5G Smart City Vertical Slice

Bogdan Rusti
Technical Departament
Orange Romania
Bucharest, Romania
bogdan.rusti@orange.com

Horia Stefanescu
Technical Departament
Orange Romania
Bucharest, Romania
horia.stefanescu@orange.com

Marius Iordache
Technical Departament
Orange Romania
Bucharest, Romania
marius.iordache@orange.com

Jean Ghenta
Technical Departament
Orange Romania
Bucharest, Romania
jean.ghenta@orange.com

Cristian Patachia
Technical Departament
Orange Romania
Bucharest, Romania
cristian.patachia@orange.com

Panagiotis Gouvas
Research & Development
Ubitech
Athens, Greece
pgouvas@ubitech.eu

Anastasios Zafeiropoulos
Research & Development
Ubitech
Athens, Greece
azafeiropoulos@ubitech.eu

Eleni Fotopoulou
Research & Development
Ubitech
Athens, Greece
efotopoulou@ubitech.eu

Qi Wang
Engineering & Computing
University of the West of Scotland
Paisley, UK
Qi.Wang@uws.ac.uk

Jose Alcaraz Calero
Engineering & Computing
University of the West of Scotland
Paisley, UK
Jose.Alcaraz-Calero@uws.ac.uk

***Abstract*—5G is the key enabler for new business and digital transformation initiatives to integrate vertical industries (e.g., automotive, energy, manufacturing, entertainment) into the network slice concept, maximizing the sharing of network resources and creating dedicated logical networks with personalized customer specific functions. In this paper we present a unique concept for the development, deployment and management of a Smart City 5G cloud native application network as a result of synergy between two 5G-PPP EU projects, namely MATILDA and SliceNet. The application development and deployment lifecycle starts with the design and composition of the application graph in MATILDA development kit, followed by on boarding of the developed application into a vertical applications orchestrator and the preparation of a "slice intent" description for the creation of an application-aware network slice. The latter is provided to the SliceNet One-Stop API to create the application-aware network slice to be deployed further over a programmable network infrastructure. The overall Smart City use case is presented, including plans for further enhancements as a collaborative activity between the two research projects. All functions and integration activities will be tested in a dedicated testbed platform.**

Keywords—5G, Marketplace, Application Orchestrator, Network Slice, 5G-ready application, IoT, LTE-M, Sensor, Smart City, Matilda, SliceNet component

I. Introduction

5G initiative's main ambition is to create "a complete, new and automated ecosystem based on increasing range of services and applications with diverse requirements on mobile broadband, machine-type, and high-reliability and low-latency communications" [1]. The 5G network slicing emerges as a solid proof framework solution to these technological and business requirements. Network slicing allows network operators to provide secured dedicated virtual networks with specific customer service functionality over a common network infrastructure and includes different technical parts (core, transport and access network) and administrative domains including management and orchestration plane.

Smart city services demand advanced requests sustained by scalable infrastructure with high data processing capacities, speeds and low latencies, capable of providing flexible provisioning, cost-efficiency and service customization. Each network slice contains a set of logical network functions created to address independently the requirements of deployed uses cases. 5G slice "supports the communication service of a particular connection type with a specific way of handling the control and user plane for this service" [2]. Network slices would maximize the sharing of network resources across domains, providing the flexibility to create dedicated logical networks and associated functions for different vertical businesses offering configurable QoS and QoE through intelligent slicing and slice lifecycle management.

MATILDA [3] and SliceNet [4] projects jointly define a 5G Smart City Lighting network slicing architecture, by designing and implementing an end-to-end operational service framework covering the lifecycle of design, development and orchestration of 5G-ready applications and 5G network services through an One-Stop API over a programmable infrastructure assuring end-to-end management, control and orchestration of slices by secured, interoperable, and reliable operations across multi-operator domains.

In section II, a brief description of related work on the topic article is presented. Next section presents in detail the architectural aspects of both MATILDA [3] and SliceNet [4] projects together with their point of interconnection. In sections IV of the article the redesign of the Smart City application as a 5G ready Application [5] is exposed together with the testbed solution designed to materialize the entire concept. Section V concludes the paper, summarizing the key technological aspects of the common MATILDA -

978-3-903176-15-7 © 2019 IFIP

SliceNet architecture and the key next steps for the actual deployment.

II. 5G SMART CITIES RELATED WORK

The element of innovation that Smart City 5G project synergy is bringing, is the design of an end to end mechanism together with the architectural components as a microservice cloud based application to be deployed automatically on a 5G network programmable infrastructure [6].

Several projects address the various technical challenges [7] in achieving network slicing in 5G or LTE networks, to meet the diverse requirements of different vertical business use cases [8]. Among them, a large portion of the existing work focus on slicing in the Radio Access Network (RAN) such as the EU 5G PPP project COHERENT [9] and the work reported in [10], which involves contributors from both Europe and US.

The proper chaining and placements of Virtual Network Functions (VNFs) is important in network slicing for service creation. The specific schemes developed in the literature (e.g., [11][12]) are complementary and useful to this work. For instance, proactive caching is jointly considered in [10] within a service chain for improved mobility support of video caching applications. Such a joint design of network functions and application services will benefit use case informed slicing as in the case of this work, highlighting a smart city use case between the MATILDA and SliceNet projects.

Initiatives addressing automation and self-organizing capabilities of underlying infrastructure are on-going [13], enabling virtualization of shared resources between different network slices [14]. Most of the scientific articles are addressing either requirements and challenges of 5G systems related to different use cases [15] or frameworks able to support different types of application related to smart city, smart energy, public safety [16,17]. Subjects as Context-awareness [18], cognitive IoT [19], autonomous control, orchestration [20] treated in recent research works are covering only a part of the flow of creating, enabling, deploying, scaling of a service by limiting as much as possible the human intervention.

Still no automated solution has been developed yet, tackling the end to end journey of 5G service starting with the development of a dedicated platform for service cloud native component design, continue with service application graph flow composition, instantiation and orchestration using an intelligent orchestration mechanism and ending with development of an application able to translate al associated demands into proper requirements for deployment over virtual network infrastructure.

III. MATILDA AND SLICENET ARCHITECTURE

MATILDA project [8] comes up with a completely new approach, tackling the overall lifecycle of applications design, development, deployment and orchestration in a 5G ecosystem. MATILDA follows a top-down perspective where applications design and development leads to the instantiation of application aware-network slices, over which vertical industries applications can be optimally served. Different stakeholders are engaged in this process, however with clear separation of concerns among them.

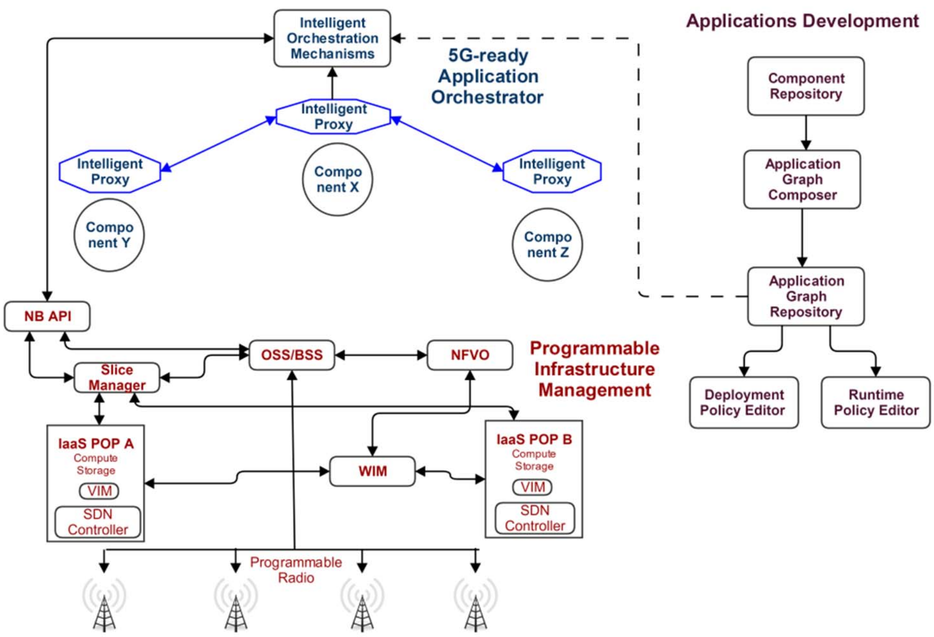

Fig. 1. MATILDA Reference Architecture

The MATILDA reference architecture displayed in Figure 1 is divided in three distinct layers, namely the 5G-ready Applications Layer, the Applications' Orchestration Layer and the Network and Computing Slice Management Layer [8]. Separation of concerns per layer is a basic principle adhered towards the design of the overall architecture. The Applications Layer is oriented to software developers, the 5G-ready Application Orchestration Layer is oriented to application/service providers and the 5G Infrastructure Slicing and Management Layer is oriented to communication service/infrastructure providers. In the current manuscript, mechanisms provided in the first two layers are applicable, since the slice creation and management request is tackled by mechanisms provided by SliceNet.

Specifically, the 5G-ready Applications Layer is responsible for the design and development of 5G-ready applications per industry vertical, along with the specification of the associated networking requirements. Such a development is realized through a development kit, while the produced software is made available in the MATILDA Marketplace. The associated networking requirements per vertical application are declared in a way that are tightly bound together with their respective 5G-ready applications' graph, which defines the business functions, as well as the service qualities of the individual application. The Applications' Orchestration Layer supports the dynamic on-the-fly deployment and adaptation of the 5G-ready applications to its service requirements, by using a set of optimization schemes and intelligent algorithms to provide the needed resources across the available multi-site programmable infrastructure. The MATILDA Vertical Applications Orchestrator is developed for supporting functionalities in this layer. The Vertical Application Orchestrator (VAO) is the entity that provides the request for the creation of an application-aware network slice based on the created slice intent, as well as for realizing placement and orchestration of the application over the created slice. The creation and dynamic management of the network slice is managed by SliceNet [4] mechanisms.

The main innovation of SliceNet [4] is a new, cognition-based, vertical oriented architecture that according to design will respond to MATILDA Smart city slice intent requirements by enabling an end-to-end multi-domain network management architecture covering an extended set of service functionalities such as Fault, Configuration, Accounting, Performance and Security (FCAPS). The network slice will be deployed on advanced slicing-based programmable infrastructure together with enablers components for the slicing control plane, management plane and cross-plane orchestration. The SliceNet framework will be completed with standards-compliant interfaces and new, open and extensive APIs facilitating the deployment of slices and slice-based/enabled services.

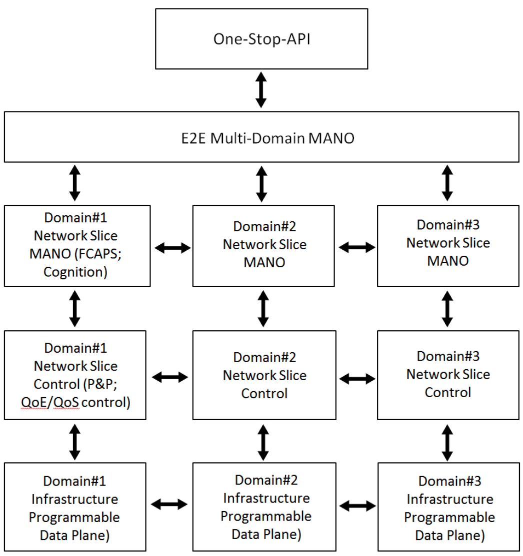

Fig. 2. SliceNet Abstract Functional Framework

Figure 2 illustrates an abstract functional overview of the SliceNet framework, highlighting the multi-domain perspective of the system for E2E 5G service deployment across multiple administrative domains owned by different Network Service Providers (NSPs). With a top-down view, the One-Stop API receives and processes the slice intent from the overlay Matilda system as described in the previous section. After the slice intent is parsed and the corresponding slice template is applied, the E2E network slice and service creation is then initiated at the E2E Multi-Domain Management and Orchestration (MANO) [21], owned by either a third-party Digital Service Provider (DSP) or a DSP collocated/integrated with the serving NSP (Network Service Provider) depending on specific deployment and business scenarios. This E2E Multi-Domain MANO is responsible of establishing the E2E slice instance for the requested service as extracted from the slice intent, by coordinating the Domain Network Slice MANOs in the involved NSPs' domains. It also manages the lifecycle of the E2E slice instance. In SliceNet, a multi-domain E2E network slice instance comprises an ordered series of network slice instances created by the involved individual NSPs respectively to meet the communication and coverage requirements imposed by the requested service. These individual domain slices are domain specific, and commonly contain different set of network functions in the service chain according to the network function forwarding graph defined for the slice. The inter-domain communication connectivity and QoS negotiation for the E2E network slice is conducted in SliceNet through peer-to-peer signaling between individual domains. Such multi-domain network slicing capabilities offer great potential for large-scale deployment of verticals' use cases that requires extended geographical coverage such as inter-smart city use cases. In the current prototyping of the smart city lighting use case, a single domain setting is focused on, although future work will seek to extend use cases to the multi-domain scenario.

Furthermore, the SliceNet control plane [22] is uniquely featured with a Plug and Play Control component, which is able to expose different levels of control capacity to a vertical regarding the network slice ordered by this vertical. For instance, for the smart city use case, additional customized VNFs can be plugged by the smart city vertical in order to optimize the performance of the network slice-based service. This Plug and Play mechanism thus expands the flexibility and richness of customizable network slices and varied services tailored to specific requirements of the vertical. Moreover, SliceNet control plane is equipped with a QoE (Quality of Experience) Optimizer, responsible for dynamically optimizing the QoE in the services at the slice level. The QoE Optimizer is empowered by the SliceNet cognition-based network management and control framework, consisting of monitoring/sensing, analytics, actuation in the management plane to enable a closed-loop autonomous management and control of network slices.

In addition, it is noted that each domain slice may operate over different infrastructures. To adapt to different network infrastructures employing various specific technologies, SliceNet designs control plane adaptors in Domain Network Slice Control to allow technology-agnostic deployment across heterogeneous network segments and multiple domains. SliceNet infrastructures contains also programmable data planes to enforce QoS control in the control plane, in response to the requirements of various slices in both the provisioning and the operation phases. The programmability in SliceNet data plane is achieved by adopting and exploring the capabilities offered by open source projects such as OpenAirInterface [23] and Mosaic5G [24]. This allows the smart city use case to truly benefit from the service differentiation and QoS control for the use case's slices through the data plane programmability. Smart City vertical will be developed as a collaborative work between these two 5GPP projects, with SliceNet project focusing on the 5G infrastructure layer and MATILDA project addressing the 5G ready application development and orchestration, which will be deployed over the infrastructure layer.

The common architecture for the Smart City Vertical is depicted at Figure 3.

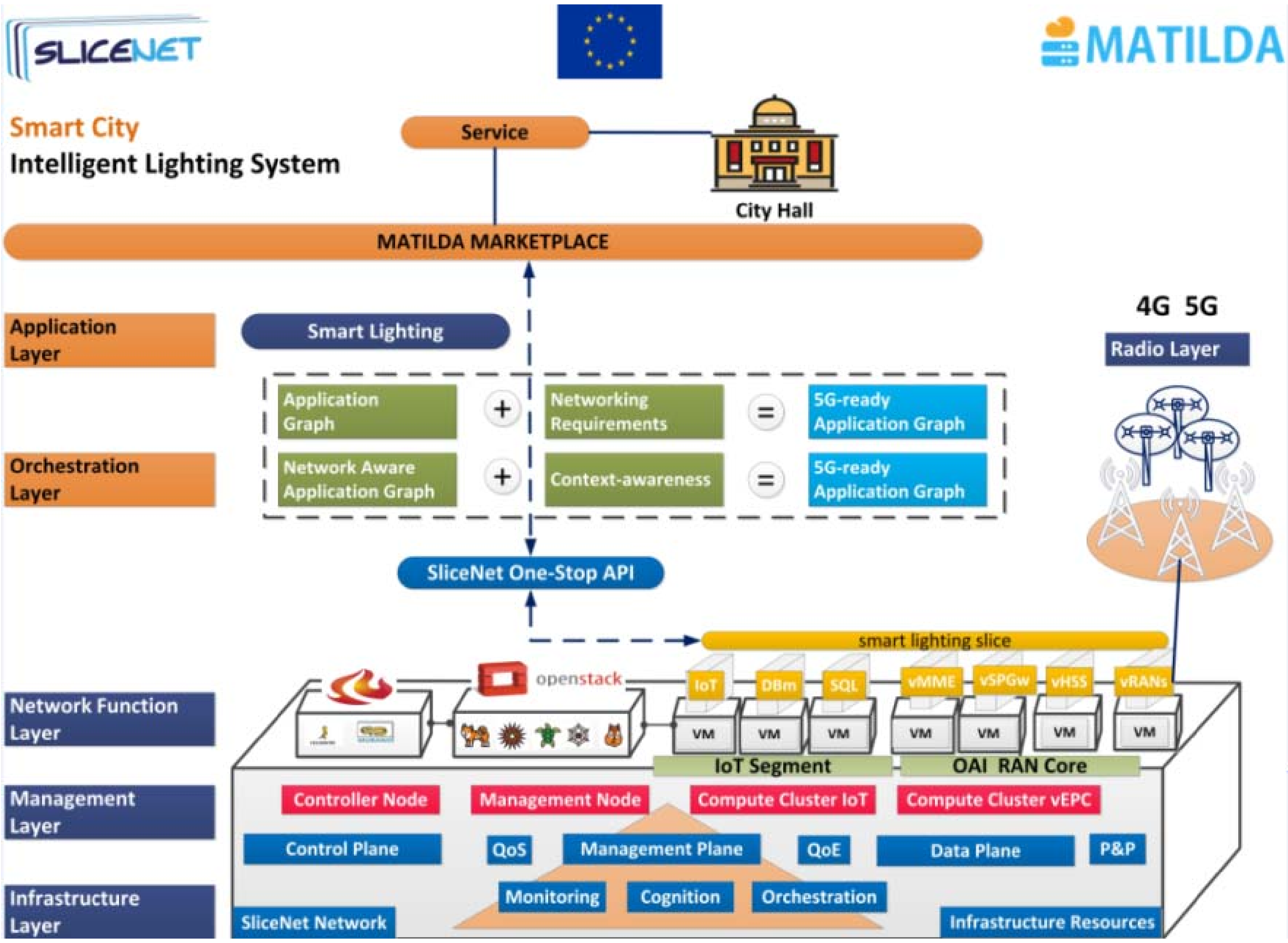

Fig. 3. MATILDA-SliceNet common architecture for the 5G smart city vertical

The application development and deployment lifecycle start with the design and composition of the application graph in the provided development kit by MATILDA, followed by on boarding of the developed application into a vertical applications orchestrator and the preparation of a "slice intent" description for the creation of an application-aware network slice. The latter is be provided to the SliceNet One-Stop API for realizing the application-aware network slice and providing back the network slice instance over a programmable network infrastructure. The Smart City use case will be further enhanced with specific components developed in SliceNet, as Plug & Play functions, QoE optimizer, QoS control, monitoring metrics, sensing and actuation through cognition mechanism.

IV. SMART CITY 5G READY APPLICATION

The Smart City application [5] is fully redesigned by Orange Romania considering the MATILDA-SliceNet common architecture presented in this paper. It is important to note that the redesign of this application shall allow automated deployment and in life management which translates in shorter time to market and cost efficiency.

The first step towards the deployment and the orchestration of the smart lighting application targets the design of the overall application graph, as depicted at Figure 4.

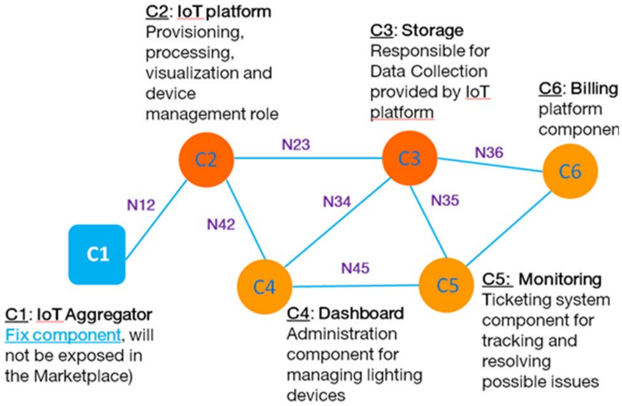

Fig. 4. Smart Lighting Application Graph

The application consists of the several components logically chained together through a set of logical graphs. C1 is a fixed component composed by IOT aggregator which assures secured connection with lighting sensors; C2 component has the role of provisioning, processing, visualization and lighting sensor management; C3 is a storage component responsible for data collection provided by the IoT platform; C4 is a dashboard component with administrative role, which assures the management of lighting devices; C5 acts as a monitoring platform with ticketing capabilities being responsible for client identification, device identification, health status for servers and database; C6 is a billing platform in charge with traffic evaluation and monetization functions. The set of deployment and operational requirements denoted at application component and graph link level lead to the creation of the slice intent for the smart lighting application following the relevant metamodel defined within MATILDA [3] project.

For each of the components of the application graph, a set of deployment requirements are declared per component (e.g. minimum CPU, RAM and storage requirements) along with constraints related to the hosting node of each component (e.g. constraint that two components cannot be deployed in the same PoP). Additionally requirements regarding the virtual links interconnecting two components, or for an access link to bind an existing component with a UE are provided (e.g. maximum acceptable end-to-end delay, maximum acceptable packet loss rate). Actually, a specific QoS class identifier (QCI) is assigned to each of the links, following 3GPP specifications.

Finally, the need for activation of network services in specific virtual links is also denoted (e.g. need for a layer-3 firewall in a specific virtual link). An example of the requirements used for the creation of the slice intent for the Smart City use case graph is depicted in Figure 5. Based on the set of provided requirements, the overall declared information is mapped to the slice intent MATILDA metamodel, leading to the preparation of the relevant slice intent descriptor. This descriptor is then sent to the One-Stop API made available by SliceNet for serving the request and providing a response with an application-aware slice instance.

Element	Level 1	Level 2	Level 3	Level 4	Example
Constraints	ComponentHosting Constraints	ResourceConstraint LocationConstraint	Latency		18 vCPU 32 GB RAM 150 GB Storage Edge&Core
	GraphLinkConstraints	GraphLinkQoS Constraint	Jitter PacketLoss		100ms < 1%
			Throughput		150 Mbps
	AccessConstraints	AccessConstraint	AccessQualityProfile	QCI gesourceType	70 eMTC
				Priority	5
				PacketDelayBudget PacketErrorLossRate	500 ms < 1%
				UE Type	LTE-M
LogicalFunctions	Firewalling VPN	FirewallConfiguration VPN Configuration			Allow/Deny VPN policy
	vEPC				vHSS, vMME, vS/PGW

Fig. 5. Slice intent requirements

Once the slice intent through the SliceNet One-Stop API is received and processed by the management plane, an end-to-end slice instance is created. The end-to-end slice instance comprises a sub-slice in the RAN, a sub-slice in the core network, and if needed an inter-domain sub-slice as well to extend to another domain. For the RAN slicing and core network slicing, SliceNet leverages Mosaic-5G on top of OpenAirInterface to create logical networks and each logical network is a slice/sub-slice. Specifically, FlexRAN [25] is explored for RAN slicing whilst LL-MEC [26] is explored for core network slicing. For the RAN-to-core-network segment, SliceNet control plane applies data plane programmability through controlling Open vSwitch (OVS) to enforce the traffic rules for QoS support according to the SLA per slice. SliceNet has extended the standard OVS to support both GTP and multi-tenancy for LTE-based 4G/5G network traffic per slice. The end-to-end VNF chaining follows the VNF-FG and is established by the FGE (Forwarding Graph Enabler) component in SliceNet. After these procedures, an end-to-end network slice instance is instantiated.

Given the existence of the slice instance, the MATILDA vertical application orchestrator is then responsible to realise the deployment and real-time orchestration of the Smart City application. A set of intelligent orchestration mechanisms are available for this purpose, including mechanisms for runtime policies enforcements, leading to the support of a self of reactive and self-management characteristics in the applications provision process.
The entire solution will be tested on a dedicated test bed composed by four main parts as depicted in Figure 6.

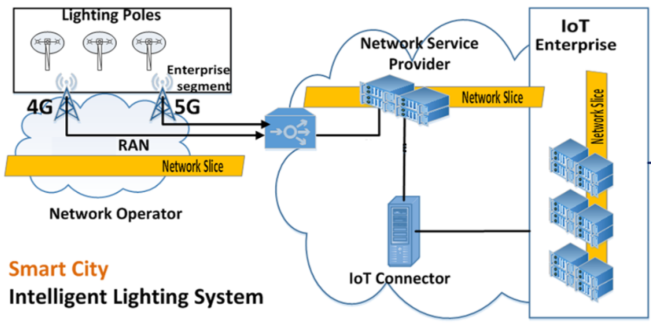

Fig. 6. ORO test bed infrastructure

RAN and Core network part composed by lighting poles/lamps/smart sensors and an OpenAirInterface (OAI) an open-source software-based implementation solution providing real-time RF (LTE-A/5G) and scalable emulation platforms capabilities covering the E-UTRAN part (eNB) and core part EPC (MME, S+P-GW, HSS)

IoT Aggregator platform consisting of a Cisco F5 Load-Balancer BigIP and an IoT connector platform that integrates a two-way communication between IoT Enterprise platform apps and the devices sensors by distributing the messages of different services and exposes multiple IoT protocols

IoT Middleware Enterprise part composed by several servers with the role of demonstrator components hosting acting as:

- controlling node server - containing VNFO (Heat), VNFM (Murano-Ceilometer) and Tacker module (Tacker) with addressing role to the orchestration module
- orchestration and management node server OpenStack Management node containing VIM (Nova- Neutron - Keystone - Glance) and OSS/BSS (Horizon)
- computing server-computing node using KVM virtualization capacity to instantiate several virtual machines for all Smart City application components
- computing server-hosting the vEPC (vMME, vHSS, vS/PGW)

Resource and Service Orchestration orchestrated by Heat project interacting with OpenStack Telemetry services to provide resources auto scaling.

V. Conclusions

This paper presents a common 5G architecture built on the collaboration of two 5GPP projects - MATILDA [3] and SliceNet [4] which enables the design, development and orchestration of Smart City 5G-ready application.

The MATILDA project integrates a set of tools, mechanisms and architectural components to enable state of the art micro service based applications independently orchestrated over a programmable infrastructure. In order to achieve this, an innovative mechanism is designed where application graph components metadata have to provide indications regarding their requirements over programmable infrastructure for both deployment and in life management phases. The Vertical Application Orchestrator is handling the slice intent which is sent towards the One Stop API developed within SliceNet.

The creation and dynamic management of the network slice is then handled by SliceNet [4] mechanisms. SliceNet [4] defines the programmable infrastructure architecture covering an extended set of service functionalities such as FCAPS.

To go beyond the level of a theoretical concept and to better highlight the benefits, the whole theoretical framework presented in this paper will be fully tested and validated using an Orange test bed environment as part of Matilda [3] and SliceNet [4] 5GPP projects.

Acknowledgment

This work has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 761898 project Matilda and grant agreement No. 761913 project SliceNet.

References

[1] 5G innovations for new business opportunities (5G PPP) [Online] Available: https://5g-ppp.eu/wp-content/uploads/2017/03/

[2] SDN and NFV Evolution Towards 5G [Online] Available: https://sdn.ieee.org/newsletter/september-2017/sdn-and-nfv-evolution-towards-5g

[3] 5G Infrastructure Public Private Partnership (5G PPP) - Matilda [Online] Available: https://5g-ppp.eu/matilda/

[4] 5G Infrastructure Public Private Partnership (5G PPP) - SliceNet [Online] Available: https://5g-ppp.eu/slicenet/

[5] Bogdan Rusti; Horia Stefanescu; Jean Ghenta; Cristian Patachia. Smart City as a 5G Ready Application. 2018 International Conference on Communications (COMM). 14-16 June 2018. DOI: 10.1109/ICComm.2018.8484752/

[6] D1.1 - MATILDA Framework and Reference Architecture, 2018, [online]. Available: http://www.matilda-5g.eu/index.php/outcomes

[7] A. Kaloxylos, "A Survey and an Analysis of Network Slicing in 5G Networks", IEEE Communications Standards Magazine, vol. 2, no. 1, pp. 60-65, 2018

[8] “5G empowering vertical industries”, white paper from 5G-PPP, ERTICO, EFFRA, EUTC, NEM, CONTINUA and Networld2020 ETP, Feb. 2016. [Online] Available at https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

[9] K. Katsalis, N. Nikaein, E. Schiller, A. Ksentini and T. Braun “Network Slices Towards 5G Communications: Slicing the LTE Network”, IEEE Communications Magazine, vol. 55, No. 8, pp. 146-154, Aug. 2017

[10] P. Caballero, A. Banchs, G. de Veciana and X. Costa-Pérez, "Multi-Tenant Radio Access Network Slicing: Statistical Multiplexing of Spatial Loads," IEEE/ACM Transactions on Networking, vol. 25, no. 5, pp. 3044-3058, Oct. 2017

[11] G. Zheng, A. Tsiopoulos and V. Friderikos, "Optimal VNF Chains Management for Proactive Caching," IEEE Transactions on Wireless Communications, vol. 17, no. 10, pp. 6735-6748, Oct. 2018

[12] R. Gouareb, V. Friderikos and A. Aghvami, "Virtual Network Functions Routing and Placement for Edge Cloud Latency Minimization," IEEE Journal on Selected Areas in Communications, vol. 36, no. 10, pp. 2346-2357, Oct. 2018

[13] SelfNet EU 5G-PPP SELFNET Project, “SELFNET: Framework for Self-Organised Network Management in Virtualized and Software Defined Networks” (H2020-ICT-2014-2/671672), 2014, [Online] Available: https://selfnet-5g.eu/

[14] A.B. Asrar, N.A. Malek, A.A. Sharaf, “Fog Computing for Network Slicing in 5G Networks: An Overview”, Journal of Telecommunication Systems and Management, 2018, 7: 172. DOI: 10.4172/2167-0919.1000172

[15] D. Marabissi, L. Mucchi, R. Fantacci, M.R. Spada, F. Massimiani, a. Fratini, G. Cau, J. Yunpeng, L. Fedele, “A Real Case of Implementation of the Future 5G City”, Future Internet, 2019, 11, 4

[16] PLEEC-Project, 2014, [Online] Available: http://www.pleecproject.eu/

[17] A. Cocchia, “Smart and digital city: a systematic literature review”. In: R.P. Dameri, C. Rosenthal-Sabroux (eds.), Smart City – How to Create Public and Economic Value with High Technology in Urban Space, Springer Heidelberg, 2014, pp. 13–44, [Online] Available: https://link.springer.com/chapter/10.1007/978-3-319-06160-3_2

[18] D. Gil, A. Ferrández, H. Mora-Mora, J. Peral, "Internet of Things: A review of surveys based on context aware intelligent services", Sensors, vol. 16, no. 7, pp. 1069, 2016

[19] Q. Wu et al., "Cognitive Internet of Things: A new paradigm beyond connection", IEEE Internet Things J., vol. 1, no. 2, pp. 129-143, Apr. 2014

[20] C.-Y. Chang, N. Nikaein, O. Arouk, K. Katsalis, A. Ksentini,T. Turletti, and K. Samdanis, “Slice orchestration for multiservice disaggregated ultra dense rans,” vol. 56, no. 8. IEEE Communications Magazine, Aug 2018

[21] Open Source MANO [Online] Available: https://osm.etsi.org/

[22] SliceNet, Deliverable 2.3 - Control Plane System Definition, APIs and Interfaces [Online] Available: https://slicenet.eu/deliverables/

[23] OpenAirInterface, Jul.2018, [Online] Available: http://www.openairinterface.org

[24] Mosaic-5G.io, Jul. 2018, [Online] Available: http://mosaic-5g.io/

[25] Mosaic-5G FlexRAN, Nov.2018, [Online] Available: http://mosaic-5g.io/apidocs/flexran/

[26] Mosaic-5G LL-MEC, Nov.2018, [Online] Available: http://mosaic-5g.io/apidocs/llmec/