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5G energy efficiency for Internet of Things: a survey

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Abstract— The Internet of Things (IoT) consists of devices capable of measuring the environment and executing tasks without human intervention. Due to its size, these devices have restrictions in processing, memory, and battery. These devices can reach a trillion nodes and, therefore, requires network connections that are capable of both handle a large number of nodes connected and low energy transmission. The fifth generation of telecommunications technology (5G) is a key concept to address those requirements as new applications and business models require new criteria such as security trustworthy, ultra-low latency, ultra-reliability, and energy efficiency. Although the next generation of connections is at its early stage, progress has been made to achieve 5G enabled IoT technologies. This paper describes a review of the main technologies such as Cloud, Software Defined Network, device-to-device communication, Evolved Package Core and Network Virtual Function Orchestration that are planned to be applied for both fields of 5G and IoT.

Keywords—Internet of Things, 5G technology, Survey

I. Introduction

IoT is one of the most researched subjects in the past five years due to its capability of connecting a vast number of affordable devices, and the numbers will overdue the number of humans by many folds until 2030 [1]. In this context, the connection technologies present a large number of limitations, such as packet size, interference mitigation, reliability, packet delay, and battery power consumption.

Repetitive transmission through radio network is one of the leading causes of energy drain [2], and many of the proposed applications are solely reliant on battery power such as; (i) utility metering, (ii) precision agriculture (iii) environmental sensors, and (iv) asset tracking (bikes, fleets, and goods). Therefore, new connection technology is needed to mitigate the power consumption problem and extend the life of IoT devices and improve their usability on the network [3]. Different approaches are taken in the search for a technology that can solve the connectivity problem of IoT devices. Some techniques were developed to allow restricted devices to be able to operate on legacy networks (3G and LTE) with emphasis on the Narrowband-IoT (NBIoT) proposal for 3GPP Release 14 [4, 5]. There are also other technologies developed focusing on this segment, such as Sigfox [6], IEEE 802.15.4g [7], and LoRaWAN [8], these use receivers with high sensitivity allowing transmitters to use the same energy in sending packets.

Technologists, however, address the device's power consumption during the *non-transmitting* phase of operation (idle or sleep mode) and do not propose methods to reduce the device's power consumption when it is transmitted. The 5th generation of connection technologies, under development by 3GPP releases 14, 15 and 16, bring a new implementation of the physical layer to: (1) support a large number of connected devices and (2) use relays and Device-to-Device (D2D) communication in order to increase network coverage and reduce energy costs in transmitting IoT devices [9, 10].

This paper is organized as follows. Section II presents a theoretical framework with the leading technologies related to 5G networks focusing on IoT operation. Section III works that address the problem of 5G networks as a solution for IoT scenarios. Section IV provides concluding remarks and future work. Finally, we present the acknowledgments and contributions to this work in Section VI.

II. Background

This section put together theoretical foundations for the understanding of the problem of energy efficiency in 5G networks for Internet-of-Things. Figure 1, on its left side, demonstrates the two macro advances in computing that enabled IoT systems: Moore's Law, which allowed for area reduction, energy consumption, and higher performance, while

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keeping costs lower, and Shannon's law, which allowed for faster and cheaper wireless network connectivity. Despite these advances, there are still problems to be addressed in order to enable large-scale IoT deployment.

The center of Figure 1 summarizes two of the primary needs of IoT systems: security and energy efficiency. The first aspect concerns overcoming security issues such as eavesdropping and denial of service [11]. The second addresses the need for the low energy consumption of these systems due to the lack of power in many cases.

a. Evolved Packet Core

The Evolved Packet Core (EPC) is the latest evolution of the 3GPP core network architecture. EPC is the basic set of a telecommunication network, e.g., network outbound gateways, authentication, among others [13].

In GSM, the architecture relies on circuit-switching (CS). This means that circuits are established between the calling and called parties throughout the telecommunication network. In GSM, all services are transported over circuit-switches telephony principally, but short messages (SMS) and some data are also seen [13].

When designing the evolution of the 3G system, the 3GPP community decided to use IP (Internet Protocol) as the key protocol to transport all services. It was therefore agreed that the EPC would not have a circuit-switched domain anymore and that the EPC should be an evolution of the packet-switched architecture used in GPRS/UMTS.

This decision had consequences on the architecture itself but also on the way that the services were provided. IP-based solutions, in the long term, will replace the traditional use of circuits to carry voice and short messages.

b. Device-to-Device

Device-to-Device Communication (D2D) is a proposed concept for 5G networks that has a direct impact on the deployment of IoT systems. Devices can communicate directly without going through a more extensive network infrastructure. This breakdown of communication decreases base station traffic, which increases network performance and reduces power consumption [14].

c. Cloud

Cloud Computing plays a crucial role in 5G due to the move from dedicated hardware to software-based network elements [15]. Cloud Computing is, therefore, a vital technology that supports the 5G infrastructure and functionalities, and that can ultimately define the success of 5G deployments.

Cloud Computing solutions range from public offerings such as Amazon Web Services (AWS), Google Compute Engine, Microsoft Azure, to name a few, to private clouds instantiated in-house through software packages provided by leading software developers such as VMWare, Mirantis, Ericsson.

Supporting these offerings are many times Open Source software solutions that can be customized by companies such as OpenStack, OpenNebula, and Eucalyptus or built upon such as Docker, Kubernetes, XenServer.

The previous solutions provide either an ecosystem of resources (Processing, Storage, Network, IAM, and others.) or a single resource (Processing in the case of Docker, Kubernetes, and XenServer). To deploy a service on top of these resources, it is necessary to orchestrate those resources. In some cases, it is even necessary to connect resources belonging to different service providers or software providers. Virtual Infrastructure Management (VIM) is, therefore, a requirement for a successful and scalable Cloud resource usage.

1. VIM Solutions

VIM (Virtual Infrastructure Management) Solutions enable the network operator to make use of Cloud Resources (Processing, Storage, and Network) to build or instantiate their network elements. The VIM solution has a strong impact on the overall 5G architecture as it will enable or limit many of the foreseen 5G functionalities.

2. OpenVIM

OpenVIM is the VIM solution of Open Source MANO (OSM), an open-source project that implements ETSI NFV architecture. OpenVIM enables all-in-one installation and is fully integrated with the other OSM components such as VNF Configuration and Abstraction and the Resource Orchestrator. OpenVIM is, therefore, the reference VIM in OSM and provides Enhanced Platform Awareness (EPA).

OpenVIM is released with Apache 2.0 license, similarly to OpenStack. OSM (which OpenVIM is part of) governance is helped by ETSI and has the support of the European Telecommunication Industry.

The project is currently in its first release (Release ONE), although it had existed before being contributed to ETSI. This means that there are various previous versions, but that the project is mostly very recent.

OpenVIM is mostly a shoehorn VIM solution to demonstrate MANO concepts. Even in the scope of OSM, OpenVIM is just one of the possible VIM solutions, being OpenStack the other most prominent VIM. Nevertheless, OpenVIM integrates perfectly with the remaining OSM components and makes it the obvious solution when all-in-one MANO solutions are desired (such as for development purposes).

Feature-wise, OpenVIM provides just about the minimum requirements of a VIM in the scope of OSM. Choosing OpenVIM as a VIM solution should be tightly coupled with choosing OSM as the overall MANO solution, and even then, one should consider the limitations of the all-in-one approach of OpenVIM.

Since in 5GInFire, at least one partner is involved in OSM, OpenVIM can be fully supported and made an adequate candidate for the VIM solution.

We enumerate the main features of OpenVIM:

1. Fully compatible with Open Source MANO (OSM);

2. Open Source License;

3. Easy to use.

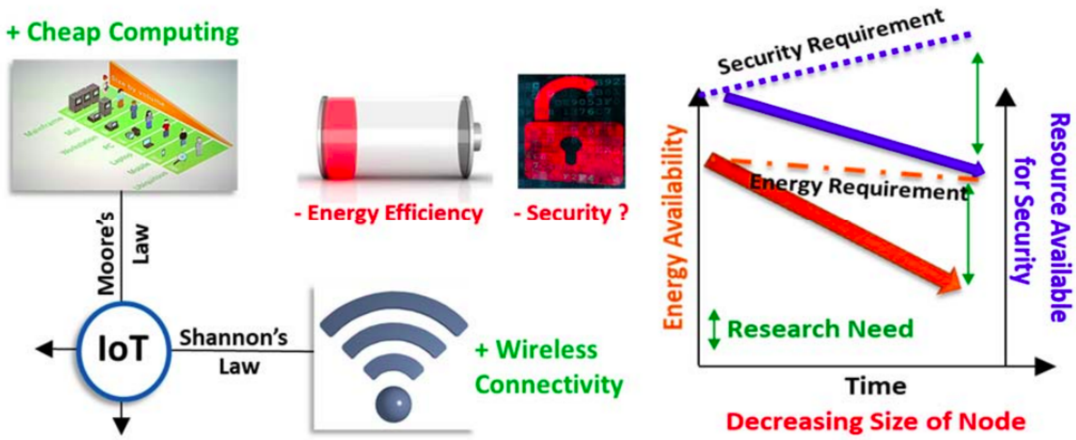

Fig. 1: Requirements for large-scale IoT system deployment. Sen et al. [12].

3. OpenStack

OpenStack is the most prominent Open Source project on Cloud Computing. OpenStack consists of an ecosystem of several smaller projects that manages compute, storage, networking, and various support functions such as Identity, Orchestration, and Monitoring.

OpenStack adopts Apache 2.0 license, which allows for the use of the software for any purpose, to distribute it, to modify it, and to distribute modified versions of the software, under the terms of the license, without concern for royalties. This licensing enables commercial companies to profit from OpenStack results and to include OpenStack on its products and services.

OpenStack is a very mature project with a governance model laid out on top of the OpenStack Foundation. This governance model is very important as there are more than 60k contributors, many of which financed by various IT companies worldwide. With many such contributors, the vitality of the project is undeniable.

OpenStack is currently on its 14th release, and seven years have gone by since the initial release codenamed "Austin" in 2010. In these years, OpenStack has kept regular biannual release cycles which receive support from the community for periods ranging one year. The project claims to be carrier-grade, with many carriers advertising the use of OpenStack in their portfolios, nonetheless several the burden of running OpenStack is very high and requires dedicated and highly trained technicians. Documentation is extensive but spread around various locations and versions, which in turn may difficult the adoption.

OpenStack has come to dominate the Private Cloud much the same way as AWS dominates the Public Cloud. In an area where defacto standards dominate the market, it is widely accepted that OpenStack API is the most supported API in the industry. OpenStack is incredibly featured rich, which means that the number of features supported by OpenStack far exceeds the needs of 5GinFire. 5GInFire requires a VIM solution that can be responsible for controlling and managing the NFV infrastructure (NFVI) compute, storage, and network resources, these easily map to OpenStack components Nova, Cinder, and Neutron. In 5GInFire, several partners are involved in OpenStack, which makes it an excellent candidate to be adopted by the project, as these partners have the right expertise to support OpenStack in the scope of the project.

We enumerate the main features of OpenStack:

1. Prominent open-source project with Apache 2.0 license;
2. Mature project with strong community;
3. Well documented;
4. Feature rich.

d. SDN

SDN (Software-defined networking) is a novel architecture that could be briefly described by providing separation of the control plane and forwarding plane and allowing through open APIs to program network dynamically. It proposes a centrally managed architecture via SDN controllers, and the role of this chapter is to strive for providing the SDN controller for the 5GinFIRE project.

1. SDN Controllers

We decided to focus on 4 of the most emerging SDN controllers that are OpenDaylight, ONOS, OpenContrail, and Ryu. We studied them by following the aspects described in section 2.2.

2. OpenDaylight

OpenDaylight is an open-source SDN controller first released in February 2014. The OpenDaylight Foundation is part of the Linux Foundation, a large open-source community pushing several projects in different fields. The architecture of OpenDaylight (Figure 2) reflects the general concepts of SDN. On the north are located the applications that control the network. They use the controller to gather information about the network and push new rules. The central control platform implements a set of pluggable modules to perform all the required actions. On the south are located the different routing elements of the network, either real or virtual. OpenDaylight southbound API implements a set of protocols to communicate with those devices, such as OpenFlow or Netconf.

A vast community backs OpenDaylight. In 2016, 524 developers contributed to the project, for a total of 920 develop-

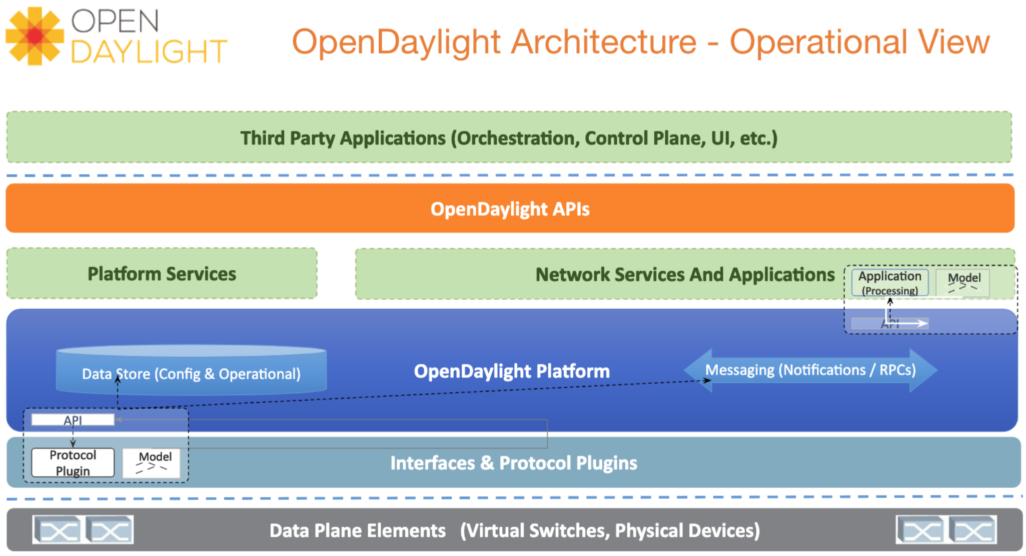

Fig. 2: OpenDaylight: An Operational view [16].

ers since the beginning of OpenDaylight, ranking OpenDaylight project team among the top teams of the open-source world. Moreover, the evolution of the project is keeping the same frequency compared to 2015. There are about 2000 commits per month [2]. The community can gather regularly during the OpenDaylight summits that take place once a year, or for more specific events such as the developer's forum. Besides the developers that participate in the project as volunteers, the companies can join the project as members. Today many companies are part of the project, with different levels of involvement. Among the most involved and most influent members (called platinum members), we can quote Cisco, Intel, or Red Hat [3]. This demonstrates the real interest of the communities of developers and enterprises for the OpenDaylight project. Thanks to this active community, the 5th version of the controller, Carbon, is already under development.

OpenDaylight is not only a demonstration product, as some SDN controllers have been in the past. It includes characteristics of carrier-grade solutions. OpenDaylight controllers can be clustered [4]. Clustering is a key feature since it allows the enforcement of High Availability and the fast scaling of resources, especially in the cloud context. OpenDaylight also uses microservices architecture to deal with complex problems with simple functions. This architecture is an asset for large, complex systems. Indeed, it makes each component lighter, simpler, more accessible to upgrade, and more efficient in its work.

As part of the Linux Foundation, OpenDaylight is a fully open-source, published under the Eclipse public license v1.0 [16]. Thanks to the broad community, which activities have been presented in the previous section, the project has quickly evolved to reach a high level of maturity, with about one new version every eight months. First released in February 2014 with the Hydrogen version, the project is now on its fourth stable version, Boron, released in December 2016. The next version, Carbon, is under development [5]. In addition to this swift-evolution, OpenDaylight has been proven to be stable and mature enough to be used in the industry. Per a 2016 study [6], 61% of the enterprises that have deployed an SDN solution have chosen OpenDaylight, and most companies that consider deploying SDN solutions in the future also want to start with this controller. Among the solutions using (or based on) OpenDaylight, we can find HPE Carrier SDN, Huawei Agile controller, Brocade SDN Controller, Extreme networks oneController, Inocybe Open Networking Platform or Virtuora Network Controller (Fujitsu). This adoption by industry tends to prove that OpenDaylight is a carrier-grade controller, and this is confirmed by the carrier-grade features that are implemented, such as clustering or microservices architecture.

Such popularity is probably due to the vast number of features displayed by OpenDaylight. On its southbound interface, the controller can handle various standardized protocols, including OpenFlow (all versions), Netconf [7], and OVSDB [8]. The northbound APIs are not standardized, as in any other SDN controllers, but they still offer many possibilities. Among all the available features, we can highlight NEMO [17], an intent NBI developed by Huawei that could represent a kind of standardized NBI.

If the available northbound applications or plugins do not fit the needs of the project, OpenDaylight offers rich documentation to help developers to code their features. This documentation is updated with each new release, which represents a high frequency.

Besides its efficiency as a standalone controller, OpenDaylight can also be integrated into a more general architecture such as the NFV architectural framework defined by ETSI [10]. In this framework, the controller is tightly linked with the MANagement Organization (MANO) component and the Virtual Infrastructure Manager (VIM). As part of the Linux Foundation, MANO Open-O is specifically designed to be able to work with a controller, and especially with the two controllers supported by the foundation: OpenDaylight and ONOS [18]. However, other MANO components, such as Open Source MANO (ex OpenMANO), can be used through some manipulations.

OpenDaylight profits from strong popularity lead the SDN controllers' community, and 5GinFIRE's partners naturally work with it on their internal projects and acquire then sig-

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nificant competences. After having gone through all the partners, a good number of them claim to have high expertise with OpenDaylight: B-COM, ITav, UnivBris, UFU, and TID, who is a Contributor of the NetIDE project and a member of the ODL Advisory Board. Summary

As we saw in the previous section, OpenDaylight:

1. Is open-source, with a vast and active community;
2. Is mature;
3. Offers a rich standardized southbound API;
4. Offers a rich northbound API;
5. Possesses a lot of features and applications;
6. Can be integrated into an NFV architectural framework using Open-O or OSM;
7. Benefits of high partners' expertise.

3. ONOS

With its first version released in December 2014, ONOS (Open Network Operating System) is the most recent mainstream, open-source controller. ONOS presents itself as an OS for networks [18], as opposed to the traditional SDN controller seen as experimental devices. As a network, OS ONOS has the same place in the architecture as a traditional SDN controller but is supposed to have much more responsibilities, such as:

1. Manage the limited resources and divide them between users;
2. Isolate different users from each other;
3. Provide abstraction to hide resource complexity;
4. Provide security;
5. Supply useful and basic features, so that developers do not have to code them again and again.

Those OS-oriented features tend to make ONOS more complete and useful than a traditional SDN controller, whose role is much more limited. ONOS supporters consider that traditional SDN controllers are rule-pushers, with not a lot of added values. Besides the attributes listed below, an essential aspect of ONOS, the most important perhaps, is the distributed aspect. ONOS is thought, from architecture to implementation, to be distributed. Distribution allows High Availability (HA) and easy scaling of resources by the addition of new servers. The Figure 3 describes the ONOS subsystem distribution.

As part of the Linux Foundation, ONOS is fully open-source. Although it is a recent project, ONOS is supported by a large community and has already many releases. The first one, Advocate, was delivered in December 2014. The 9th and last one, Ibis, was delivered in December 2016 [18]. ONOS is adopted by many professionals, which demonstrates its maturity. 23% of the enterprises that have deployed an SDN solution have chosen OpenDaylight, and 21% of the companies that consider deploying SDN solutions in the future also want to start with this controller [19]. Those figures show that ONOS is not as popular as OpenDaylight, by far. However, this might change in the future, for two reasons. Firstly, as explained in the previous section ONOS is more recent than OpenDaylight, which gives OpenDaylight an advantage, but at the same time, it is supposed to be more carefully designed, more mature, which could give it an essential advantage in the long run. Secondly, OpenDaylight and ONOS are not designed to play the same role: while OpenDaylight is more data center-oriented, ONOS is more adapted for WAN management. Since SDN is more deployed in the data centers today, it seems logical that OpenDaylight is more adopted, but this might change in the future. Among the solutions using ONOS, or a controller based on ONOS, we can find Huawei, ECI, Virtuora Network Controller (Fujitsu) or Atrium (ONF).

ONOS architecture pays much attention to its NBI and SBI. As an OS, ONOS is designed to accept any new southbound protocol to communicate with any network device and hide the complexity and diversity of the network to higher levels. Among the southbound protocols already supported, we can quote OpenFlow (all versions), Netconf, and OVSDB. The north API is not standardized, but ONOS provides a REST API for northbound applications. Besides this generic API, ONOS provides an intent framework to simplify application developers' work and a general view of the network [18].

If the available northbound applications or plugins do not fit the needs of the project, ONOS offers rich documentation to help developers to code their own features. This documentation is updated with each new release, which represents a high frequency. Regarding MANO architecture, ONOS is equivalent to OpenDaylight. As part of the Linux Foundation, Controllers Open-O is designed to integrate it [20]. It is also possible to use it in Open Source MANO.

Even if its notoriety cannot be compared to OpenDaylight, ONOS is a serious alternative and very promising. By polling partners of the project, few of them declared having strong expertise with ONOS, but for most of them, they already started considering it and improving their skills.

As we saw in the previous section ONOS:

1. Is open-source, with a larger and larger community;
2. Is mature, although it is not as much adopted as OpenDaylight;
3. Offers a rich standardized southbound API;
4. Offers a rich northbound API, including a homemade intent API;
5. Possesses features and application, maybe less than OpenDaylight;
6. Can be integrated into an NFV architectural framework using Open-O or OSM;
7. Benefits of medium expertise from the partners.

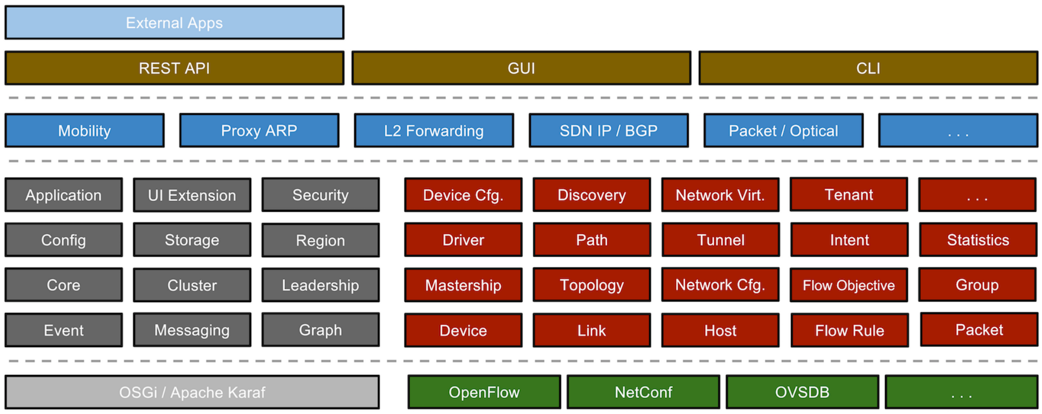

Fig. 3: ONOS subsystem. Bogineni et al. [18].

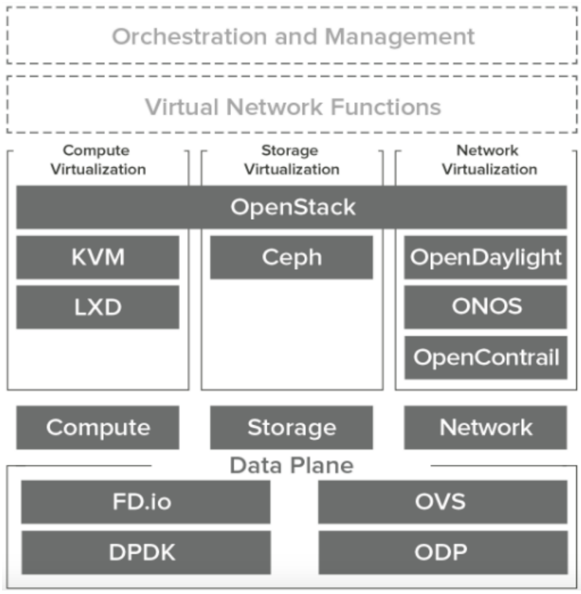

Fig. 4: NFV-MANO Architecture [21].

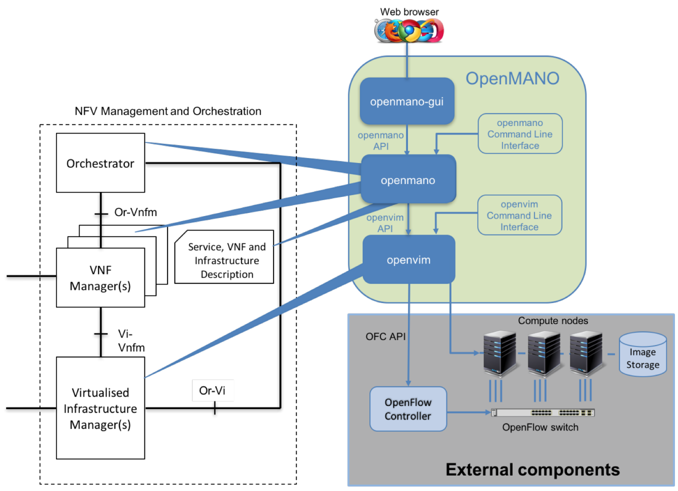

Fig. 5: OSM Mapping to ETSI NFV MANO [22].

e. NFV

This section presents an overview of the main projects and technologies that have been identified by the 5GinFIRE consortium as relevant in the field of Network Functions Virtualization (NFV). In the following, we analyze the diverse functionalities provided by these solutions in the context of the NFV reference architecture defined by the ETSI Industry Specification Group for Network Functions Virtualization (ISG NFV). We conclude this section is presenting a summary of the main features and functionalities of the analyzed solutions, along with a set of considerations to motivate the selection of technologies to support NFV functionalities within 5GinFIRE.

The most relevant projects and open-source initiatives that focus on the development of specific solutions to support the management and orchestration of NFV services and resources. To serve as a reference, Figure 4 presents the structure of the NFV management and orchestration (MANO) system defined by ETSI and its interrelation with the other components of the NFV reference architectural framework. This subsection does not cover Virtualized Information Manager (VIM) solutions.

1. Open Source MANO

Open Source MANO (OSM) [22] is an ETSI-hosted open-source project involving leading network operators, NFV cloud providers and research and academic centers, including Telefónica, British Telecom, Telenor, Telecom Austria Group, Intel, Canonical, RIFT.io, Mirantis, VMware, 6WIND, IMDEA Networks and DELL, among others (the up-to-date list of members and participants is provided in the OSM website [23]). The project aims at providing a practical open-source implementation of an NFV Management and Orchestration (MANO) stack aligned with the NFV reference architectural framework defined by the ETSI NFV ISG [24].

The Network Service Orchestrator (NSO), based on RIFT.ware [23] from RIFT.io/Intel, takes care of the delivery of end-to-end network services, interacting with the Resource Orchestrator and the VNF Configuration & Abstraction components of the OSM architecture. It provides the point of contact in the OSM architecture to support the lifecycle management of network services, catalog management, and on-boarding/configuration of network services and VNFs, among others. The current OSM software stack implementation includes a Graphical User Interface (GUI), which provides an intuitive, easy-to-use mechanism to interact with the NSO, providing the necessary tools for VNF on-boarding and the creation and instantiation of network ser-

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vices.

The resource orchestrator (RO), which is based on OpenMANO, coordinates the allocation and setup of the computing, storage, and network resources that are necessary for the instantiation and interconnection of VNFs. For this purpose, the RO may interact with multiple Virtualized Infrastructure Managers (VIMs), which may be of different types (see the Evaluation section). This component provides most of the functions associated with the NFV Orchestrator defined by the ETSI NFV framework and follows a plugin model to support the addition of other types of VIM and SDN Controllers.

Finally, the VNF Configuration and Abstraction layer (based on Juju Charms from Canonical) is aligned with the VNF Manager defined by the ETSI NFV reference architectural framework, overseeing VNF configuration per the corresponding VNF descriptors, following a model-driven approach.

This architecture of the OSM stack has been developed following four guiding principles:

1. Layering that allows the plugin replacement of the various layers (NSO, RO, VIM, etc.) with additional or alternative components;
2. abstraction, helping to clarify what is required by the different layers of the system;
3. Modularity, even within layers, that enables a plugin model to facilitate module replacements as the OSM develops and evolves;
4. Simplicity, trying to have the minimal complexity necessary to implement the governing information models in the solution.

OSM source code is available under the Apache License, Version 2.0 [22]. The implementation includes contributions at the different architectural levels from outstanding organizations in the field of NFV, particularly:

1. VIM: Telefonica's OpenMANO's OpenVIM;
2. VNFM: Juju from Canonical;
3. NFVO: Rift.ware, OpenMANO, Murano (by Mirantis).

Besides, the current release of the OSM software stack (OSM ONE), available from October 2016, includes a one-step installing process based on containers and Juju modeling, aiming at simplifying testing, customization, and deployment processes concerning the previous release (OSM ZERO). This version supports a plugin model framework that facilitates maintenance operations and future extensions of the platform while improving the interoperability with other components like VNFs, VIMs, or SDN controllers. OSM plugin model allows integrating multiple VIMs (the current release supports OpenStack, OpenVIM, and VMware vCloud Director). Release ONE allows the deployment of multi-site network services that span across multiple datacentres and includes OpenVIM as part of the OSM run-time environment to provide a reference VIM for all-in-one installations with the support of Enhanced Platform Awareness (EPA), aiming at having greater awareness about the capabilities of the platform under control.

Moreover, OSM provides a wiki with up-to-date documentation covering technical details concerning the project, along with an installation and a user guide. The initial expectation of the project is to provide new releases with a periodicity of six months.

Finally, we want to highlight that the 5GinFIRE consortium includes partners with direct involvement in the development of OSM, particularly Telefónica, as an OSM member, and UC3M, as an OSM participant.

In the following, we enumerate the main features of OSM, as previously presented:

1. ETSI-hosted open-source project;
2. Practical open-source implementation of an NFV MANO stack aligned with the ETSI NFV reference architectural framework;
3. Supported by leading network operators, NFV cloud providers, and research and academic centers (at the time of writing 26 members, 31 participants);
4. Licensed under Apache License 2.0;
5. Available up-to-date documentation;
6. Supports a plugin model framework to facilitate maintenance, future extensions, and interoperability;
7. Multi-VIM support;
8. One-step installing process;
9. Providing an intuitive, easy-to-use GUI.

III. 5G PROJECTS

This session discusses IoT-focused 5G standard projects. These projects were chosen because they are funded by the European Union's Horizon 2020 (H2020) project. It is noteworthy that projects linked to other areas such as mobile telephony will be treated briefly or ignored in this session.

H2020 is an EU Research and Innovation program with nearly €80 billion of funding available over seven years (2014 to 2020). Within this program is the 5G-Public-Private Partnership (5G-PPP), a stimulus program for the development of 5G (5G) telecommunication technologies.

This program aims to stimulate the study, validation, and implementation of technologies for connection in various (vertical) areas to ensure that all compatible devices can communicate with each other, even when they use different infrastructure. The requirements of the 5G standard include:

- Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
- Saving up to 90% of energy per service provided. The main focus will be in mobile communication networks where the dominating energy consumption comes from the radio access network
- Reducing the average service creation time cycle from 90 hours to 90 minutes
- Creating a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision

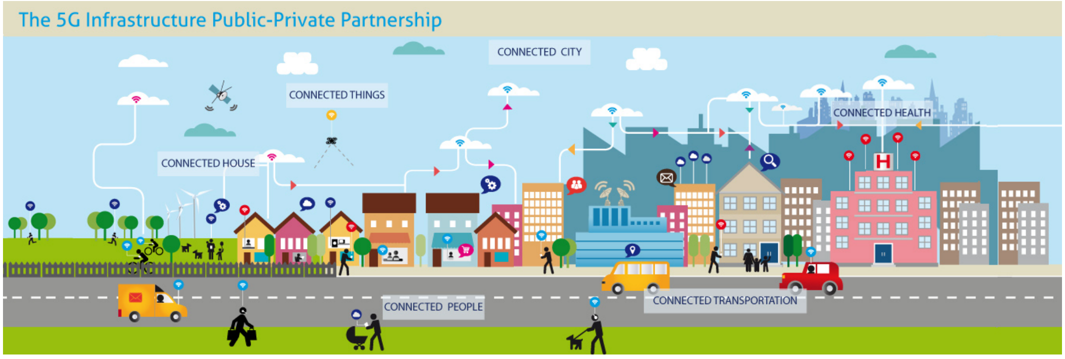

Fig. 6: 5G-PPP Proposal [25].

- Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people

- Ensuring for everyone and everywhere the access to a wider panel of services and applications at lower cost

a. 5G-Range

5G-Range is a project focused on developing technologies to enable access to 5G infrastructure to provide affordable internet access with quality of service in remote areas [26].

The 5G-RANGE proposal has specified two use cases: Internet Access and High Mobility Application in Remote Areas. 5G-RANGE will be designed to achieve ten times more cell radius than the conventional 4G technology, supporting high data rates within cell sizes of 50 km radius. Based on these features, it is expected that this project will provide a cost-effective 5G system which can stimulate feasible business models for remote areas [26].

In the context of IoT, this project allows the connection of sensors and devices in remote environments, minimizing the cost of the necessary communication infrastructure. Among its applications can be mentioned use in agricultural environments.

b. 5G-HEART

Healthcare, transport, and food verticals are hugely important in Europe, in terms of jobs, size, and export trade. Not only that, but they are also vital from a social point of view. 5G-HEART is one of 5G PPP Phase 3 projects focused on deploying a communications infrastructure for healthcare, transport and aquaculture industry partnerships.[27]

Providing better patient care or optimizing food production and distribution is one of the things 5G technology can be of great importance. 5G proves essential for these verticals in terms of providing a keyboard substrate for e-medicine and food supply focused devices.

Novel applications such as smart medical devices can use this technology as a communications infrastructure to provide more efficient patient care, optimizing today's healthcare system. Trials will run on sites of 5G-Vinni (Oslo), 5Genesis (Surrey), 5G-EVE (Athens), as well as Oulu and Groningen, which will be integrated to form a powerful and sustainable platform where slice concurrency will be validated at scale.

c. 5G!Drones

5G!Drones is a 5G project for Drone-based Vertical Applications. The focus of this project is driving UAV verticals inside 5G networks infrastructure by providing low-latency and reliable communication, a massive number of connections, and high bandwidth requirements, simultaneously [28].

d. 5GSMART

5G is foreseen as a key enabler for the future manufacturing ecosystem, termed Industry 4.0. 5G-SMART is focused on applying 5G in real manufacturing environments.

Its main idea is applying a 5G standard for technologies such as digital twins, industrial robotics, and machine vision-based remote operations. It also plans to explore new business models, including the roles of mobile network operators. The trial sites are an Ericsson factory in Kista (Sweden), a Fraunhofer IPT shopfloor in Aachen (Germany), and a Bosch semiconductor factory in Reutlingen (Germany) [29].

e. 5GInFire

The 5GINFIRE aims to propose an architecture for open and Extensible 5G Reference ecosystem, along with integrating IoT projects such as FIWARE, FIRE to the 5G Networks. This environment will work as an experimental playground to validate devices, network function, and APIs before they are ported to industrially, Smart cities and other "mainstream" 5G network technologies [10]. Figure 7 demonstrates the infrastructure for IoT using the 5GInFire architecture model.

f. 5GTOURS

This project aims to provide tourism and e-health services and mobility for tourists, citizens, and patients. Its test sites are Rennes, the safe city where e-health use cases will be demonstrated, Turin, the touristic city focused on media and broadcast use cases, and Athens, the mobility-efficient city that brings 5G to users in motion as well as to transport-related service providers [30].

g. 5G-SOLUTIONS

5G-SOLUTIONS is the flagship ICT-19 RIA project supporting EC's 5G policy by implementing the last phase (Phase 3b) of the 5G PPP roadmap [31].

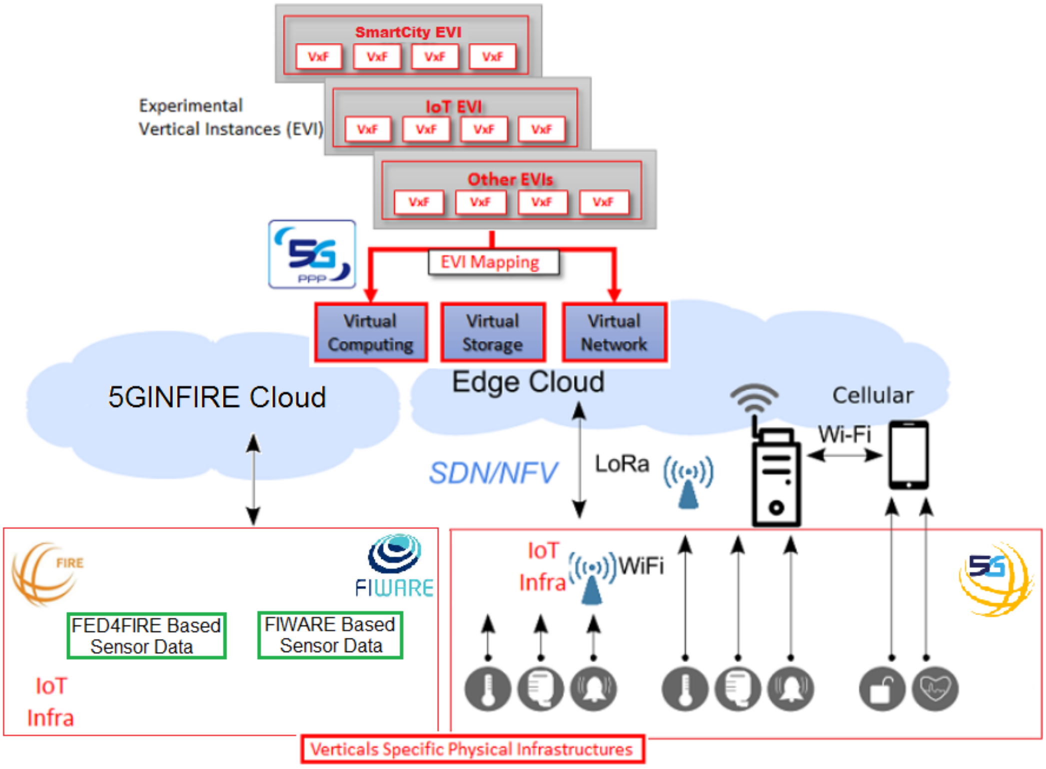

Fig. 7: 5GINFIRE IoT architecture. 5GinFire [10].

This project focuses on validating 5G technologies for their final implementation, and thus, bringing the 5G vision closer to realization. This will be achieved through conducting advanced field-trials of innovative use cases, directly involving end-users across five significant industry vertical domains in five countries:

- Factories of the Future, in Belgium, Ireland, and Norway
- Smart Energy, in Italy
- Smart Cities, in Ireland and Norway
- Smart Ports, in Norway
- Media & Entertainment in Greece and Norway

h. Comparison Table

This session brings a comparison table between the 5G technologies mentioned. It also brings a glossary for a better understanding of the table.

On the range column, we mention the expected range of the technology. It is divided according to the list below into short, medium (mid), and long-range.

- Short Range: < 1 KM
- Mid Range: 2KM - 5KM
- Long Range: > 5KM

In the Throughput session, we mention the expected data throughput of the technology. It is divided according to the list below into short, medium (mid), and long-range.

- Small: < 200Kb/s
- Mid: 200Kb/s - 10Mb/s
- Large: > 10Mb/s

IV. Conclusion

We can conclude that 5G is a set of technologies to provide telecommunication support for multiple different platforms. In order to meet the specific needs of each vertical, the 5G standard is subdivided into multiple designs.

Within these verticals, IoT has multiple specific needs, in scopes too narrow to be met by a single project. Therefore, several proposals were made to remedy these problems.

This survey described some of these technologies, their applications, and their scope. It is noteworthy that within the context of 5G, the standards are not yet fully defined, and are subject to change.

References

[1] P. Cerwall, P. Jonsson, R. Möller, S. Bävertoft, S. Carson, and I. Godor, "Ericsson mobility report," *On the Pulse of the Networked Society. Hg. v. Ericsson*, 2015.

[2] N. Zaman, "Energy optimization through position responsiverouting protocol (prrp) in wireless sensor network," *International Journal of Information and Electronics Engineering*, 01 2012.

[3] P. Andres-Maldonado, P. Ameigeiras, J. Prados-Garzon, J. J. Ramos-Munoz, and J. M. Lopez-Soler, "Optimized lte data transmission procedures for iot: Device side energy consumption analysis," in *2017 IEEE International Conference on Communications Workshops (ICC Workshops)*. IEEE, 2017, pp. 540–545.

[4] Y.-P. E. Wang, X. Lin, A. Adhikary, A. Grovlen, Y. Sui, Y. Blankenship, J. Bergman, and H. S. Razaghi, "A primer on 3gpp narrowband internet of things," *IEEE communications magazine*, vol. 55, no. 3, pp. 117–123, 2017.

TABLE 1: COMPARISON BETWEEN TECHNOLOGIES AND PURPOSES IN 5G.

Project	Range	Objective	Throughput
5G-Range	Long Range	Long Range Communitations	Large
5G-HEART	Short Range	E-Health	Large
5G!Drones	Mid Range	UAV and Drones	Large
5GSMART	Short Range	Manufacturing	Large
5GInFire	Mid/Long Range	IoT	Small/Mid
5GTOURS	Long Range	Tourism, E-Health, Mobility	Large
5G-SOLUTIONS	Not Apply	Tests and Validation	Not Apply

[5] A. Hoglund, X. Lin, O. Liberg, A. Behravan, E. A. Yavuz, M. Van Der Zee, Y. Sui, T. Tirronen, A. Ratilainen, and D. Eriksson, “Overview of 3gpp release 14 enhanced nb-iot,” *IEEE Network*, vol. 31, no. 6, pp. 16–22, 2017.

[6] M. Lauridsen, B. Vejlgaard, I. Z. Kovacs, H. Nguyen, and P. Mogensen, “Interference measurements in the european 868 mhz ism band with focus on lora and sigfox,” in *2017 IEEE Wireless Communications and Networking Conference (WCNC)*. IEEE, 2017, pp. 1–6.

[7] U. Raza, P. Kulkarni, and M. Sooriyabandara, “Low power wide area networks: An overview,” *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 855–873, 2017.

[8] M. Rizzi, P. Ferrari, A. Flammini, and E. Sisinni, “Evaluation of the iot lorawan solution for distributed measurement applications,” *IEEE Transactions on Instrumentation and Measurement*, vol. 66, no. 12, pp. 3340–3349, 2017.

[9] S. Parkvall, E. Dahlman, A. Furuskar, and M. Frenne, “Nr: The new 5g radio access technology,” *IEEE Communications Standards Magazine*, vol. 1, no. 4, pp. 24–30, 2017.

[10] A. P. Silva, C. Tranoris, S. Denazis, S. Sargento, J. Pereira, M. Luís, R. Moreira, F. Silva, I. Vidal, B. Nogales *et al.*, “5ginfire: An end-to-end open5g vertical network function ecosystem,” *Ad Hoc Networks*, vol. 93, p. 101895, 2019.

[11] J. Koo, R. K. Panta, S. Bagchi, and L. Montestruque, “A tale of two synchronizing clocks,” in *Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems*, ser. SenSys ’09. New York, NY, USA: ACM, 2009, pp. 239–252. [Online]. Available: http://doi.acm.org/10.1145/1644038.1644062

[12] S. Sen, J. Koo, and S. Bagchi, “Trifecta: Security, energy efficiency, and communication capacity comparison for wireless iot devices,” *IEEE Internet Computing*, vol. 22, no. 1, pp. 74–81, Jan 2018.

[13] J. Roessler, “Lte-advanced (3gpp rel. 12) technology introduction white paper,” *Rohde & Shwarz*, 2015.

[14] X. Lin, J. G. Andrews, A. Ghosh, and R. Ratasuk, “An overview of 3gpp device-to-device proximity services,” *IEEE Communications Magazine*, vol. 52, no. 4, pp. 40–48, April 2014.

[15] D. Wübben, P. Rost, J. Bartelt, M. Lalam, V. Savin, M. Gorgoglione, A. Dekorsy, and G. Fettweis, “Benefits and impact of cloud computing on 5g signal processing,” *IEEE Signal Processing Magazine*, vol. 31, p. 10, 11 2014.

[16] “Lithium.” [Online]. Available: https://www.opendaylight.org/what-we-do/current-release/lithium

[17] “Openvim installation (release one).” [Online]. Available: https://osm.etsi.org/wikipub/index.php/OpenVIM_installation_(Release_One)

[18] K. Bogineni *et al.*, “Introducing onos—a sdn network operating system for service providers,” *White Paper*, 2014.

[19] “Sdxcentral releases 2017 network virtualization and sdn controller report.” [Online]. Available: https://www.epicos.com/article/154885/sdxcentral-releases-2017-network-virtualization-and-sdn-controller-report

[20] E. OSM, “Opensourcemano,” 2016.

[21] D. Gomes, “5ginfire experimental infrastructure architecture and 5g automotive use case.” [Online]. Available: https://bscw.5g-ppp.eu/pub/bscw.cgi/d302168/D2-2-5GINFIRE_Experimental_Infrastructure_Architecture_and_5G_Automotive_Use_Case-v1-0.pdf

[22] “Osm release six is now is open source is community is collaboration.” [Online]. Available: https://osm.etsi.org/

[23] “Etsi sol interoperability with rift.ware.” [Online]. Available: https://riftio.com/

[24] A. Israel, A. Hoban, A. Sepúlveda, F. Salguero, G. de Blas, K. Kashalkar, M. Ceppi, M. Shuttleworth, M. Harper, M. Marchetti *et al.*, “Osm release three,” *Open Source MANO, Technical Overview*, 2017.

[25] G. PPP, “5g-ppp,” https://5g-ppp.eu/, 2019, (Accessed on 12/01/2019).

[26] G. Range, “5g-range remote area access network for the 5th generation,” http://5g-range.eu/wp-content/uploads/2019/02/5G-Range_D2.1_V3.pdf, 2018, (Accessed on 12/01/2019).

[27] “5g heart,” Nov 2019, (Accessed on 12/01/2019). [Online]. Available: https://5gheart.org/

[28] “5g!drones.” [Online]. Available: https://5gdrones.eu/

[29] “5g smart,” Nov 2019, (Accessed on 12/01/2019). [Online]. Available: https://5g-ppp.eu/5g-smart/

[30] “5g tours,” Nov 2019, (Accessed on 12/01/2019). [Online]. Available: https://5gtours.eu/

[31] “5g-solutions,” Nov 2019, (Accessed on 12/01/2019). [Online]. Available: https://www.5gsolutionsproject.eu