Martinello, M. (2017). How can emerging applications benefit from EaaS in open programmable infrastructures? . In *IEEE Summer School on Smart Cities 2017: IEEE S3C2017*

How can emerging applications benefit from EaaS in open programmable infrastructures?

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Abstract—**Providing experimentation facilities in urban-scale infrastructures such as Smart City testbeds is a priority – and a challenge. Real-time performance, security, resource allocation and network convergence are only few of the issues to be tackled in order to provide proper and flexible *Experimentation as a Service* (EaaS) facilities in city-scale infrastructures. Software Defined Networking (SDN) and Network Function Virtualisation (NFV) appear as important enablers for providing such large-scale testbeds, while promoting them as completely open programmable infrastructures. In this paper, we take the position of emerging applications or services designers/programmers that have stringent network requirements and want to know how to benefit from EaaS provided by open programmable (city-scale) infrastructures. Our focus is to evaluate the impact of SDN and NFV systems running real-time applications with low end-to-end latency and high bandwidth requirements correlated.**

I. INTRODUCTION

Providing experimentation facilities in urban-scale infrastructures is of utmost importance to support researchers and developers to accurately anticipate unforeseen hurdles inherent to wide-scale deployments. Additionally, it can create unexpected opportunities for innovation, besides providing controlled environments to assess socio-economic impact of new technologies in urban scenarios [1]. Trialability, or the "degree to which experimentation is possible with the technology" [2] has actually been presented as one of the main requirements for current Smart City platforms.

Nevertheless, testing and experimenting new technologies in such wide-scale environments is absolutely challenging. Real-time performance, security, resource allocation, network convergence and latency are few of the issues that need to be tackled to provide proper experimentation facilities in Smart City testbeds [3]. To cope with all these issues, *Software Defined Networking*[1] (SDN) and *Network Function Virtualisation*[2] (NFV) have been identified as crucial enablers for providing effective *Experimentation as a Service* (EaaS) in city-scale infrastructures [4][5].

With SDN and NFV as enablers of such open programmable infrastructures, experimenters are allowed to completely control their experiments (*e.g.*, reservation, instantiation, execution, monitoring and un-instantiation), while the infrastructure controls simultaneous or exclusive access to shared resources (computing, networking, IoT devices, *etc.*). Orchestration mechanisms might be deployed when emerging applications with strict real-time requirements need flexibility regarding the location of their processing units. Network controllers capable of controlling wireless, optical, and/or packet-switched networks might also be provided to experimenters, allowing them, for example, to dynamically test different traffic engineering strategies while running bandwidth-sensitive IoT applications or services. In addition, experimenters may even require to test end-to-end network services for Smart Cities employing functionalities hosted at the cloud. In this case, network orchestration mechanisms might be used to steer traffic between *Virtual Machines* (VMs) to form a service chaining support and to provide VM migration.

Thus, in this paper, we take the position of emerging applications (or services) designers and developers that have stringent network requirements and want to know how to benefit from EaaS provided by open programmable (city-scale) infrastructures. Our focus is to evaluate the impact of SDN and cloud computing technologies in systems running real-time applications with low *end-to-end* (E2E) latency and high bandwidth requirements correlated. More specifically, we aim to integrate diverse technologies (*e.g.*, SDN, NFV and edge computing) to meet these stringent network requirements by bridging communication and cloud computing ecosystems and exploiting the use of a converged control framework and federated resources.

In order to proceed with this evaluation, an experiment in the domain of robotics has been developed. The experiment has been integrated to the FUTEBOL[3] platform (*Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory*), which leverages on SDN and NFV to provide a federation of research infrastructures, such as the open programmable infrastructure of *Bristol Is Open* – BiO[4].

The remainder of this paper is structured as follows. Section 2 describes some related work regarding Smart City testbeds

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[1] https://www.opennetworking.org/sdn-resources/sdn-definition

[2] http://www.etsi.org/technologies-clusters/technologies/nfv

[3] http://www.ict-futebol.org.br/

[4] http://www.bristolisopen.com/

and other urban-scale experimentation environments. Section 3 presents the open programmable infrastructure of BiO and its integration to the FUTEBOL experimental platform. Section 4 explains the proposed robotics experiment and its integration to the FUTEBOL platform. Section 5 presents some preliminary experimental results. Section 6 outlines some conclusions and future works.

II. RELATED WORKS

Smart City platforms or IoT solutions for Smart Cities have been increasingly introduced by several municipalities around the world in an attempt to improve different aspects of citizen's lives and to optimize urban infrastructures and services [6]. Remarkable examples are the Smart City platforms of Barcelona [7], Amsterdam[5] and Seattle [8]. However, these are "industry-grade" platforms [9] which do not really aim attention on providing experimentation facilities.

CitySense [10], deployed in the city of Cambridge (Massachusetts, USA), is one of the first testbeds to be created as "an open laboratory" through a city-wide platform. Its main goal is to enable large-scale wireless sensing and wireless network research in a real-world urban setting. One of the particular aspects of this project is that the sensing nodes can be directly programmed by the experimenters. IoT-Lab [11] is another example of urban-scale IoT testbed with fully programmable nodes (sensors or even wireless robots). The environment provides more than 2,700 wireless sensors distributed over six different sites in France.

SmartSantander [12], a Smart City deployment in the Spanish city of Santander, is currently one of the most important and cited urban-scale testbeds for IoT technologies. It provides a platform for experimenting with a variety of IoT technologies and one of its main focuses is on heterogeneity aspects of IoT systems. The testbed is designed based on an architectural reference model for open IoT experimentation facilities, which includes a particular subsystem for providing specific operations to support the user during the experimentation lifecycle.

Notice that the previously mentioned testbeds are mainly concerned with providing facilities for testing and experimenting IoT or wireless sensors networks. None of them provides flexibility or programmability at the network infrastructure level. To our knowledge, FESTIVAL [4] is the only SDN based federated platform aiming to provide EaaS in open programmable Smart City infrastructures. FESTIVAL is an EU-Japan collaborative project which federates ten testbeds that provide different types of resources: open data platforms, IoT devices, IT resources, Living Lab resources. Particularly, the IT resources comprise computational power (VMs) and SDN-based service orchestration allowing the experimenters to dynamically modify the network configuration. The SDN-based services are currently supported in one of the federated testbeds – the JOSE testbed – which provides advanced SDN capabilities and high speed networks for interconnecting several computer servers and sensors distributed throughout Japan.

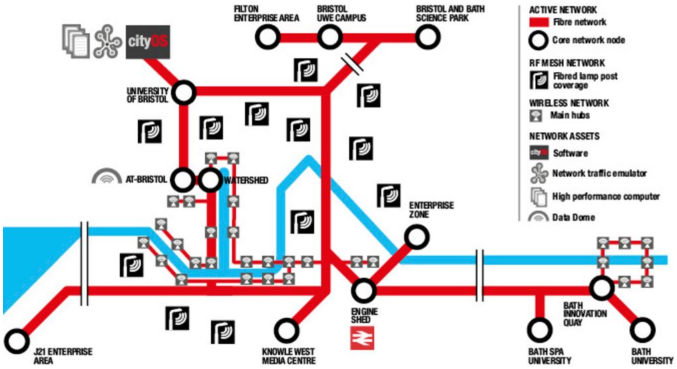

Fig. 1. BiO Open Programmable city region - Phase II overall network (2016-18)[4]

One considerable limitation of the FESTIVAL approach is that SDN and NFV are not being employed as the main enablers for the federated platform. The federation approach is actually been achieved via homogeneous access APIs with an EaaS model for experimenters to test their services.

In the next section, we present BiO's open programmable infrastructure and its integration to the FUTEBOL federated platform in the light of SDN and NFV.

III. *Bristol Is Open* AND THE FUTEBOL PROJECT

Bristol is Open (BiO) is an open programmable city-scale testbed which has been created as a joint venture between the Bristol City Council and the University of Bristol. Funded by different UK government initiatives, Industry and EU projects, the platform is already operational across Bristol and is currently being extended across the West of England.

Underpinned by SDN and cloud technologies, BiO aims to provide *City Experimentation as a Service* (CEaaS) to different partners profiles, such as academics, small hi-tech start-ups, public service delivery organisations, or even large Telecom and Software companies. Its digital infrastructure represents a realistic and completely controllable and secure environment dedicated to run user-defined experimentation deploying different physical (or even emulated) technologies.

In order to run their experiments, partners are given slices of the network to work with. Using virtualisation and logically isolated resources, experimenters can, for example, (i) measure and demonstrate radically new network architectures, (ii) test large-scale, multi-technology network and IoT systems at laboratory, city-scale and UK national level, and (iii) experiment on seamless convergence of heterogeneous technology domains (*i.e.* wireless, optical, data centre). They can also use BiO's IoT Mesh network or deploy new sensors to BiO local network.

BiO's city network (Figure 1) comprises different active nodes (*i.e.*, Core Network Nodes) which are connected through an heterogeneous optical and layer 2 infrastructure including fibre, flexi WDM and 10/40G Ethernet technologies. Each of the active nodes presents a number of advanced network

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[5] https://amsterdamsmartcity.com/

and IT modules, such as SDN enabled (optical and electrical) switches and high performance servers supporting virtualisation (*e.g.*, Xen, KVM, OpenStack). BiO also provides an heterogeneous wireless infrastructure comprising a cluster of Access Points supporting Wi-Fi, LTE and 60Ghz technologies. Just as the wired infrastructure, the entire wireless infrastructure has also been designed to use SDN control principles (*e.g.*, support to SDN-enabled 802.11ac). Relying on OpenDayLight controlers[6], multiple experiments can be carried-out simultaneously across the network. Besides, BiO's experimenters are also provided with the ability to dynamically program heterogeneous network elements to handle the experiments' specific needs.

Concerning the IoT Mesh, BiO leverages on the FIWARE-IoT platform[7]. Different FIWARE instances are deployed in the BiO's cloud such as *Context Broker* (Orion Context Broker), *Short Term Historic* (aka Comet) and *IoT Agents* supporting a number of protocols and data formats, like Ultralight 2.0 and JSON. In order to connect new IoT devices to BiO's infrastructure, experimenters just need to select the right *IoT Agent* (depending on the IoT protocol used by the devices). IoT devices can be accessed an controlled through the FIWARE platform, either on dedicated or shared basis.

BiO's infrastructure also provides network emulator facilities, including server farms as well as FPGA/SoC/NP farms. This allows experimenters to incorporate more complex network topologies to their experiments. The University's Blue Crystal High Performance Computer facility, a supercomputer capable of 200 trillion calculations per second, is also integrated to the infrastructure.

A. Getting into FUTEBOL

The recently EU-BR funded project FUTEBOL (*Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory*)[3] works towards the integration of different testbeds from Europe and Brazil for network and IoT researchers (experimenters) from both academia and industry. BiO is currently one of the testbeds to be integrated and offered to the experimenters as part of the FUTEBOL platform. Inspired by BiO's infrastructure, a second open programmable city-scale testbed has been designed in the city of Vitória (ES/Brazil). This testbed will connect the data centre hosted in the NERDS/UFES laboratory[8] to the MetroVix's metropolitan network, which includes 50 km of optical fibre along Vitória island.

In order to achieve the testbeds integration, a federated *Control Framework* (CF) has been designed and developed. The operation of the FUTEBOL experimental platform will be supported by the set of tools and functionalities provided by the FUTEBOL CF, enabling experimenters to reserve, allocate and manage heterogeneous wireless and optical resources in order to run their experiments in different FUTEBOL testbeds.

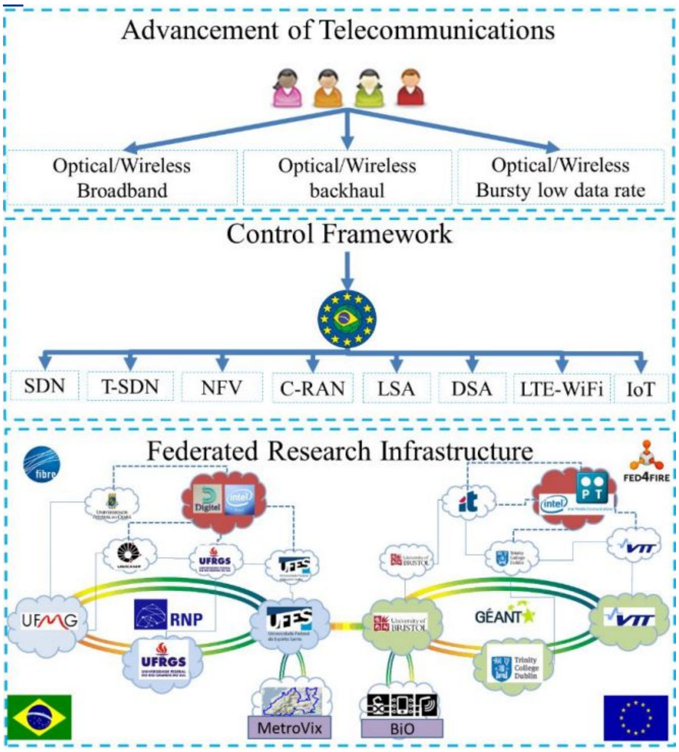

Fig. 2. FUTEBOL overarching vision [5]

Figure 2 illustrates the main elements of the FUTEBOL project.

FUTEBOL CF has been designed considering two main phases:

1) Testbed management and experiment provisioning, when reservation, allocation and release of different isolated experiments take place.
2) Experimentation control, when experimenters configure and control the resources in order to execute the experiment scenarios.

One of the focus of the FUTEBOL project is on wireless-optical network convergence. The FUTEBOL CF will enable FUTEBOL users to reserve and to allocate resources to run their experiments using heterogeneous wireless and optical resources in the different FUTEBOL testbeds. Relying on SDN and NFV, the FUTEBOL CF seeks to support different options of experimental resources to be reserved and managed. For instance, one illustrative scenario is to move processing units from wireless controlled devices (on the edge) to the cloud in order to apply centralized joint processing.

IV. An Intricate Use Case: Robotics as a Service

The demand for novel Smart City services and applications in different categories is accelerating across the world [13]. It can be really challenging to design, develop and test many of these applications (or services), mainly due to their underlying infrastructure requirements.

Interesting applications are in the robotics and computer vision domain, as they can be both hard real-time (delay-

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[6] https://www.opendaylight.org/

[7] https://www.fiware.org/

[8] http://nerds.ufes.br

sensitive) and CPU-demanding applications, while requiring bandwidth-intensive transmissions. Some examples of applications that use robotics and computer vision in Smart Cities may go from monitoring or cleaning public areas, assisting citizens with special needs (*e.g.,* disabled people) on streets, providing information in historical zones or tourist spots, counting vehicles, searching for specific license plates, controlling an intelligent transportation system based on autonomous vehicles and drones.

All these applications can actually be implemented as *Robotics as a Service* (RaaS). RaaS is a cloud computing unit that facilitates the seamless integration of robot and embedded devices into Internet and cloud computing environment [14]. In RaaS design and implementation, a robot is a *Service-Oriented Architecture* (SOA) unit [15], which separates the virtual services from the physical devices and decouples the robotics application from the specificity of the devices.

RaaS is very promising regarding the fact that it can be the most effective way to create and monitor robotic applications, particularly for servicing robotics in Smart Cities. It is worth to mention that the RaaS can be applied to all the computer vision applications previously mentioned. By leveraging RaaS, these applications will be able to go beyond their local limited processing capabilities and take advantage of network computing. While cloud computing can provide plentiful resources to perform complex real-time control algorithms computation, E2E low latency networking can provide extreme low-latency and reliable connectivity [16].

Thus, as a proof of concept, we propose an experiment in the context of the FUTEBOL project that illustrates real-time remote control of robots as an application of RaaS. The main idea is to show how to leverage SDN and NFV in order to support highly stringent RaaS experiments. To the best of our knowledge, this is the first work that proposes such approach.

To this end, as a first step, an application of RaaS provided by an intelligent space has been integrated to the FUTEBOL platform. Intelligent spaces can be described as environments equipped with a network of sensors, able to gather information about the surroundings, and a network of actuators that enables user interaction, task execution and environment changing through computational services. Sensors, actuators and computational services should be managed by a software infrastructure able to collect and analyses information captured by the sensors in order to make decisions.

The intelligent space used by FUTEBOL has an architecture with four layers: *Application, Middleware, Communication* and *Sensing*. The first 3 layers correspond to the software infrastructure. The goal of this infrastructure is to be used as a development and experimentation platform for robotics. A software infrastructure with these features is usually called a *Platform as a Service* (PaaS).

The last layer, *Sensing*, consists of four cameras containing a wirelessly commanded mobile robot unit, which will have very little onboard computation, memory, or software. Thus, this experiment will integrate SDN and cloud computing techniques in leveraging latency-bound and dependable communication and computation resources to enable RaaS in intelligent spaces.

Figure 3 presents a more detailed description of the RaaS experiment. Our assumption is that the robot runs in an indoor scenario, containing only the components needed for wireless communication and execution of control commands, *i.e.*, no GPS signal and poor odometry. The mission of the robot is to achieve a desired place indicated by the user, as it can be seen in Figure 3. Four cameras gather images and send them to image processing and localization services in the cloud (*i.e.*, edge and remote data centres). The estimated localization is, then, used by a control service in the cloud to produce a command, which is transmitted back to the robot using wired and wireless networks.

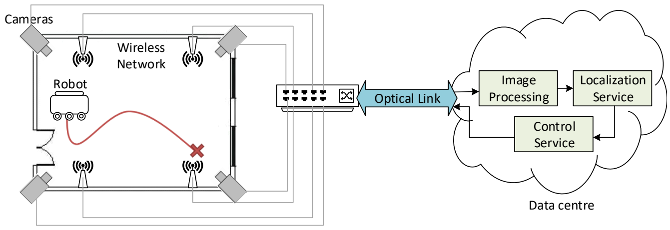

Fig. 3. General architecture of Robotics as a service

Basic functional blocks are shown in Figure 4 for both intelligent space and remote services related to image processing, robot localization and control. The wired and wireless networks are included as a means to reach out computation resources from both edge or remote data centres.

Notice that the interval between image frames will dictate deadlines for both network latency and services. Basically, all the steps shown in Figure 4 should happen within this interval, otherwise when the commands reach the robot, the localization information is no longer accurate and deviation from the planned trajectory will occur.

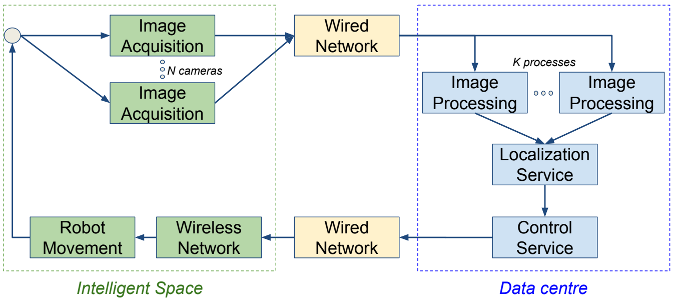

Fig. 4. Intelligent space network and datacentre elements involved in the experiment

Another important consideration is that more complex or faster movements, such as performing a specific trajectory, or a lower error tolerance, require more accuracy in robot localization, which can be accomplished by increasing the camera frame rate and, consequently, increasing the bandwidth demand. However, a higher frame rate decreases the interval between images, which requires a faster answer from the control loop, decreasing the acceptable E2E latency. Thus, the application can combine realistic traffic scenarios that will definitely challenge FUTEBOL CF with conflicting bandwidth and processing capacity versus latency requirements.

A. Integration with the FUTEBOL Federation

Regarding FUTEBOL federation, this experiment depends on the development of federation support for slice allocation of resources. Part of the federated resources are located in the Vitória testbed and comprise: a robot, cameras, access points, a programmable L2 packet switch and an edge data centre (NERDS/UFES) with a set of physical machines and networking devices. An NFV manager component will also be implemented in order to manage computing slices dedicated to run the virtual functions (*e.g.*, mobility management, traffic engineering control, image processing, localization service, and robot control).

In a second phase, the experiment will be extended to use remote cloud data centre processing, testing the impact on E2E network latency when executing computation tasks in remote data centres, represented by virtual machines federated in BiO testbed. In addition, it will be necessary to provide network level connectivity between the participants testbeds.

This experiment also involves a great amount of effort on the control framework in order to dynamically control the resources. Firstly, we can highlight the development of the application that will run in the SDN controller for network orchestration considering the high bandwidth and low latency requirements. This application will comprise the control of the SDN-enabled switch that connects the intelligent space to the edge data centre through an optical fibre link to provide traffic engineering and the intra data centre network orchestration. The FUTEBOL CF will also be responsible for the orchestration functionalities in both edge and remote data centres, such as placement, elasticity, and service chaining. Finally, special attention needs to be devoted to the development of strategies for the Wireless Access Network, such as low latency and handover mechanisms, since current wireless solutions (*i.e.*, Wi-Fi and 4G) maybe not be enough to guarantee the QoS of the proposed control loop.

The goal with our experiment based in robotics is visually to demonstrate how communication infrastructure, including fibre-wireless integration and data centre networking, needs to evolve to support future applications of RaaS.

B. Proof of Concept

As a proof of concept, we have run preliminary experiments locally in the intelligent space located at UFES, without relying on any data centre for processing the services. The intelligent space is composed by:

- four IP cameras,
- one Dell OptiPlex 9020 (Intel Core i5-4590, 3.3 GHz, 8GB RAM),
- one Dell PowerEdge T410 (2 x Xeon E5504, 2.0 Ghz, 6GB RAM),
- one Gigabit Switch,
- and a wireless router to communicate with the robot.

The mobile robot used in the experiments was a Pioneer P3-AT, from Adept MobileRobots, with a black and white pattern attached to its top, as shown in Figure 5. The pattern is used to localize the robot in the intelligent space. To obtain the robot position and orientation, the pattern has a grid of white circles, where one of them is greater than the others. The bigger circle indicates the robot back left side.

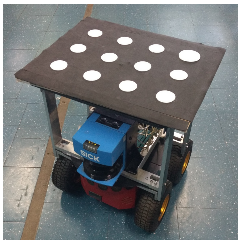

Fig. 5. Mobile robot used in the experiment

Robot and cameras are defined as virtual entities in the intelligent space infrastructure and all the needed functions or tasks such as cameras configuration, calibration, images acquisition, processing, robot localization and control, are provided as services and executed on the computing devices of the local infrastructure.

Images are gathered by 4 synchronized cameras and then are consumed by processing services that return the robot pose. After this, the robot pose is used by another service that controls the robot linear and angular velocities.

To run the experiment, the following parameters have been configured:

- Camera frame rate was set to 5 fps, which means that the deadline window, *i.e.*, the E2E latency requirement is 200 ms.
- Image resolution is 1280x728 (BW image), that results in the following processing workload, *i.e.*, bandwidth requirement per camera: $5 * 1280 * 780 * 8 \approx 40$Mbps.
- Control function is defined as the final position the robot must achieve in the working space.
- The final position will be defined by selecting (clicking at) a given location in one of the 4 images captured in the intelligent space.

A video of one of the experiments can be found at the following URL: https://youtu.be/6ZQKyhZVjuc .

As it can be seen in the video, the robot could be localized and controlled using the images captured by the intelligent space cameras. Nevertheless, the local infrastructure imposes limitations to the performance of the experiment. In some moments the time window of 200 ms was not sufficient for completing the image processing and sending the commands to the robot. In these cases, all the processing done is ignored and the robot keeps the previous linear and angular velocities. If the deadline is missed for 5 consecutive times, the robot stops as a security procedure.

If an increase in the cameras frame rate is wanted, for a more accurate control of the robot, the local infrastructure would not allow it. As shown in the experiment, it does not have the capacity to perform the whole processing needed in a time window smaller than the current one.

To solve this problem, the intelligent space, being a PaaS, can be migrated to a cloud infrastructure, where resources can be provisioned according to the needs of the application. The cloud infrastructure, as proposed in this paper, allows the intelligent space to provide RaaS, without the performance limitations presented by the local infrastructure, and in a transparent way to the developer. The expected decrease in the overall processing time obtained by migrating the application to the cloud compensates any extra latency that appears in the communication between the physical entities (sensors and actuators) and the cloud.

V. CONCLUSION

According to recent predictions, in 2018, “90% of IT projects will be rooted in the principles of experimentation [...]” [17]. In this paper we have sought to show how emerging applications can benefit from experimentation facilities in open programmable (city-scale) infrastructures. As a specific case of emerging applications with restricted operating requirements, we have proposed a *Robotics as a Service* use case.

The preliminary experiments conducted in this work confirm the need for an infrastructure that provides computational and network resources for the full operation of RaaS applications. The federation of open programmable SDN-NFV-based infrastructures presented in this paper will thus allow the development of RaaS applications, not only because it supports the demand for resources required for these applications, but also because it is flexible enough to get adapted to new requirements from the applications.

It is worth noting that our current experiments on RaaS present a concept that can be expanded to more complex tasks and scenarios, where the proposed infrastructure can contribute in a crucial way to the success of the applications.

Considering indoor applications of RaaS, we can think of having robots to serve the public, guiding people to desired locations, distributing documents or medicine in offices and hospitals, controlling wheelchairs and other robotic devices to help elderly people and patients, or even increasing the use and control of mobile robots in industrial plants. Regarding outdoor scenarios, RaaS can be used in Smart Cities in the form of many applications as the ones previously discussed in Section IV, for example, cleaning streets, helping pedestrians and controlling autonomous devices.

With all these in mind, our next steps are:

- Testing and validating SDN-NFV based new architectures for intra-data centre to elastically serve real-time bandwidth-intensive and latency sensitive applications.
- Assessing the FUTEBOL federated infrastructure and control framework in terms of time to process the services of the intelligent space (*e.g., Image Processing*) and to generate the robot control signals using edge and remote data centre scenarios.
- Running future RaaS experiments in outdoor scenarios using the BiO testbed integrated to FUTEBOL.

ACKNOWLEDGMENTS

This work is supported by CNPq under Grant 456143/2014-9 and EU-Brazil FUTEBOL project (grant no. 688941).

REFERENCES

[1] “Next generation internet experimentation: drivers transforming next generation internet research and experimentation,” June 2016. [Online]. Available: https://eprints.soton.ac.uk/397641/

[2] E. Curry, S. Dustdar, Q. Z. Sheng, and A. Sheth, “Smart cities–enabling services and applications,” *Journal of Internet Services and Applications*, vol. 7, no. 1, p. 6, 2016.

[3] A. Corici, R. Steinke, T. Magedanz, L. Coetzee, D. Oosthuizen, B. Mkhize, M. Catalan, J. C. Fontelles, J. Paradells, R. Shrestha *et al.*, “Towards programmable and scalable iot infrastructures for smart cities,” in *Pervasive Computing and Communication Workshops (PerCom Workshops), 2016 IEEE International Conference on*. IEEE, 2016, pp. 1–6.

[4] T. Akiyama, S. Murata, K. Tsuchiya, T. Yokoyama, M. Maggio, G. Ciulla, J. R. Santana, M. Zhao, J. B. Do Nascimento, and L. Gürgen, “Festival: Design and implementation of federated interoperable smart ict services development and testing platform,” *Journal of Information Processing*, vol. 25, pp. 278–287, 2017.

[5] M. Martinello, “Futebol: Experimental research at the boundary between wireless and optical networks,” in *TRANSFIERE, 7 Foro Europeo para la Ciencia, Tecnologa e Innovacin*, Malaga, Spain, Feb. 14-15 2017. [Online]. Available: http://www.ict-futebol.org.br/wp-content/uploads/2017/02/FUTEBOL-transfiere.pdf

[6] A. Cocchia, *Smart and Digital City: A Systematic Literature Review*. Cham: Springer International Publishing, 2014, pp. 13–43. [Online]. Available: http://dx.doi.org/10.1007/978-3-319-06160-3_2

[7] T. Bakıcı, E. Almirall, and J. Wareham, “A smart city initiative: the case of barcelona,” *Journal of the Knowledge Economy*, vol. 4, no. 2, pp. 135–148, 2013.

[8] S. AlAwadhi and H. J. Scholl, “Aspirations and realizations: The smart city of seattle,” in *System Sciences (HICSS), 2013 46th Hawaii International Conference on*. IEEE, 2013, pp. 1695–1703.

[9] S. Latre, P. Leroux, T. Coenen, B. Braem, P. Ballon, and P. Demeester, “City of things: An integrated and multi-technology testbed for iot smart city experiments,” in *Smart Cities Conference (ISC2), 2016 IEEE International*. IEEE, 2016, pp. 1–8.

[10] R. N. Murty, G. Mainland, I. Rose, A. R. Chowdhury, A. Gosain, J. Bers, and M. Welsh, “Citysense: An urban-scale wireless sensor network and testbed,” in *Technologies for Homeland Security, 2008 IEEE Conference on*. IEEE, 2008, pp. 583–588.

[11] C. Adjih, E. Baccelli, E. Fleury, G. Harter, N. Mitton, T. Noel, R. Pissard-Gibollet, F. Saint-Marcel, G. Schreiner, J. Vandaele *et al.*, “Fit iot-lab: A large scale open experimental iot testbed,” in *Internet of Things (WF-IoT), 2015 IEEE 2nd World Forum on*. IEEE, 2015, pp. 459–464.

[12] L. Sanchez, L. Muñoz, J. A. Galache, P. Sotres, J. R. Santana, V. Gutierrez, R. Ramdhany, A. Gluhak, S. Krco, E. Theodoridis *et al.*, “Smartsantander: Iot experimentation over a smart city testbed,” *Computer Networks*, vol. 61, pp. 217–238, 2014.

[13] P. Neirotti, A. De Marco, A. C. Cagliano, G. Mangano, and F. Scorrano, “Current trends in smart city initiatives: Some stylised facts,” *Cities*, vol. 38, pp. 25–36, 2014.

[14] Y. Chen, Z. Du, and M. García-Acosta, “Robot as a service in cloud computing,” *Proceedings - 5th IEEE International Symposium on Service-Oriented System Engineering, SOSE 2010*, pp. 151–158, 2010.

[15] T. Erl, *Soa: principles of service design*. Prentice Hall Press, 2007.

[16] A. Koubaa, “A service-oriented architecture for virtualizing robots in robot-as-a-service clouds,” *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 8350 LNCS, pp. 196–208, 2014.

[17] D. Bartoletti, L. E. Nelson, A. Cser, J. R. Rymer, A. Kindness, and B. Martorelli, “Predictions 2016: The cloud accelerates,” Forrester Research Technical Report, https://www.forrester.com/report/Predictions+2016+The+Cloud+Accelerates/-/E-RES125317, 2015.