Smart City as a 5G Ready Application

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***Abstract* - 5G is developed around its capability to integrate and support different industry verticals (health, manufacturing, media, automotive, IoT, smart cities) requirements, thus becoming a key enabler for new business opportunities and digital transformation. In the current paper we present an unique theoretical concept for the development, deployment and in-life management of a network aware Smart City 5G cloud native application using a three layer architecture. The existence of a marketplace is a key innovation of the architecture proposed and facilitates the development and management of the applications that will be instantiated over the programmable 5G infrastructure using the Service Mesh concept. The evolved Service Mesh is deployed in the form of a network slice, closely aware of the available network resources and tightly coupling the Orchestration Layer to the OSS/BSS from the Network function layer. By deploying this unified programmability model augmented by the creation of an open development environment for the application and virtual network functions developers, Matilda EU project facilitates the 5G adoption.**

Keywords—5G, Smart City, Network Slice, IoT, LTE-M, Sensor, 5G-ready application, Verticals, NFV, VNF, BSS/OSS, VIM, NFVO, UE

I. Introduction

The key difference added by 5G compared with 4G technologies is the adoption and in-depth integration of network of verticals, thus enabling the development of new digital business models. MATILDA is a 5GPP phase 2 project [15] enabling a holistic 5G end-to-end services operational framework tackling the overall lifecycle of design, development and orchestration of 5G-ready applications and 5G network services over programmable infrastructure, following a unified programmability model and a set of control abstractions. MATILDA is a joint initiative between the European Commission and European ICT industry (ICT manufacturers, telecommunications operators, service providers, SMEs and researcher Institutions).

MATILDA proposes a three layer architecture comprising of: (1) application layer/marketplace where the 5G enabled application are built; (2) Orchestration Layer where the Service mesh for the cloud native applications is enabled; (3) Network function and Resource management Layer which facilitates the operational demands of service meshes to be handled and retrieves feedback from the infrastructure. The Marketplace adds the business oriented vision of MATILDA as it represents both a development environment for application developers but also provides a dashboard for the Service Providers that will enable them to chain different application components in form of a graph in order to easily deploy and manage certain tailored vertical use cases that today reside in very specific, time consuming and not very cost efficient implementations. The instantiation of an application graph will further execute at the Orchestration Layer for the creation of the Service Mesh that will enable the component to component communication. Basically, today the Service Mesh concept exists [1] and it is typically implemented for any cloud native application as an array of lightweight component intelligent-proxies which are deployed alongside the component, without the latter needing to be aware. In MATILDA the Service Mesh is evolved as it becomes aware of the available network resources since the Orchestration Layer is tightly coupled to the OSS/BSS from Network function and Resource management Layer. This concept in which an application becomes aware of the network resources and vice versa is key for 5G. This imposes a complete new approach for the network operator and a shift of paradigm: (1) the operator has to migrate towards a virtualized and programmable infrastructure, (2) the operators has to expose APIs to third parties and advertise its resources, (3) the operator becomes aware of the applications running through its network using network slices. A network slice is a logical infrastructure partitioning with appropriate isolation, allocated resources and optimized topology to serve a particular purpose of an application graph. The high level architecture is further presented in section II.

Section III presents a future Smart City solution that can be deployed and managed using the MATILDA framework. [6] The business perspective is also added in this section describing the process together with the advantages of different stakeholders (Service Provider, Telecom Operator, Service Consumer) for deploying such a solution.

Section IV concludes the paper, summarizing the key technological aspects of deploying the future Smart City solution using the MATILDA framework [6], the main benefits and the key next steps for the actual deployment.

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II. MATILDA HIGH LEVEL ARHITECTURE

The MATILDA project applied a top-down approach in order to design the reference architecture which is composed by an integrated set of tools, mechanisms and architectural components to enable cloud applications to rely on and to benefit from the performance/operational advantages of 5G infrastructures and services.

The basis for this reference architecture stands on different functional and non-functional requirements elicited by the several key use cases that span across various verticals (media & entertainment, emergency infrastructure, manufacturing, smart cities and automotive industries). On top of this there were also defined general requirements which are key for the successful implementation of any of the use cases, we refer here to: modularity, extensibility/upgradability, maintainability, openness and user friendliness.

The MATILDA reference architecture is depicted in Figure 1 and it comprises three distinct layers:

1. Development Environment and Marketplace
2. 5G-ready Application Orchestrator
3. Programmable 5G Infrastructure Slicing and Management

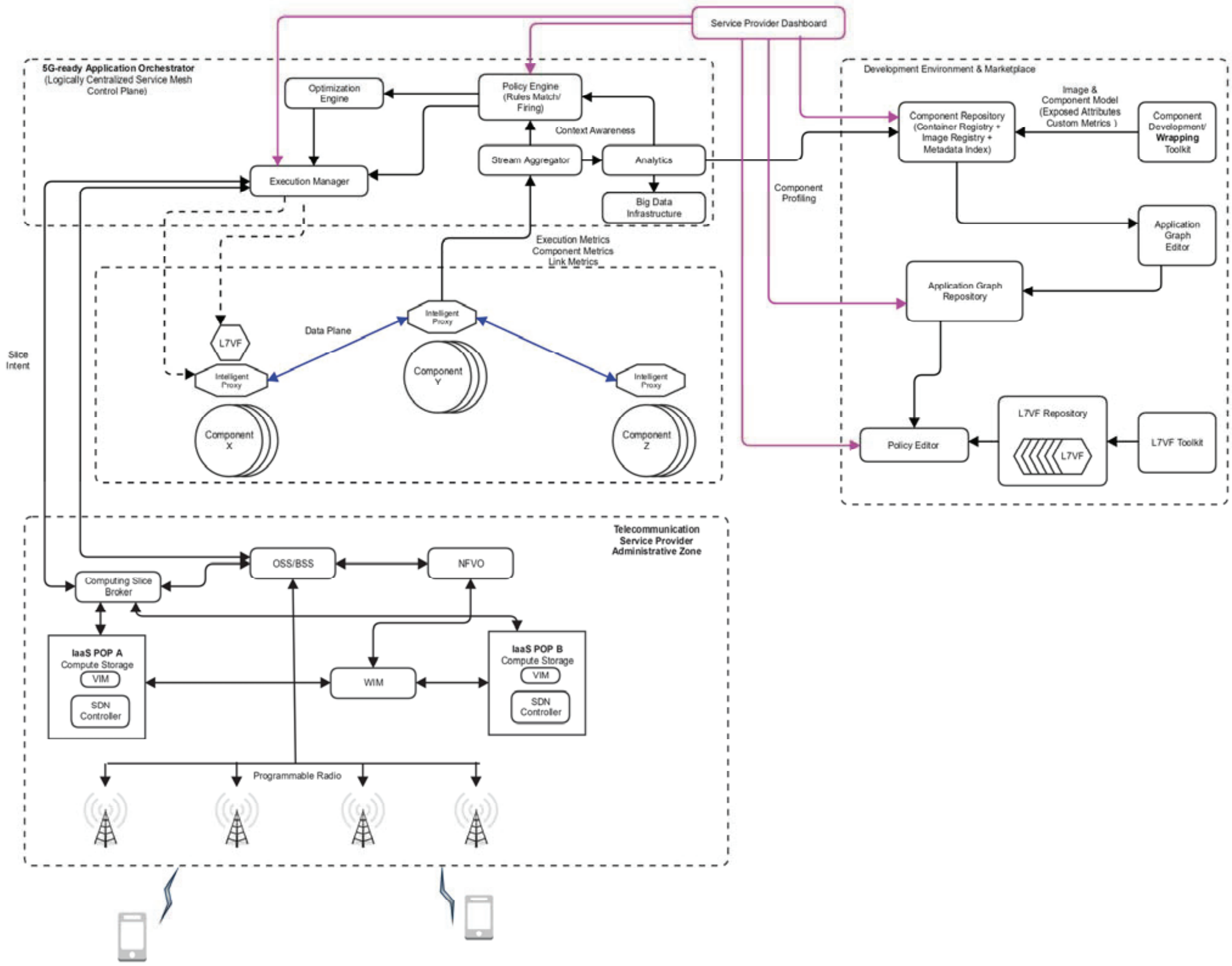

Figure 1 Matilda reference architecture [2]

The Development Environment and Marketplace has several modules designed with the scope to support all pre-deployment steps of a 5G-enabled application, through proper packaging and combination of cloud-native components. The main modules of this layer include the Component Wrapping Toolkit, an Application Graph Editor, a Component Repository, an Application Graph Repository and a Policy Editor. The Component Development/Wrapping Toolkit aims to assist the software developer wrap cloud native components in a proper format so as to be publishable in the Component Repository and reusable in the frame of complex Application graphs. While the component wrapping toolkit is a developer-centric environment, the aim of the Application Graph Editor is to help a service provider create application graphs that combine the chainable components that are released by the component wrapping toolkit. The module allows application graph creation and validation and graph serialization. The Component Repository acts as a persistency layer for the (wrapped) cloud-native components and allows for scalable storage and searchability. The Application Graph Repository is in charge of storing and searching composed application graphs. The last module of this layer, the Policy Editor allows for every application graph to be subjected to runtime changes/reconfiguration, aiming to satisfy a set of business goals that are bundled in the form of a Service Level Agreement (SLA). The 5G-ready Application Orchestrator layer modules rely on the concept of an abstracted network layer, materialized by a service mesh. The interaction between the service mesh proxies constitutes the data plane, while the configuration actions of the proxy are based on information gathering that is performed by the proxies per se. The information gathering, along with the actions' enforcement, is addressed as the service mesh control plane. The proxy will be responsible to undertake several tasks, such as dynamic service discovery, load balancing, transport layer security (TLS) termination, circuit breaking, health checking, traffic shaping. The Execution Manager module interacts with the intelligent proxies, in order to properly configure them, with the Policy Engine, which will infer appropriate actions that are required in order for selected policies to be enforced, and with the programmability layer of the telecommunications provider. The Stream Aggregator collects information regarding availability and usage of physical resources over the programmable infrastructure, information regarding resource usage per deployed component and information regarding custom metrics of the deployed application graphs and/or components. The purpose of Analytics module is to process the aggregated data in order to infer several operational aspects of the running application graph: e.g. performance degradation, load prediction, resource usage prediction, component profiling, etc. The Policy Engine module is responsible for the enforcement over the deployed 5G-enabled applications following a continuous match-resolve-act approach. The Optimization Engine module produces results in terms of optimized deployment plans to support pro-active adjustment of the running configuration, as well as re-active re-configurations of deployments, based on measurements that derive from Monitoring and Analysis Engine. In the end, the Optimization Framework produces deployment plans to satisfy zero-service disruption and optimal configuration across time.

The Programmable 5G Infrastructure Slicing and Management which aim is, on one hand, to facilitate the operational requirements of the service mesh and, on the other hand, to provide feedback from the infrastructure, which will be taken under consideration by the policy engine. The main control and management blocks, are: the Vertical Application Orchestrator, managing the lifecycle of the graph of microservices composing the application, and acquiring network and computing resources as-a-Service from the underlying blocks; the Business and Operational Support Systems, providing resources of the telecom service providers as-a-Service to vertical industries; the NFV Orchestrator (NFVO), managing the network services composing the network slices activated by the BSS/OSS; the Mobile Edge Orchestrator (MEO) managing the embedding of mobile edge applications, and the management of their lifecycle, triggered by the BSS/OSS; the Virtualization Infrastructure Manager (VIM), exposing the computing and storage resources of point of presence datacenters mainly to the NFVO and to the MEO/VAO; the Wide-area Infrastructure Manager (WIM), realizing the logical interconnectivity among sets of service/application components instantiated in different point of presence's (PoPs) and/or towards 5G UE.

III. SMART CITY MATILDA APPLICATION

Smart City solution is composed by several 5G ready application components exposed in the graph that will be orchestrated independently during network deployment process. The application components will be linked with other components through dedicated interfaces in the form of an application graph. The application graph together with the corresponding networking requirements that should be satisfied during network instantiation, are coupled together to deliver a 5G-ready application [2]. The application should be modular and agnostic to different network infrastructure, needs to be fully correlated with all demands raised by stakeholders involved in the process regarding usability and market needs relevance. Several stakeholders are involved in the process development, orchestration, instantiation of the Smart City application over the programmable infrastructure. (1) The Service Consumer as part of vertical industry ecosystem is the first and the last actor in the overall process chain having the first role as consultant, providing the market specific requirements in the conducted survey during the deployment phase and the final stage role as consumer of the application offered by the Service Provider (2) Service Provider is responsible with the creation of the application graph in line with the requirements provided by the Service Consumer and also is responsible with instantiation of the 5G-ready application created over the sliced programmable infrastructure in order to be delivered to the end-user; (3) The Application Developer is responsible with the development of two functionalities parts according to Matilda proposal:

- the Marketplace (application store) where the Smart City applications will be stored to be downloaded by the Service Provider;
- the Smart City application component with all associated characteristic need for an operational application graph composition;

The application component design should be aware of the end to end application functionality requirements, the chaining and interoperability characteristics and the dependencies needed to form the logical application graph. (4) Infrastructure Providers assure the infrastructure resources, network, storage, compute during Smart City application graph instantiation. This role can be associated to several actors depending on the nature of requested resources: (a) Telecom Infrastructure Providers - assure a programmable (5G) network infrastructure , radio/fixed access, transport and core network;
(b) Cloud Infrastructure Providers - operating cloud/edge, offering compute and storage programmable resources.

In Matilda project the stakeholders can have multiple roles, a single role can be shared by more than one stakeholder depending on the nature of the 5G application/service requirements.

In the following paragraphs we will present the top-down approach of Smart City solution deployment through MATILDA proposed framework. Smart City application use case scenario is divided in three parts (Fig 2):

- lighting controllers
- middleware platform
- management interface with administration, alerting and ticketing functions

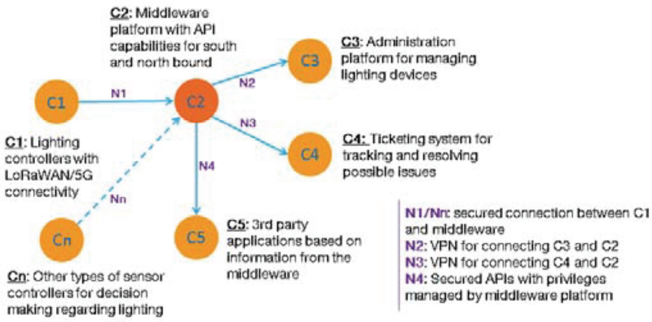

Fig. 2 Smart City application graph components

The lighting controllers are installed on lighting poles assuring the capability of remote control. The middleware platform collects, stores and secures the data from the controllers in order to be used later through open APIs by any other application. The management interface is divided in two parts: (1) administration of the lamps' schedules and (2) the alert and ticketing system. The administration part gives administrators the potential to remote control and to access lamp's data but also to set a schedule on groups of lamps (turn on after sunset, dim to 70% after 1AM, turn off after sunrise). The alert and ticketing system provides administrators a way to rapidly inform the maintenance team. Another role of the alert and ticketing function is to keep track of every service required by all of the poles. In the context of the 5G ready Matilda application, the lighting controllers will be converted to be able to access the 5G network, in order to fully take advantage of roaming functions but also to increase the lifetime of the device's battery and coverage in restricted areas. The middleware platform accesses not only the lighting controllers, but also other types of sensor controllers in order to drive complex decisions regarding lighting.

The subsequent flow will be followed during Smart City end to end operational deployment over Matilda architecture. The application components are stored in the Marketplace repository along with the application graphs being called by the Service Provider and delivered to the Application Orchestrator during Smart City slice vertical instantiation.

The application components should have a cloud-native design in order to be hosted on the cloud infrastructure, therefore all its adaptive configuration parameters values, quantitative metrics regarding the QoS level and chainable required interfaces [2] should be accessible to the other cloud-native components in order to create a functional service application graph. A separation approach will be used between the business logic part of a component and the network layer specific functionalities. The communication between them is realized through a dedicated proxy sidecar attached to each component. Smart City Matilda 5G-ready application will be developed as a Service Mesh to exploit the 5G cutting edge technologies. "A service mesh is a dedicated infrastructure layer for handling service-to-service communication. It's responsible for the reliable delivery of requests through the complex topology of services that comprise a modern, cloud native application. In practice, the service mesh is typically implemented as an array of lightweight network proxies that are deployed alongside application code, without the application needing to be aware." [3]

Each component in the Service Mesh will be described by a set of complex type elements. These elements are: Distribution (exposes the information regarding the final image/container and components location), Exposed Interface (contains the interface typology and interface identifier needed to assure the connection between components), Configuration (set of component variables used during instantiation), Volume (capability of the Hypervisors [4] to provide storage to a virtual machines via volumes), Minimum Execution Requirements (to be met by the hosting environment for the proper execution – VCPU, RAM, Storage), Exposed Metric (the metrics that will be reported by the proxy sidecar), Required Interface(contains the information regarding the graph link) and Capability(encapsulates runtime capabilities of the components). The components are logically interconnected through a graph link forming in this way the application graph. Each component has at least one graph link according with the design of the application. The graph link is a logical link deployed with the associated network and compute constraints.

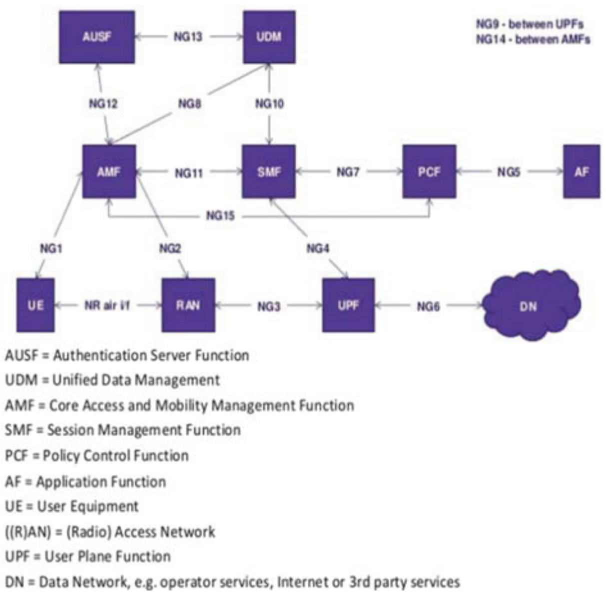

Fig. 3. 5G Network Architecture [5]

With the rising of 5G/NFV technologies the service orchestration landscape has become even more complex and fragmented . Smart City application instantiation will be managed by the Application Orchestrator responsible with instantiation and orchestration of the application over the network slice. 5G infrastructure will be composed by modular components design using dedicated virtual network functions (NFs) . In the Smart Lighting System use case, the connection between C1 (Lightning controllers) and C2 (Middleware platform) may be deployed using network functions (NFs) as presented in the Fig. 3.

The instantiation process takes into account the requirements imposed by the application and also the defined policies managed by a context awareness engine (orchestrator block) using knowledge based on a set of data monitoring, analytics and profiling production streams. 5G framework is going to be the first generation of mobile network architectures which simultaneously exploits and provides intrinsic virtualization capabilities through the "network slicing"[6] concept (defined as a set of network functions and associated resources configured under a logical network, with the purpose to respond to certain network characteristics [7]). The network slicing concept includes networks and devices to be suitable to diverse business models. A network slice instance (NSI) includes all functionalities and resources necessary to support a certain set of communication services and thus serving a certain business purpose. NSI contains network functions like those belonging to Access Network and Core Network [7] and each slice of a network instance represents an independent end-to-end network [3].

The multi-site management of the allocated resources per network slice, along with a multi-site network function virtualization orchestrator (NFVO) supporting the lifecycle management of the network functions embedded in the deployed application's graph as well as supporting a set of network monitoring and management mechanisms is performed by a multi-site wide infrastructure manager supporting (WIM) [6]. The entire management of the lifecycle of network functions over the network slices is performed through a set of a set of interfaces towards OSS/BSS systems of Telecom Infrastructure Providers, based on requests provided by the application orchestrator.

IV. CONCLUSIONS

Smart City 5G ready application main challenge is to provide the creation of the on-demand required networking and computational infrastructure in the form of an application-aware network slice and the activation of the appropriate networking mechanisms for the support of the industry vertical requirements. Developing an intelligent orchestration platform able to support end-to-end Smart City 5G-ready application and services provision over programmable infrastructure implies several aspects mandatory to be addressed:

- design of Smart City 5G-ready applications to provide a real advantage for business to fully exploit the new 5G network capabilities
- develop a programming and verification platform for designing, developing and verifying the Smart City application components (NFV building blocks, VNFs) with open-source or commercial exploitation capabilities
- build an unified and intelligent orchestration mechanisms for managing the entire lifecycle of 5G-ready applications and network services
- build support mechanisms for compute and storage resource management needed for deployment and management of distributed applications components and network functions

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 deployed on Alba Iulia and Bucharest city locations deployed as part of MATILDA EU project.

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