GAIA 5G: A Multi-Access Smart-Campus Architecture

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Abstract. Smart-campuses are an emerging ecosystem that permit to enhance the performance and efficiency of academic facilities. Besides, they are also adopted as research, development, and testing platforms for the integration of novel management and governance mechanisms in complex ICT infrastructures. In this line, they are considered as small smart-city-like scenarios which can be used as a playground prior to large-scale deployments. This work presents the GAIA 5G smart-campus, located in the Espinardo campus of the University of Murcia (Spain). In the first place, its technological architecture is presented, detailing the multi-access platform that provides 5G, Internet of Things (IoT), and vehicular communications connectivity. Also, the virtualized computation environment is described. Thanks to these two pillars, GAIA 5G has the potential to host diverse use cases in multiple verticals, such as 5G connectivity, Network Function Virtualization (NFV) management and orchestration, or cybersecurity, which are also described. As discussed along the paper, GAIA 5G is an operative smart-campus infrastructure ready to support state-of-the-art research and accommodate novel 5G-and-beyond (B5G) test cases.

Keywords: Smart-campus · 5G · MEC · SDN · NFV · IoT · B5G.

1 Introduction

The convergence of multiple radio access technologies in a single scenario is fueling the development of smart environments. This is true specially in urban settings, thanks to the omnipresence of broadband solutions such as Wi-Fi or cellular networks, e.g., 4G/5G, together with the incipient expansion of the Internet of Things (IoT)-based solutions, e.g., LoRaWAN, Sigfox, or Narrow Band IoT (NBIoT). Given the different features provided by these technologies, the range of enabled applications is huge, including user-centric, vehicular, sensorization services, etc. [2].

Smart-campus spaces are gaining relevance as they provide similar characteristics to those offered by smart-cities but at a lower scale, which is notably interesting for research and development purposes [17]. Thus, different academic institutions are investing important resources and efforts for turning their traditional facilities into a rich smart-campus environment to promote multidisciplinary research among their academics as well as the arrival of visiting researchers [3].

In this line, as depicted in Fig. 1, the University of Murcia (Spain) is developing its own smart-campus infrastructure encompassing different state-of-the-art radio access, virtualization, and computation technologies. As comprehensively detailed in next sections, the GAIA 5G smart-campus provides a private functional 5G infrastructure, which is the pivotal element of its communication architecture. Besides, attached to its core network other radio technologies are also available with different purposes: Wi-Fi for improved indoor coverage, LoRaWAN and NBIoT for IoT applications, and 802.11p-based radio access for vehicular services. From a computational and virtualization perspective, the infrastructure is currently equipped with a Cloud platform which hosts the core network components, as well as Software Defined Networking (SDN), Network Function Virtualization (NFV) and Multi-Access Edge Computing (MEC) deployments. Still under development, since its origins, GAIA 5G has enabled previous research advances [13, 14, 11] and it is currently being employed in different European projects such as 5G-MOBIX [16], 5GASP [4], or INSPIRE-5Gplus [10], among others.

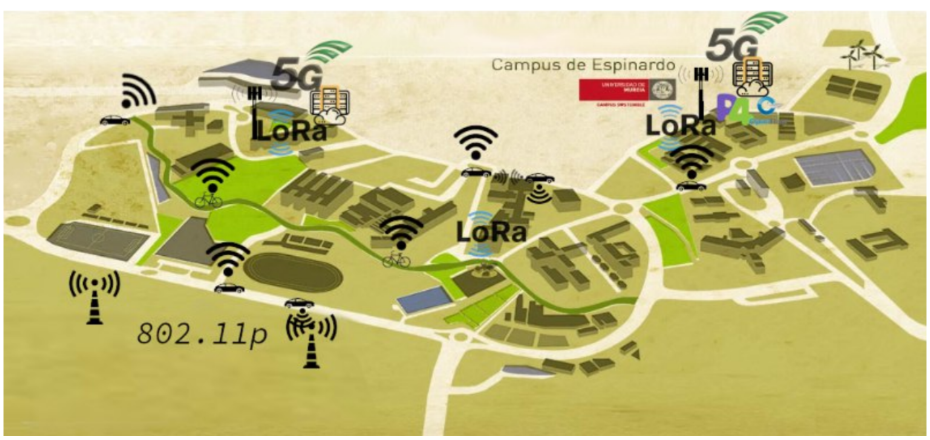

Fig. 1. University of Murcia's GAIA 5G architecture.

The main objective of this work is to present the GAIA 5G smart-campus architecture to the community. Therefore, its principal characteristics will be dissected along the paper and three different illustrative use cases will be also described. Concretely, the aim of these demonstrators is to evidence the functionality of the infrastructure in different planes, namely, 5G connectivity, NFV management, and cybersecurity. Therefore, the contribution of this work is twofold: (i) A detailed overview of the University of Murcia's smart-campus GAIA 5G is given, and (ii) the description of recent functional demonstrators implemented over the GAIA 5G infrastructure are presented.

The rest of the document is organized as follows. Section 2 discusses about other functional smart-campus infrastructures in order to place in context the GAIA 5G one. Section 3 describes the GAIA 5G smart-campus architecture. Three illustrative use cases and their preliminary results are presented in Section 4. Finally, the paper is closed in Section 5, remarking the most important facts as well as future research lines.

2 Background

The idea of increasing the level of intelligence and automation of university campuses has been explored in the literature during the last years from multiple points of view. From a sustainability perspective, authors in [8] included IoT and data science mechanisms for monitoring and managing university energy-related activities to help efficient decision making in all levels. The presented proposal was focused on enabling good sustainability indicators through the establishment of monitoring systems that permit regular data collection with certain levels of quality, to ease the decision-making processes of involved stakeholders. From a Cloud computing point of view, in [6] a smart-campus service platform based on Cloud computing aiming at promoting the development of smart-campuses was presented. Apart from the infrastructure considerations, this work also focused on teaching-related issues such as course and equipment management and identity authentication access. From an AI perspective, work in [7] explored the creation of an open AI platform to achieve multi-application integrated management. The architecture of this platform can integrate all the services deployed in the smart-campus and enhance its management capabilities with dynamic and sustainable development. From a network infrastructure angle, Njah *et al.*[9] presented a fully-programmable SDN architecture with a multi-flow optimization model to manage the massive number of heterogeneous traffic flows that are typically generated in smart-campuses scenarios. The proposed solution is ready to be implemented in all kind of scenarios and can be integrated also with a large IoT environment. Regarding multi-access infrastructures, work in [5] presented a smart-campus framework based on a 5G test network, sensor technologies, augmented reality, and AI. The framework functioning is oriented towards three main use cases: university key operations, campus services, and campus surroundings. Besides, this research showed that a local micro operator would be an essential action to fulfill the smart-campus requirements. Finally, work in [1] presented a comprehensive review of the research efforts during the last decade and current challenges related to smart-campuses. The survey work pointed out that the main challenges in this field are the interoperability among heterogeneous entities, infrastructure sustainability, and the open data access policies.

In this way, the objective of this work is to present the GAIA 5G smart-campus as a research and development playground. The environment found in smart-campuses is very similar to the one found in smart-cities, but in a reduced scale with less people and buildings. However, it has to offer the same set of characteristics and services. In this way, the introduction of the GAIA 5G research and development smart-campus will pave the way to the design and shaping of new services and applications that could be later directly transferred to smart-cities scenarios.

3 GAIA 5G: A smart-campus Architecture

The GAIA 5G smart-campus is an initiative funded by the Spanish Ministry of Science and Innovation through the European Regional Development Fund (ERDF) with the aim of providing the Murcia Region with the necessary technological infrastructure to reach excellence in areas such as logistics and agriculture, in which the Region is already a reference. The University of Murcia is in charge of the deployment and management of the infrastructure and at the same time relies on it to materialize its smart-campus vision. To this end, a multi radio access technology focused on empowering broadband-, IoT-, and vehicular-oriented vertical services is being deployed.

3.1 Technical Description

The already functional GAIA 5G backbone network presents a twofold purpose. On the one hand, the network devices provide a production-ready environment in which a more traditional and well-tested network management approach is used; on the other hand, the backbone devices need to be compliant with state-of-the-art networking technologies, e.g., SDN or NFV, and also be capable of providing advanced network management strategies such as network slicing or dynamic resource allocation, among others. To this end, the employed switches, namely, Delta AG7648 white boxes, run PicOs which is able to manage the Broadcom's data plane as a regular switch but also provide cross-flow ports that can be attached to different OpenVSwitch instances. Therefore, in the future a pure OpenFlow approach can be deployed making use of the same devices.

However, OpenFlow is not the unique solution to manage SDN-based infrastructures and it is regarded as ossified in terms of development of new protocols. Thus, to provide with beyond state-of-the-art protocol match-action capabilities at line-rate, the backbone infrastructure is also provisioned with P4-compliant devices (EdgeCore Wedge 100bf-32X and APS-BF2556X-1T) that permit complete programmability of both the control and data planes, removing the constraints imposed by white boxes with vendor-managed data-planes. Finally, from a capacity point of view, the backbone is provisioned with 40 Gbps trunks between buildings and 10 Gbps service ports, which can be upgraded up to 100 Gbps ports after properly configuring the P4 devices.

Considering the available radio access technologies, firstly it is worth mentioning that GAIA 5G offers 5G Stand Alone (SA) access empowered by a commercial fully functional solution from Amarisoft. Concretely, the 5G infrastructure presents two macro cells (see Fig. 1) enabled by their respective Remote Radio Heads (RHHs), which are connected via Common Public Radio Interface (CPRI) fiber links to a gNB powered by the Amarisoft software. These RRH provide 20 MHz each with a 2x2 MIMO configuration and 20 W of Radio Frequence (RF) power. Besides, GAIA 5G also presents a 5G laboratory, located at the Computer Science faculty that provides small-scale testing via different Software Defined Radio (SDR) devices (various BladeRF x40, Ettus USRP B210, N310) and also an Amarisoft Callbox, with 3 2x2 full duplex SDR elements and an Amarisoft Simbox, capable of simulating up to 64 User Equipments (UEs). This laboratory is connected to the rest of the GAIA 5G backbone via two 10 Gbps dedicated links. This lab testbench is further equipped with assorted RF equipment like spectrum analyzers, signal generators, etc. Other specialized 5G tools like the Keysight Nemo for network performance validation, the Anritsu's MS2090A for New Radio (NR) layer 1 validation, and diverse 5G SA capable modems are available as well as different embedded solutions to deploy and demonstrate multiple IoT scenarios. Besides the professional Amarisoft software, the experimental Free5GC 5G core, which is a full 5G core instance developed as an open source implementation based on microservices, is also deployed and running for researching purposes.

In order to provide long-range IoT connectivity inside the campus, GAIA 5G also provides LoRaWAN access. This infrastructure relies on three Kerlink iStation gateways distributed along the campus (see Fig. 1). These gateways, working in the 868 MHz band, are connected to a self deployed LoRaWAN network server based on the Chirpstack implementation. The data received by the gateways are also forwarded to The Things Network (TTN) servers aiming at enabling an open access to this widespread IoT network. Besides, NB-IoT can also be integrated into the architecture by external providers as to compare different Low Power Wide Area Network (LPWAN) solutions [15]. This unique mix of radio access technologies has enabled the development of solutions like the on-device smart selection of access network [12].

Besides the coverage offered by 5G and IoT radio technologies, a vehicular-specific communication solution has been deployed to evaluate different alternatives in this crucial vertical sector. Concretely, a 802.11p-based infrastructure has been installed at the south area of the campus (see Fig. 1). The adopted 802.11p solution is based on the OpenWRT system, which enables the deployment of both On-Board Unit (OBU) and Road-Side Unit (RSU) software on a variety of hardware platforms such as Raspberry Pi or similar boards, or even more powerful x86-64 devices. As can be seen, with the different available radio access deployments, diverse Intelligent Transportation Systems (ITS) solutions can be evaluated, such as the 802.11p-based ITS-G5 scheme or the cellular-powered C-V2X alternative.

Finally, regarding the computation infrastructure, GAIA 5G is currently equipped with a Cloud platform which hosts core network components, as well as SDN, NFV and MEC deployments. Two Virtual Infrastructure Managers (VIMs) based on OpenStack are currently operative; OpenStack's Rocky version, a full-fledged deployment offering 160 vCPUs and 512 GB RAM split in two Compute nodes; and Openstack's Queens version, a lightweight deployment providing 12 vCPUs with 48 GB RAM and some Raspberry Pi nodes with 4 vCPUs and 8GB RAM. Additionally, the laboratory offers an Hyper-Converged infrastructure with a 4-node cluster with 128 vCPUs and 4 TB RAM and two Edge clusters with 24 vCPUs and 512 GB RAM each, which extends the VIM capabilities and offers MEC provisioning. All these nodes are interconnected using the aforementioned P4 and SDN-enabled programmable devices. To manage and orchestrate the dynamic deployment of VNFs in this infrastructure, Open Source MANO (OSM) is the chosen orchestrator. Besides, a Kubernetes cluster is deployed and tested to complete the computation infrastructure and offer a different VIM alternative.

4 Use Cases

4.1 5G Connectivity

One of the principal challenges when a new radio-communication infrastructure is deployed is to ensure its connectivity and reachability along the covered area. During the design phase, a series of location were considered in order to place the two 5G base stations described in the previous section. Finally, the two points indicated in Fig. 2 were selected given the joint coverage provided along the campus. Given the importance of having a good 5G coverage for supporting current and present test cases, the first functional demonstrator within the GAIA 5G infrastructure was oriented to validate the 5G deployment.

In this use case, a High Definition (HD) video delivery service was enabled for the local fire brigade. Concretely, a fire truck, a drone, and a firefighter were provisioned with 5G connectivity for allowing the production and reception of several video-flows in real-time. Both, the truck's On-Board Unit (OBU) and the drone made use of a USB 5G modem connected to their Linux-based processing platforms, while the firefighter employed a commercial 5G smart-phone. Besides, a multimedia dashboard where all the video-streams were cast was developed and placed at an Edge node (Fig. 3). The aim of this joint initiative together with the city of Murcia's fire brigade, is to increase the effectiveness and safety of risky operations by making these video-flows accessible to the deployed units (including individuals and vehicles) as well as the emergency control center. This successful preliminary evaluation of the infrastructure 5G connectivity is currently being further developed with the implementation of network slicing mechanisms to ensure the Quality of Service (QoS) offered to this kind of critical applications.

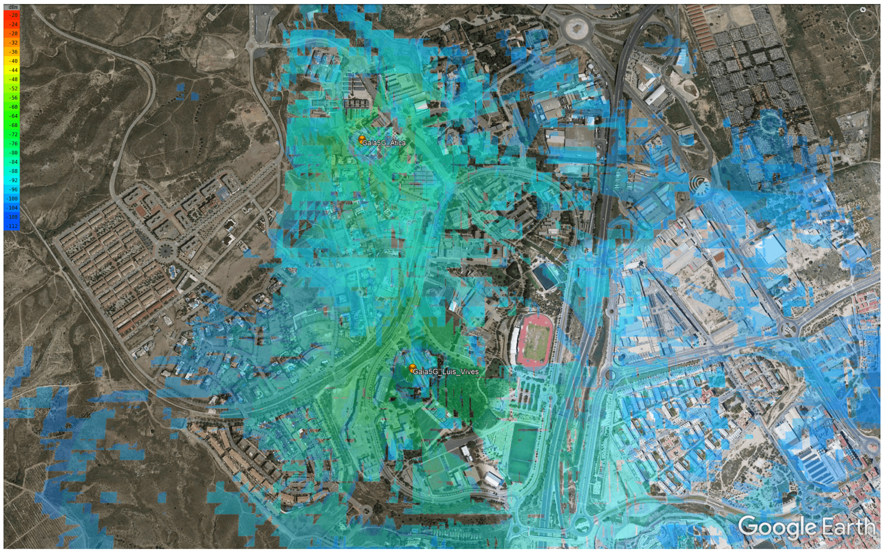

Fig. 2. 5G coverage in the campus calculated as NR RSRQ dBm.

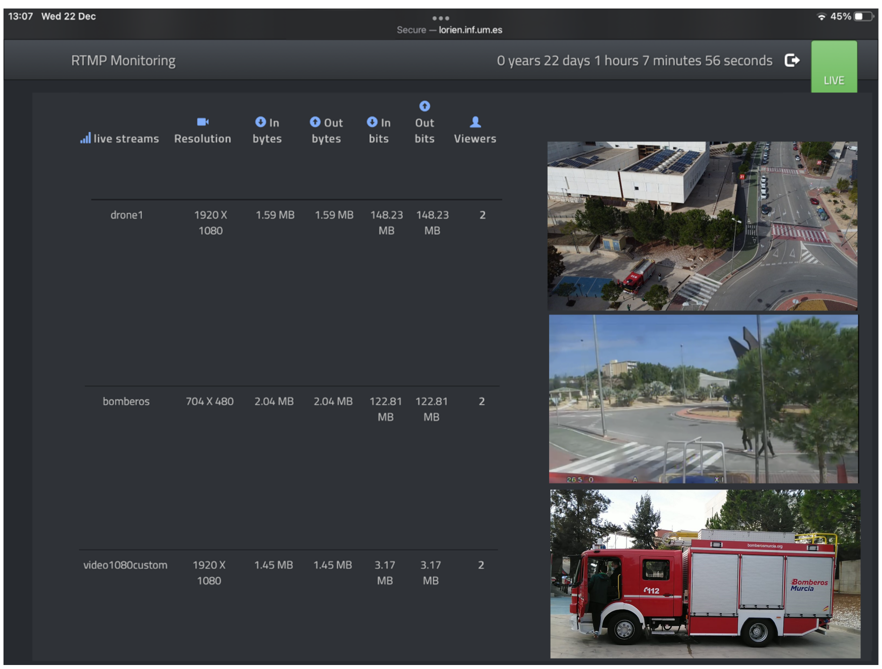

Fig. 3. 5G-enabled video-flows dashboard.

4.2 NFV Management

Regarding Network Function Virtualization (NFV), it is worth mentioning that virtualization technologies and their use as network function enablers resulted in an explosion of alternatives to deal with new and on-demand deployments. These so-called Virtual Network Functions (VNFs) are considered the present and future of new architectures such as 5G. Nonetheless, they can not be regarded as totally independent functions, as their synchronization and coordination (subsumed under the term of NFV Orchestration) is crucial for their proper operation and handling. Furthermore, preparing the underlying infrastructure to be used along with NFV is a fundamental, but also complex and transversal, process that requires a significant effort.

In this line, the H2020 project 5GASP, in which GAIA 5G is involved through a collaboration between the University of Murcia and Odin Solutions (a private company), aims to ease the VNF development and on-boarding processes by offering a "ready-to-use" infrastructure. Its objective is to shorten the idea-to-market process by creating an automated, self-service, European testbed for Small-Medium Enterprises (SMEs) to foster the development and testing of innovative NFVs (NetApps (Network Applications) in 5GASP jergon) using the 5G and NFV-based reference architecture.

The smart-campus architecture presented in this work is one of the physical settings that are being integrated in the 5GASP ecosystem. It provides the experimenters with the underlying infrastructure and tools required to test and validate their NetApps in a real-world 5G network (see Fig. 4). In this case, as mentioned previously, GAIA 5G uses OSM as NFV orchestrator and two OpenStack substrates that serve as VIMs for the facility. Besides, the Murcia testbed offers to 5GASP multiple types of User Equipment (UE) in the form of 5G SA

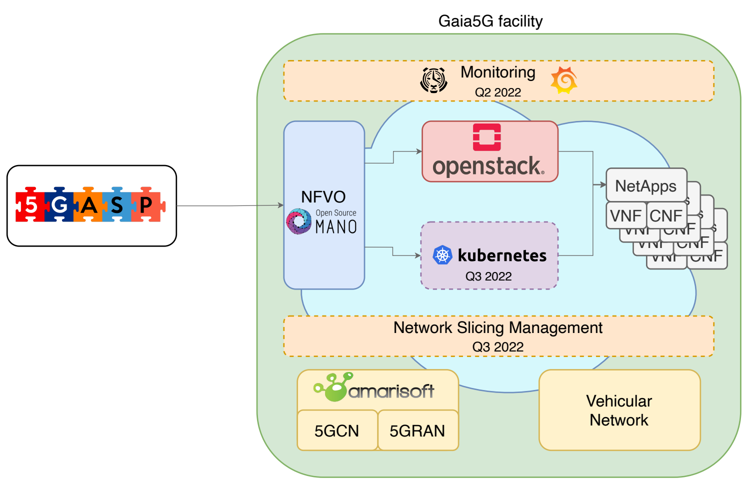

Fig. 4. University of Murcia's 5GASP framework.

smartphones and modems, and vehicular On-Board Units (OBUs) to host the user applications of the NetApps deployed in the framework.

4.3 Cybersecurity

5G is changing the way we interact with services, leaving aside static and rigid configurations and services. 5G networks, interconnect an heterogeneous set of devices and technologies and offer services tailored to the needs of the connection and the constraints of those technologies and devices. This wide diversity becomes a major challenge when it comes to ensuring cybersecurity, as the possible attack surface becomes complex and difficult to manage. This challenge is even greater with the onset of the pandemic, where the flexibility and scalability that characterizes 5G becomes a must. Millions of companies standardize teleworking while users change their habits and are connected to the network 24 hours a day. This causes the network congestion to reach unprecedented levels and, together with the increase in the attack surface, cybercrime is finding a perfect place to take place.

In this regard, the University of Murcia-participated INSPIRE-5Gplus project leverages Zero touch network & Service Management (ZSM) architecture (defined by ETSI) to deliver automated E2E policy-based security management driven by a closed-loop of 5G and B5G networks. Fig. 5 showcases the INSPIRE-5Gplus high-level architecture, that presents a two-tier hierarchical architecture. On the one hand, it provides Security Management Domains (SMDs) that are horizontally positioned, with self-management capabilities that allow the orchestration of dynamic reactions to security events or security predictions that occur at intra-domain level (inside of the SMD). On the other hand, these SMDs are coordinated, directed and validated through an E2E Security Management Domain (E2E SMD) that orchestrates proactive and reactive E2E security policies by involving multiple SMDs (inter-domain).

The INSPIRE5G-PLUS closed-loop is a combination of the stages of OODA (Orient-Observe-Decide-Act) and MAPE-K (Monitor-Analyse-Plan-Execute Knowledge) models with integration of cognition capabilities leveraging AI/ML techniques. Conceptually there are two interconnected loops, the outer loop which is managed including the E2E SMD orchestration and policy distribution to the different SMDs and the inner loop which is present on each SMD to maintain its self-management capabilities. Each loop is formed by Governance, Action, Observation, Orientation and Decision which heavily relies on the knowledge that is generated and needs to be trustable. This ZSM approach as identified and defined by ETSI, relies on the use of integration fabrics. These fabrics provide communication and security capabilities between and within the SMDs as well as other service management features such as registration, discovery that needs to be performed inter/intra-domain.Isolation features are not only provided within computers but also on the network itself. To this aim, network slicing is also provided across multiple self-managed SMDs.

To validate the implementation of the framework in a real 5G environment, a part of INSPIRE-5GPlus framework has been deployed in GAIA 5G smart

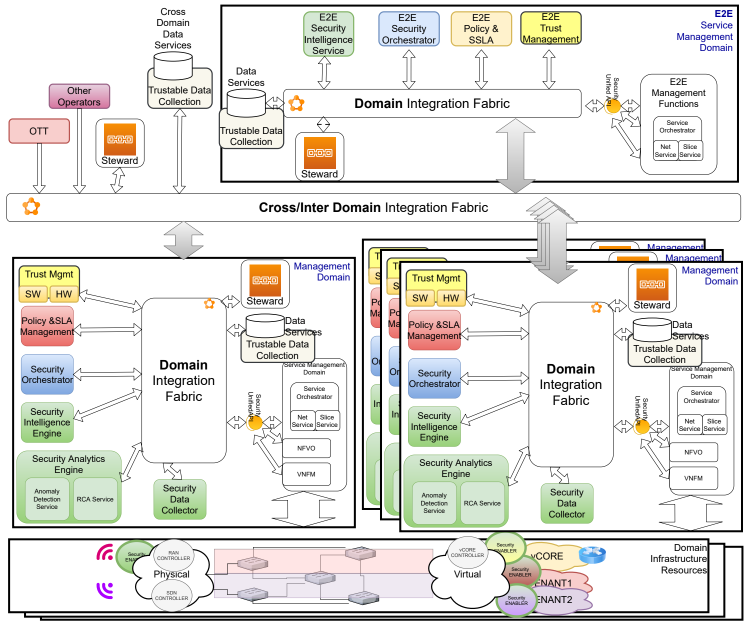

Fig. 5. INSPIRE-5Gplus framework.

campus. Current experiments are specially focused on providing dynamic E2E 5G security involving different SMDs such as 5G Core, transport and RAN by orchestrating dynamically 5G, SDN and NFV resources.

5 Conclusion

Smart-campuses are acquiring great relevance as they permit increasing the automation, monitoring, and control of the complex university infrastructures. Besides, from a research perspective, they are understood as small-scale smart-city environments where bounded and controlled tests may be conducted before their final deployment in larger scenarios. In this work, the University of Murcia's smart-campus infrastructure, so-called GAIA 5G, has been presented. Firstly, the available multi radio access scheme, encompassing 5G, IoT, and vehicular communication technologies, has been described. This range of connectivity alternatives permits the implementation of a plethora of services and vertical use cases. Besides, GAIA 5G presents a rich and powerful computation infrastructure that allows the exploitation of state-of-the-art virtualization schemes considering the different domains within the architecture: Fog, Edge, and Cloud. Finally, a series of demonstrators have been discussed with the aim of evidencing the potential of the infrastructure. Although it is in an advanced deployment status, GAIA 5G will continue evolving to integrate novel B5G technologies and enable the development and evaluation of new application and services.

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References

1. Chagnon-Lessard, N., Gosselin, L., BarnabÃľ, S., Bello-Ochende, T., Fendt, S., Goers, S., Silva, L.C.P.D., Schweiger, B., Simmons, R., Vandersickel, A., Zhang, P.: Smart campuses: Extensive review of the last decade of research and current challenges. IEEE Access **9**, 124200–124234 (2021). https://doi.org/10.1109/ACCESS.2021.3109516
2. Cirillo, F., Gomez, D., Diez, L., Elicegui Maestro, I., Gilbert, T.B.J., Akhavan, R.: Smart City IoT Services Creation Through Large-Scale Collaboration. IEEE Internet of Things Journal **7**(6), 5267–5275 (jun 2020). https://doi.org/10.1109/JIOT.2020.2978770, https://ieeexplore.ieee.org/document/9026979/
3. Dong, Z.Y., Zhang, Y., Yip, C., Swift, S., Beswick, K.: Smart campus: definition, framework, technologies, and services. IET Smart Cities **2**(1), 43–54 (mar 2020). https://doi.org/10.1049/iet-smc.2019.0072, https://onlinelibrary.wiley.com/doi/10.1049/iet-smc.2019.0072
4. Gallego-Madrid, J., Sanchez-Iborra, R., Skarmeta, A.: From Network Functions to NetApps: The 5GASP Methodology. Computers, Materials & Continua **71**(2), 4115–4134 (2022). https://doi.org/10.32604/cmc.2022.021754, https://www.techscience.com/cmc/v71n2/45796
5. Jurva, R., Matinmikko-Blue, M., NiemelÃď, V., Nenonen, S.: Architecture and operational model for smart campus digital infrastructure. Wireless Personal Communications **113**(3), 1437–1454 (2020). https://doi.org/10.1007/s11277-020-07221-5
6. Li, Y.: Research on building smart campus based on cloud computing technology. In: 2020 5th International Conference on Mechanical, Control and Computer Engineering (ICMCCE). pp. 723–726 (2020). https://doi.org/10.1109/ICMCCE51767.2020.00159
7. Liang, W.: Analysis of the application of artificial intelligence technology in the construction of smart campus. In: 2020 International Wireless Communications and Mobile Computing (IWCMC). pp. 882–885 (2020). https://doi.org/10.1109/IWCMC48107.2020.9148200
8. Negreiros, I., Francisco, A.C.C., Fengler, F.H., Faria, G., Pinto, L.G.P., Tolotto, M., Rogoschewski, R.B., Romano, R.R., Netto, R.S.: Smart campusÂő as a living lab on sustainability indicators monitoring. In: 2020 IEEE International Smart Cities Conference (ISC2). pp. 1–5 (2020). https://doi.org/10.1109/ISC251055.2020.9239017

9. Njah, Y., Pham, C., Cheriet, M.: Service and resource aware flow management scheme for an sdn-based smart digital campus environment. IEEE Access **8**, 119635–119653 (2020). https://doi.org/10.1109/ACCESS.2020.3005569
10. Ortiz, J., Sanchez-Iborra, R., Bernabe, J.B., Skarmeta, A., Benzaid, C., Taleb, T., Alemany, P., Muñoz, R., Vilalta, R., Gaber, C., Wary, J.P., Ayed, D., Bisson, P., Christopoulou, M., Xilouris, G., de Oca, E.M., Gür, G., Santinelli, G., Lefebvre, V., Pastor, A., Lopez, D.: INSPIRE-5Gplus: Intelligent security and pervasive trust for 5G and beyond networks. In: Proceedings of the 15th International Conference on Availability, Reliability and Security. pp. 1–10. ACM, New York, NY, USA (aug 2020). https://doi.org/10.1145/3407023.3409219, https://dl.acm.org/doi/10.1145/3407023.3409219
11. Sanchez-Gomez, J., Gallego-Madrid, J., Sanchez-Iborra, R., Santa, J., Skarmeta Gómez, A.F.: Impact of SCHC Compression and Fragmentation in LPWAN: A Case Study with LoRaWAN. Sensors **20**(1), 280 (jan 2020). https://doi.org/10.3390/s20010280, https://www.mdpi.com/1424-8220/20/1/280
12. Sanchez-Iborra, R., Bernal-Escobedo, L., Santa, J.: Machine learning-based radio access technology selection in the internet of moving things. China Communications **18**(7), 13–24 (2021). https://doi.org/10.23919/JCC.2021.07.002
13. Sanchez-Iborra, R., Sanchez-Gomez, J., Santa, J., Fernandez, P.J., Skarmeta, A.F.: IPv6 communications over LoRa for future IoV services. In: 2018 IEEE 4th World Forum on Internet of Things (WF-IoT). pp. 92–97. IEEE (feb 2018). https://doi.org/10.1109/WF-IoT.2018.8355231, https://ieeexplore.ieee.org/document/8355231/
14. Sanchez-Iborra, R., Santa, J., Gallego-Madrid, J., Covaci, S., Skarmeta, A.: Empowering the Internet of Vehicles with multi-RAT 5G network slicing. Sensors **19**(14), 3107 (jul 2019). https://doi.org/10.3390/s19143107, https://www.mdpi.com/1424-8220/19/14/3107
15. Santa, J., Bernal-Escobedo, L., Sanchez-Iborra, R.: On-board unit to connect personal mobility vehicles to the iot. Procedia Computer Science **175**, 173–180 (2020). https://doi.org/https://doi.org/10.1016/j.procs.2020.07.027, https://www.sciencedirect.com/science/article/pii/S1877050920317063, the 17th International Conference on Mobile Systems and Pervasive Computing (MobiSPC),The 15th International Conference on Future Networks and Communications (FNC),The 10th International Conference on Sustainable Energy Information Technology
16. Serrador, A., Mendes, C., Datia, N., Cota, N., Cruz, N., Beire, A.R.: A Performance Measurement Platform for C-ITS over 5G. In: Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit). pp. 478–483. IEEE (jun 2021). https://doi.org/10.1109/EuCNC/6GSummit51104.2021.9482603, https://ieeexplore.ieee.org/document/9482603/
17. Villegas-Ch, W., Palacios-Pacheco, X., Luján-Mora, S.: Application of a Smart City Model to a Traditional University Campus with a Big Data Architecture: A Sustainable Smart Campus. Sustainability **11**(10), 2857 (may 2019). https://doi.org/10.3390/su11102857, https://www.mdpi.com/2071-1050/11/10/2857