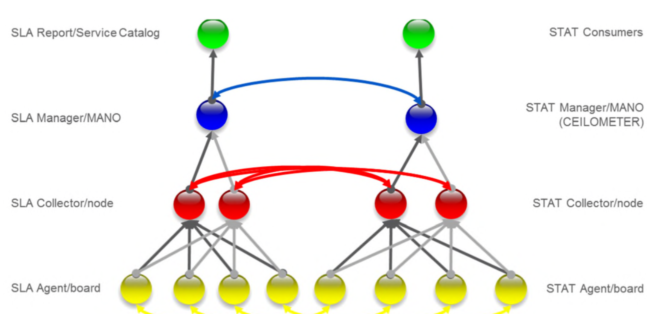

Figure 6. The hierarchical structure and co-relation of SLA and STAT

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B. 3PP Hosting Platform for the edge

The hardware board is just the same as the compute one and likewise we can say about OS and virtualization layer. Platform components are the same or agents of the same functions in the compute board. For example, UE metadata client interworks with its server in order to provide the complete list of metadata info and 3PP bridge is the active component of its controller, devoted to provide connectivity channel between 3PP application and external internet/radio channels and, for that reason, responsible for security check, registration, authorization and encryption/decryption. The available connectivity channels are not the same: 3PP hosting - for security reason - shall not have a possibility to use the radio bus directly. This will allow resource control according to the SLA in the compute board, avoiding any possible malicious or faulty behavior of the 3PP applications themselves.

C. Radio-Interface Platform for the Edge

The board could be armed with dedicated hardware accelerators, needed to speed up the radio access protocols handling. It is not a limitation, as long as they are designed to be controlled as virtualized resource by the resource manager. With such differentiation, the board and the platform components/functions are not different from the components/functions mentioned so far for the SEED platform.

D. SEED Characterization

Connectivity and the efficient implementation of it is the critical key of the SEED. It is mandatory to avoid any bottleneck and additional overhead that will cost a lot for latency time. At the same time, the connectivity handling shall never be an obstacle for the service chain deployment concept (the operational agility is a mandatory requirement for the server at the edge of the network). Once one decides to share resources between different actors, it is fundamental that they can access them without creating disturbances to each other and according to the resource sharing agreement they have. It is like job scheduling where one wants threads continuously working and not starve them out. In case that happens, the thread may steal a job from someone else. Thereby maybe using another set of resources. The virtual path concept is trying to do the same with the connectivity access. Different VMs running should be able to access connectivity as they are running alone, based on the maximum available bandwidth defined in its SLA (the virtualized slice of connectivity assigned to it) and avoiding performance drawback due to system overhead (minimum or zero cost of virtualization layer, VM walkthrough data handling). The nature itself of SEED sets a specific requirement for the platform: provide a wide range of computing characterization and guarantee the agreed slice of computing resources won't be affected by other VMs running on board. This is quite clear once one starts thinking on a platform where there are strong time constrains application types, like radio services, relaxed time-constrains application types, like video or audio services, and no time-constrains application types, like general services. But that is not enough. If someone pays for a specific bandwidth and computing, platform shall protect those resources for it. Again, the macro effect should be that, no matter if the VM is working alone or not, it can always count on the resources slices assigned by SLA. For that reason, the platform shall schedule VM jobs according to the following rules: a) Provide strong isolation for VMs with strong time-constrains; b) Provide maximum CPU utilization for VMs with relaxed time constrains using SCHED_DEADLINE policy. SLA and Statistics are strictly correlated to each other and actually hierarchically spread all over the system (this concept is also emphasized in Figure 6). Indeed, STATs are far from being a passive snapshots recording, they are actively interworking with SLA and resource manager in order to deploy the best resource utilization of the network. The hierarchical implementation of resources and metrics handling is fully devoted to simplify the SON. SON brings a set of self-configuration and self-optimization use cases that allow a better control of the operational cost for the complex radio access technologies. Here, the role of the real-time data analysis, by all means, makes the difference. It involves all resources of the system, removing the over-allocation, which today is dominating the dimensioning of RAN and causes a huge wasting of money in most of the operational time [19] [20].

V. CONCLUSION

The opportunity to move SDN-NFV into the Radio Access Network is a crucial objective for the communication system in the next years. Fulfilling the customers' needs means to answer on the demand for the next generation mobile, create new business models for the operators and open new service market share for the infrastructure vendors. However, mobile cannot be handled as data center or networking nodes. Location, latency time, UE metadata are unique and added value for the radio access, which means an ad-hoc solution is the enabler for a successful and high performing product. A complete C-RAN solution is not considered suitable due to the fronthaul capacity explosion it meant and the more flexible approach of the Radio Access Network as a Service (RANaaS) looks more promising. The ad-hoc solution is based on the right implementation of the ETSI concept called MEC. This paper emphasizes the role of it as server@edge of the network, calling it SEED. SEED is a suitable set of heterogeneous hardware solution, designed to dramatically reduce the cost of virtualization. The engine of the SEED is the so called C-mobile platform, a horizontal, per sever distributed, platform able to support the main functions characterizing the SEED: SDN-NFV controller, UE Metadata access service, Radio Access as Service solution, 3PP hosting and granted SLA. To be fully dynamic, SDN applications need to be responsive to their environment, therefore, triggers for network changes need to be state-driven. This automated management will be based on real-time network data analysis. Hierarchical Resource Manager and big data handling in the meaning of SON support is a key enabler together with the needed support.

VI. FUTURE WORKS

All the concepts in the paper need investigation and future study. For example, the usage of sched_deadline in a virtualized environment needs c-groups extension for a complete control of container's thread. Moreover, a Greedy Reclamation of Unused Bandwidth (GRUB)-like mechanism implementation would decrease the Constant Bandwidth Server (CBS) effect of sched_deadline, providing a more performing latency time [21][22]. Usage of resources meters and statistics is a very interesting topic. One of the natural next steps is the evaluation of the taxonomy framework introduced in [23] for the characteristic resources of the Radio Access Network:

network slices, load balancing, resource abstraction and resource control as defined in [24].

REFERENCES

[1] http://www.ericsson.com/res/docs/2015/mobility-report/ericsson-mobility-report-nov-2015.pdf [retrieved: 03, 2017].

[2] Chetan Sharma Consulting, “US Mobile Market Update – Q1 2014, 2014.

[3] Ericsson Mobility Report, On the pulse of the networked society, June 2015.

[4] T. Kridel, “The End of Profitability”, Tellabas Insight Q2, 2011, pp.14-15.

[5] K. Shatzkamer, “Applying Systems Thinking to Mobile Networking”, Brocade Communications Webinar, 2015. Available from http://docplayer.net/8990528-Applying-systems-thinking-to-mobile-networking.html [retrieved: 03, 2017].

[6] ETSI paper, “Network Functions Virtualisation (NFV); Use Cases”, ETSI GS NFV 001, v1.1.1, 2013, available from http://www.etsi.org/deliver/etsi_gs/NFV/001_099/001/01.01.01_60/gs_NFV001v010101p.pdf [retrivied: 03, 2017].

[7] Y. C. Hu, M. Patel, D. Sabella, N. Sprecher and V. Young, "Mobile Edge Computing - A Key Technology Towards 5G", Sept. 2015, availble from http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp11_mec_a_key_technology_towards_5g.pdf [retrieved: 03, 2017].

[8] ETSI paper, “Network Function Virtualisation (NFV); Network Operator Perspectives on Industry Progress”, SDN & OpenFlow World Congress, Dusseldorf, 2014, available from https://portal.etsi.org/Portals/0/TBpages/NFV/Docs/NFV_White_Paper3.pdf [retrivied: 03, 2017].

[9] G. Karagiannis et al, “Mobile Cloud Networking: Virtualisation of Cellular Network”, 21st International Conference on Telecommunications (ICT), 2014, pp. 410-415.

[10] C.Vitucci, J.Lelli, A.Pirri, and M.Marinoni, “A Linux-based Virtualized Solution Providing Computing Quality of Service to SDN-NFV Telecommunication Applications”, In Proceeding of the 16th real time Linux workshop (RTLWS 2014), Dusseldorf, Germany, 2014, pp. 12-13.

[11] NGMN Alliance, “5G White Paper”, NGMN, 2015 J.S. Harrison, M.M. Do, “Mobile Network Architecture for 5G Era – New C-RAN Architecture and distributed 5G Core”, Netmanias, 2015, available from https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf [retrivied: 03, 2017].

[12] J.S. Harrison and M.M. Do, “Mobile Network Architecture for 5G Era – New C-RAN Architecture and distributed 5G Core”, Netmanias, 2015, available from http://www.netmanias.com/en/post/blog/8153/5g-c-ran-fronthaul-kt-korea-sdn-nfv-sk-telecom/mobile-network-architecture-for-5g-era-new-c-ran-architecture-and-distributed-5g-core [retrivied: 03, 2017] .

[13] G. Brown, “Service Chaining in Carrier Networks”, Heavy Reading, 2015, available from http://www.qosmos.com/wp-content/uploads/2015/02/Service-Chaining-in-Carrier-Networks_WP_Heavy-Reading_Qosmos_Feb2015.pdf [retrivied: 03, 2017].

[14] T.A. Satria, M. Karimzadeh, and G. Karagiannis, “Performance evaluation of ICN/CCN based service migration approach in virtualized LTE systems”, IEEE 3rd International Conference on Cloud Networking (CloudNet), 2014, pp. 461-467.

[15] M.J. McGrath, “Network Functions as-a-Service over virtualized infrastructures”, Ref. Ares(2015)3376865, 2015, available from http://cordis.europa.eu/docs/projects/cnect/0/619520/080/deliverables/001-TNOVAD32InfrastructureResourceRepositoryv10Ares20153376865.pdf [retrivied: 03, 2017].

[16] OpenStack, “OpenStack Operations Guide”, OpenStack Foundation, 2014, avaiable from https://docs.openstack.org/ops-guide/ [retrivied: 03, 2017].

[17] C. Dixon, “OpenDayLight: Introduction, Lithium and Beyond”, available from http://colindixon.com/wp-content/uploads/2014/05/brighttalk-odl-webinar.pdf [retrivied: 03, 2017].

[18] N. Nikaein et al, “Network Store: Exploring Slicing in Future 5G Network”, in Proceeding of the 10th International Workshop on Mobility in the Evolving Internet Architecture, 2015, pp. 8-13.

[19] K.Trichias, R.Litjens, A. Tall, Z. Altman, and P. Ramachandra, “Self-Optimisation of Vertical Sectorisation in a Realistic LTE Network”, Europen Conference on Networks and Communications, 2015, pp.149-153.

[20] S. Fortes, A. Aguilar-Garcia, R. Barco, F. Barba, J.A. Fernandez-Luque, and A. Fernandez-Duran, “Management Architecture for Location-Aware Self-Organizing LTE/LTE-A Small Cell Networks”, IEEE 53(1) Communications Magazine, 2015, pp. 294-302.

[21] L. Abeni, J. Lelli, C. Scordino, and L. Palopoli, “Greedy CPU reclaiming for SCHED DEADLINE”. In Proceedings of the Real-Time Linux Workshop (RTLWS), Dusseldorf, Germany, 2014.

[22] G.Lipari and S. Baruah, “Greedy reclaimation of unused bandwidth in constant bandwidth servers”. In IEEE Proceedings of the 12th Euromicro Conference on Real-Time Systems, Stockholm, Sweden, 2000, pp.193-200.

[23] S. Cai, B. Gallina, D. Nyström, and C. Seceleanu, “A Taxonomy of Data Aggregation Processes”, IEEE DAGGERS project paper, 2016, available from http://www.es.mdh.se/pdf_publications/4628.pdf [retrivied: 03, 2017].

[24] VG. Nguyen, TX. Do, and Y. Kim, “SDN and Virtualization-Based LTE Mobile Network architectures: A comprehensive Survey”, Wireless Personal Communications, 2016, Volume 86, Number 3, pp. 1401-1438.