



Architecture and Operational Model for Smart Campus Digital Infrastructure

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Abstract

Nations and cities are eagerly joining the global trend of transition to digitized society. Through digitalization, societies aim to streamline their key functions and to develop modern services to inhabitants. 5G wireless networks are being built globally with lots of expectations put on them. It is anticipated that at the first phase of 5G, the technology will benefit the most different verticals like factories, hospitals and campuses. Universities have likewise awoken to establish digitalization projects to respond to the disruption of education and to overcome in the growing global competition. The transition to digital campus will inevitably rely on campus ICT and IoT infrastructures. Additionally, the number of terminals, devices, sensors and robots will multiply. This article proposes a technical architecture for future Smart Campus consisting of 5G and IoT networks complemented by distributed computing and data analytics. Increasing complexity of digital environment calls for a specific actor to operate the Smart Campus infrastructure and also services, which has not been widely discussed. It is foreseen that the university IT Administration is probably not willing to adopt the responsibility of enlarging infra and growing number of devices. Similarly, mobile network operators are not seen appropriate to take this role being commonly profiled to offer merely connectivity. To tackle this question, a novel operational model for the Smart Campuses is presented based on the recently proposed micro operator concept. Moreover, a case study of the University of Oulu campus is presented, where smart technology in the form of 5G test network has been deployed.

Keywords Smart Campus · 5G · Vertical · Local network · Micro operator · Mobile network operator

1 Introduction

Digital transition is strongly ongoing in many sectors of society. This phenomenon has significance also from the urbanization perspective, where cities need to develop their capability to manage and serve a growing number of inhabitants. The cities are challenged

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to solve the development of persuasive services to crowds and to produce these services efficiently through digitalization, which is expected to enable streamlining of complex processes allowing the development of advanced smart services. At the same time there is a growing migration of people moving to cities [1]. These trends and phenomena assume cities to develop seamless co-operations between business life, educational institutes and different societal functions [2]. To develop intelligent location specific services, ICT and IoT technology deployments play a significant role [3–5]. They assume careful consideration on what type of systems to implement to get the full benefit from investments. High technologies like 5G networks together with IoT sensor networks and data analytics are expected to generate evolution in various verticals such as e.g. industry, health care, energy and education to mention a few [6]. Furthermore, it is foreseen, that the new technologies will bear all new business models in many sectors [7]. Universities likewise need to catch up in the digitalization. This is emphasized by the fact, that in the past years we have seen the increasing emergence of virtual universities. They enable students to choose courses from global offering which brings a revolutionary change compared to past. There are several other benefits that a virtual university may offer like higher quality of teaching, hi-tech learning environments, global networking and career opportunities [8]. The universities for face-to-face meetings will be indisputably needed also in the future, but they face a challenge in defining how and with what kind of role they stay attractive and competitive. A Smart Campus can be considered to offer sophisticated services and individual information for students, teachers, researchers and visitors based on their profile [9]. Furthermore, the students want to learn working in the digital world. This is partly what numerous Smart Campus projects are trying to solve [2, 10]. Nowadays, students set high requirements for their education. Sitting in a classroom and listening, writing, exercising and demonstrating are not the only means of education anymore. Technological development has been clearly visible in education environments, which has raised also concerns about the technology-enhanced learning benefits [11]. Students expect increasingly, that the learning environment is high quality both technically and content-wise. Moreover, they have a chance to choose when and where to study. A wide selection of courses is available in virtual universities globally and studying can be done at any time of the day. As a practical example, it is attractive to participate in a lesson of a world-famous professor even if it is remote studying. Subsequently, university campuses need to consider how to profile themselves and compete with virtual campuses. As digitalization is behind the smartness, it can be stated generally that modern high technology is in a key role in the Smart Campus environment.

Based on the review of existing literature on Smart Campuses [9, 12–15], there is very little research on 5G network deployments and architecture descriptions in the university campus use cases. There is not much research conducted on the operational aspects of Smart Campuses either. Articles [2, 9, 12, 14, 16] focus on services and applications developed for campus environments, but the actual operational activity of the campus infra is not described. Researchers have recently recognized the operational challenge of local 5G networks and this requires university campus to find alternative models to deploy and operate 5G networks [16–20]. The local operation of a digital infrastructure calls for contributions from different stakeholders, such as mobile network operator (MNO), network infrastructure vendor, network constructor, property owner, and regulator to name a few [17, 18]. The research key outcome was, that a specific vertical service provider, (micro operator) is necessary to accelerate digitalization in different verticals of local 5G networks.

This paper introduces a technical architecture for Smart Campus and proposes a local operational model for Smart Campus. It also presents a case study of the digitalization of the University of Oulu campus where the deployment of new technologies like 5G network,

sensor technology, positioning technology, augmented reality (AR), virtual reality (VR) and artificial intelligence (AI) has been started several years ago. The operational model of Smart Campus was built upon the outcome of research conducted in the university campus. To manage the future Smart Campus infrastructure with increasing complexity and stakeholder expectations, a magnitude of higher effort is required compared to previous campus infrastructures. The model introduced here is named as micro operator (uO) ecosystem.

The rest of this paper is structured as follows. Section 2 reviews related work on the Smart Campus concept in the wider context. Section 3 proposes a Smart Campus framework including operational aspects. Section 4 presents the findings of Smart Campus case study at University of Oulu including a realization of the architecture. Section 5 presents conclusions of the article.

2 Related Work

2.1 Realizations of Smart Campuses

There are numerous studies conducted about Smart Campus realizations or concepts [9, 12–15] whereof many are focusing on technological frameworks and architectures in particular use cases. Authors in [12] consider managing the growing number of devices and applications in campus. They propose a model of role-based campus network slicing using an OpenFlow based authentication controller and virtualization technology. The target is to divide the campus network into virtual networks based on user types, which typically have varying service requirements. Authors in [13] describe a Smart Campus construction based on IoT sensors or devices and big data management and analysis in cloud. A framework composed of four pillars is proposed including communication, environmental, data and service frames and functionalities from data collection to offering of services. Moreover, the author presents a comprehensive system architecture consisting of six functional layers: sensing layer, network communication layer, cloud computing layer, big data layer, application layer and intelligent terminal layer with the vertical support systems including information security service and system operation and maintenance service. Similarly, a Smart Campus is constructed in [14] based on IoT network and cloud computing. The author presents the IoT system framework and education cloud system framework. Subsequently, a three-layer Smart Campus model is presented including portal architecture, management, service and decision support layer, smart learning and management layer, and infrastructure layer. Additionally, an application framework is introduced, in which various entities like teaching, logistics and library functions of the campus and their specific needs are noted. In [9] different wireless technologies including WiFi, Bluetooth and ZigBee are compared to realize Smart Campus services. The targeted service is to offer specific individual information for students, teachers, researchers and visitors. The complete system consists of beacons, a smartphone application and a database with management functionality for updating information and for administering the system. The infrastructure and architecture are very light but suitable for the targeted purpose. Finally, in [15] the authors introduce a similar layered model and emphasize the importance of extendable architecture for easy adding of new data sources. The framework is based on three pillars, which are IoT network of mobile and fixed sensors for data collection, ubiquitous computing to enable computing anytime everywhere and crowdsourcing (crowdsensing) model, where the users act also as data producers with their mobiles.

2.2 Operational Models

Recent technical articles about Smart Campus concepts have primarily focused on platforms, architecture and services, which are undeniably the cornerstones when developing any intelligent environment [9, 15, 21, 22]. The authors in [15] introduce a case where the focus is to define intelligent services and architecture behind them to produce data and to generate contents. The paper emphasizes the importance of extendable architecture presenting a model developed by the authors. Finally, the paper introduces examples of Smart Campus applications. Another Smart Campus paper [9] targets to propose a solution for university wireless infrastructure development, which is grounded on deployment of beacons. The paper introduces a comparison of different wireless technologies after which the authors focus on describing the hardware and software solution in detail. Benefit of the solution is that, it is flexible and can be adopted in many types of smart environments. Author in [14] introduce a system framework in IoT environment as well as higher level Smart Campus model. Moreover, an application framework is presented considering the specific functions and society groups of a university. Article [13] presents smart city business models using Osterwalder's Canvas. The modelling is conducted for city services (e.g. water, waste, traffic) comparing conventional service management and service management with IoT. The analysis defines the local university to manage IoT infrastructure, but does not describe it in detail. Paper [2] describes comprehensively both smart city and Smart Campus development but finally focus on IBM software platform for infrastructure management.

Smart Campus infrastructure management has recently become an important research topic to raise in discussion. Another point of view of the authors in [17] is the operational aspect of local campus 5G network. Generally, the transition to digitalized environment assumes extensive deployments of ICT and IoT infrastructure. When considering beneficial implementation of the most enhanced characteristics of 5G technology like ultra high data rate and low latency it is presumed that the 5G networks are deployed indoors or in a limited geographical areas with a dense small cell network topology [19]. Subsequently, the number of terminals, devices, sensors and robots will increase heavily. Despite these facts, it has not been widely discussed who could be an appropriate actor to operate digital Smart Campus infrastructure and services. One could consider the university IT administration to take responsibility of campus network infrastructure operation but seemingly they are not prepared to adopt the role. Another obvious actor in the speculation would be a mobile network operator (MNO). Doubts have been presented if the MNOs are motivated and capable to take the business. Firstly, the MNOs are typically operating national wide area networks and adjusting the business processes to local networks may not motivate them. Secondly, the service requirements of local verticals are continuously tightening to fulfil the specific expectations of each stakeholder. This assumes domain specific competence, which MNOs may not have. A profound research has been conducted to find alternative operator models and to respond to vertical's growing business needs [17–20]. The research demonstrates that a particular micro operator is a vital actor to develop and to fulfil operative's expectations of 5G networks and to accelerate digitalization [19]. The micro operator concept focuses on local 5G networks and suggests an ecosystem model and expected micro operator functions. To deploy 5G network, the micro operator needs a license for frequency spectrum. Perceiving that local licensing has not been enabled by regulation with the past generations of mobile networks, a special model for local frequency licensing has been developed together with authorities [20]. The articles [17, 18] introduce cases of campus

5G deployment and an operational model of a micro operator. The micro operator can be also defined as a local service provider, which runs the campus digital infrastructure and services based on ecosystem model.

2.3 Digitalization of Cities

University has been called university since there is need to achieve more synergy between city and campus. The university is not any more isolated from the city. As university campus are more interlinked with the city it is important to discuss about digitalization and urbanization also in the context of cities. The cities need to solve how to effectively produce sophisticated services to an increasing amount of inhabitants. Considering various population groups desiring to move in, probably one of the most wanted squad for any city are young families. Highly skilled innovative young professionals in turn motivate enterprises to establish specific functions in a city. Tempting of the young professionals to move into the city is commonly done by introducing wide offering of high education institutes. Many of the adolescents choose their favourite city to live based on their professional interests and career plans [23]. The quality of high education is an important competition factor to any city [24]. Moreover, when cities are competing in the transition to develop as smart city, they welcome universities to co-operate in the process to develop enhanced digital services for the inhabitants. Smart city projects commonly aim to compose ecosystems consisting of particular stakeholders having a specific role to contribute to the project [25]. University is typically a desired project partner together with government, private sector, research centres and recently also the civil society representatives [3]. Campus locations and the quality of their facilities and research infrastructure are pull factors for students, professors and researchers in the battle for brains [26, 27]. While smart city projects are usually infrastructure oriented, recently the value of knowledge has been highlighted. This is where universities have been given a dedicated role in terms of knowledge intermediaries, gatekeepers, providers and evaluators, which means tasks like knowledge or technology origination and transfer among projects [3, 28]. On the other hand, universities are seen to have a key role in innovation, integration and engagement in the co-development within smart city ecosystems. It has been proposed, that the traditional tasks of research, education and knowledge should be updated and rethought by emphasizing student's role as key stakeholder to enhance the success of sustainable innovation [28]. Moreover, universities need to seek stakeholders beyond geographical areas of city regions and across different sectors like housing, transport, health and the environment as deem necessary. This assumes that all the key stakeholders understand complex economic, social and environmental trends and are able to co-operate with city's actors as well as to develop long-term plans in insecure conditions [28].

2.4 Technical Framework

A smart environment is commonly assumed to provide sophisticated and advanced services, which are highly focused on context and content in an appropriate location. In the campus environment a smart service means offering of highly location specific generic or individual information for the campus society like students, teachers, researchers, other staff groups and visitors. The services are offered depending on their profile and time of day [9]. In the development of education there has been discussions on personal learning tracks, which means monitoring of learning performance by analysing

student's personal data collected with wearables [29]. Furthermore, positioning enables guidance for people and tracking for specific objects. To realize a Smart Campus with sophisticated services, the fundamental assumption is the deployment of ICT and IoT technology [3–5]. We next present the technical framework, on which the Smart Campus infrastructure and services architecture is based in (Fig. 1). In the technical framework for Smart Campus, sensors and devices are utilized to collect environmental or object specific data, which is typically related e.g. to air-quality, premises control, identification or status monitoring. In 5G era, the amount of sensors, devices and actuators is expected to grow explosively. Wireless technologies are harnessed for data transfer. There are wireless systems both with unlicensed and licensed frequency spectrum in use, applicability of which is case dependent. The unlicensed WiFi and Bluetooth interfaces are workable for many applications though having more performance limitations. The 3GPP standard based cellular wireless systems operating in licensed bands offer higher capacity and reliability.

5G technology brings distributed data processing close to terminals by edge computing. The edge computing can off-load the processing workload from mobile terminals to the network edge server close to the base station. However, it increases processing time together with data transfer time due to distant and increasingly more loaded centralized cloud servers thereby causing long delays, when considering specific delay-sensitive applications [30]. The edge computing thus allows to develop very low latency services; while centralized cloud computing is crucial for larger data volumes generated by significantly growing number of sensors and devices to enable services, which tolerate longer delays. In 5G architecture core network functionality is virtualized in the cloud environment as well as the network services. The computing algorithms are used to refine the data for end user services for various types of terminals. Together with smart phones, the number of various AR and VR goggles, special displays and holograms are increasing.

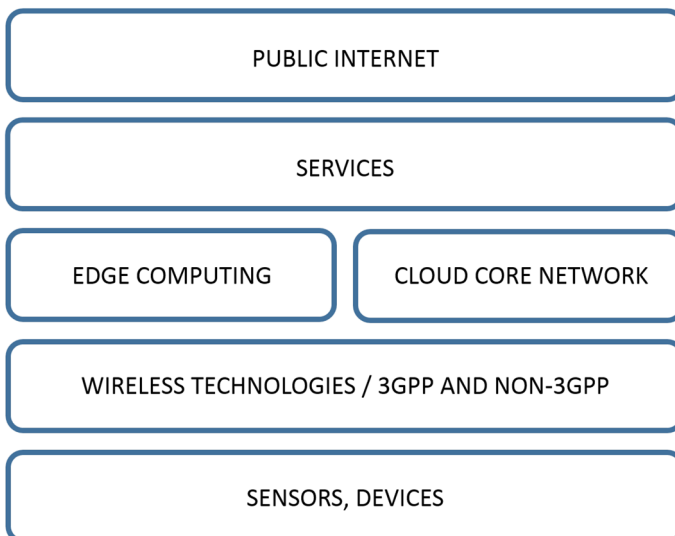


Fig. 1 Technical framework of Smart Campus architecture

3 Proposed Smart Campus Framework

This section introduces the proposed Smart Campus framework that is based on the results of more than 20 interviews of campus stakeholders, when they were asked about expectations and requirements of Smart Campus infrastructure and services. The interviewed stakeholders are located in a university campus, where deployment of 5G test network, sensor technology, AR/VR and AI technology was started few years ago. Various definitions of the Smart Campus may contain technical, functional, stakeholder or service aspects. In this article the framework is approached by dividing the Smart Campus into three functional entities which are combined by technology platform. The three entities of the framework are defined as University key operations, Campus services and Campus surroundings. Each of those is described in detail in the following subchapters. The interviews are likewise described there. The framework was developed based on empirical information, which was gathered by interviewing representatives of various research groups and IT administration of the campus.

3.1 University Key Operations: Education, Research and Support Functions

The University key operations denote the most consequential functions of university related to education i.e. teaching, learning, research, innovation and support functions. Education is under strong transformation where high technology is increasingly being harnessed to support teaching and learning methods. Specifically, AR, VR and AI systems are considered as the most promising technologies to be utilized in modern education methods [28, 29]. Moreover, IoT and 5G networks will be deployed for mass data generation, monitoring and ultra-fast wireless communication to be used for education. Many universities are growingly investing in specific technology infra to offer hi-tech Smart Campus environment for students and researchers. A common use case today is a virtual reality environment where students can step into virtual working place to get adapted with the environment and control some of the production machinery and systems remotely. Demonstrations have been presented about applying 5G technology and mixed reality technology in hospital operation room and in remote location for medical students. Subsequently, in addition to the education in real physical campus, technology utilization benefits universities to attract students to participate in distant lessons from any place globally. Today we are close to enable high quality immersive teaching surroundings for students. It can be assumed e.g. that a medical university would invest in educational operating room with high resolution cameras, mixed reality goggles and high capacity wireless networks. With this special education platform the university enables distant medical students to participate advanced top quality education by following world-class professors teaching and demonstrating demanding surgery operations.

Research is likewise among university's key functions, which assumes a particular setting to succeed. Considering e.g. technical or medical sciences domains, the research facilities are commonly equipped with high technology. It can be anticipated that e.g. AI technology will emerge in essential role in any research domain. Subsequently, the outcome of any research program may lead into pilots and deployments in digital campus environment. Interviews with specific research groups within education, technology, medicine, computing and economics in the university campus have enabled to compose a wider perspective on the expectations towards Smart Campus, which are presented next and summarized in

Table 1 Smart campus contributors

Research group / Contributor	Focus area	Research plan
Wireless communications	Developing test networks to be used in university campus	Deployment of test networks to be offered for others for piloting
Education	Development of interdisciplinary high technology infrastructure	Piloting 5G technology in education
Medicine	Development of high technology operation room	Piloting sensor technology and 5G technology
Computing	Piloting sensor technology and AI for property management	Piloting digital twin system and positioning technology
Economics	Developing novel business models for 5G micro operators	Piloting 5G micro operator business model
IT administration	Maintaining and developing university IT systems	Deployment of positioning system

Table 1. Research group in wireless communications has established the 5G test network in the campus in question. The purpose of test network is to realize a live network to help to reach the aspiring targets set for the extensive wireless communications research executed in the university. More than ten research and industry co-operative projects has been conducted in the test network. Additionally, over 40 organizations have utilized the test network services and the test network community consists of almost 100 members. The test network obviously composes a consequential part of the Smart Campus infrastructure.

Several other research groups exploit the network for interdisciplinary research. Research group in education has conducted comprehensive studies for several years focusing in research of the learning sciences and technology-enhanced learning. The research has covered e.g. wireless networks, mobile tools and internet applications for interaction, collaboration and sharing among users. Moreover, the research has resulted in the deployment of interdisciplinary high technology environment utilizing wireless connectivity, AR/VR technology, 360 video cameras, eye-tracking and biosensor devices to mention a few. Exploiting of 5G technology, IoT devices, AI and robotics are likewise interest areas of the technology-enhanced learning research group. These interest areas connect perfectly with the deployed and planned infra in the specific Smart Campus case described in this article. Moreover, this allows to enhance interdisciplinary research in campus. Another discussion has been ongoing with the research group in medicine, which is likewise engaged with high technology. The interest of this specific group is to study opportunities to employ 5G technology, AR/VR technology and sensor technology in medical operations and in the education of medical students including also distant learning aspects. The described setting has been recently demonstrated successfully. Another study area of interest for the medical technology research group is critical communications in health care having an exemplary use case of communication between ambulance and hospital to produce a snapshot of the patient's condition to hospital care group for starting the required preparations in advance before patient's arrival. Subsequently, specific research programs have been conducted to outline the future hospital technological requirements. Moreover, a test laboratory has been established by the research group to pilot high technology devices and platforms. The research group in economics has carried out technology-focused research covering techno-economic modelling. The research group expects to see specific novel business models, which can be potentially demonstrated in the Smart Campus environment. University educational key functions include support functions, which are likewise experiencing a transition. Digitalization of support functions in Smart Campus framework signify mostly upgrading of existing IT infra and WiFi access points and piloting and deploying new platforms and applications. These actions follow typically university IT strategy authorized by university management. The amount of infra, computers and devices will grow enormously due to the Smart Campus development. The next deployment is the upcoming positioning system. According to the IT Administration it is not eager to adopt the responsibility of enlarging digital ambience.

The research topics and expectations of the interviewed research groups clearly indicate the need for the campus digital infrastructure including e.g. 5G, IoT, AI and AR/VR technology. Together with the technological development of education environments the requirements of research groups show that digitalization is inevitably transforming universities into the new era. Considering the remarkable societal role of universities they need stay in forefront also in technical evolution, which is expected to reflect in the development of other sectors of society. By adopting new technology it allows to advance multidiscipline research, which is seen to have growing importance in terms of finding new innovations. At the first phase the digital campus research pilots will probably result in growing

co-innovation activities between universities, cities and enterprises to develop solutions for Smart Cities. Successful pilots in the campus environment can be up-scaled into city environment to offer future-proof services for inhabitants.

3.2 Campus Services

Campuses are offering increasingly versatile services to the campus community. The services are commonly the same as anyone can have in the city center or shopping centers like restaurants, shops, events, well-being, health and sports. On the other hand, location specific services will become increasingly important, being enabled by 5G and IoT technology. In the Smart Campus ambience it could mean e.g. guidance, property related information, parking and charging of vehicles. The services need to follow the digitalization trend to be easily available and attractive. Interviews with the research group of computing technology revealed that they have examined technology platforms for property management. A pilot has been accomplished by harnessing 5G and IoT sensor network, big data and edge computing and illumination technology in campus premises. The motivation has been to ensure comfortable indoor air-quality with comfortable lightning as well as energy saving in the pilot premises. Moreover, the research group has plans to continue piloting digital twin including accurate positioning to verify its applicability in property management and in creating advanced services for campus society. The interviews likewise highlighted the need for the emergence of a new campus operator to maintain digital systems. Concurrently with the university premises, the Smart Campus connects with the surrounding society assuming to target seamless merging of these two entities. To ensure fusing it requires tight co-operation with the city officials responsible for the Smart City development. Meaningful everyday services for the campus community would be intelligent mobility service covering the development of public transportation and cycling and pedestrian routes smart infra. Mobility services development is likely included in most Smart City projects. Subsequently, seamless merging of campus and municipal services require interoperation of platforms. Interviews with the city officials evidenced the aspiration of co-development of Smart Campus and Smart City. Additionally, sports venues, shopping centers, restaurants, day cares are facile to be connected in Smart Campus ecosystem.

3.3 Smart Technology

The proposed Smart Campus framework leans on high technology. Technology platform is composed of data collection devices, edge computers, data management servers, data refinement algorithms, terminals, applications and user interfaces connected with wireless and fixed networks. 5G technology is expected to enhance the deployment of smart environments significantly. The characteristics of 5G technology as very high speed, low latency and reliability avail to connect vast number of machines, robots and vehicles. Moreover, data produced by IoT sensor networks together with AI technology and accurate positioning systems will further intensify intelligent and autonomous environments to emerge.

Figure 2 illustrates the developed Smart Campus framework. The vertical segments including University Key Operations, Campus Services and Campus Surroundings were described in previous sub chapters. Additionally, the framework contains horizontal segments for Interoperating Platforms, Interdisciplinary Research and Pilots. Interoperating Platforms address the importance of open interfaces and functionality between different

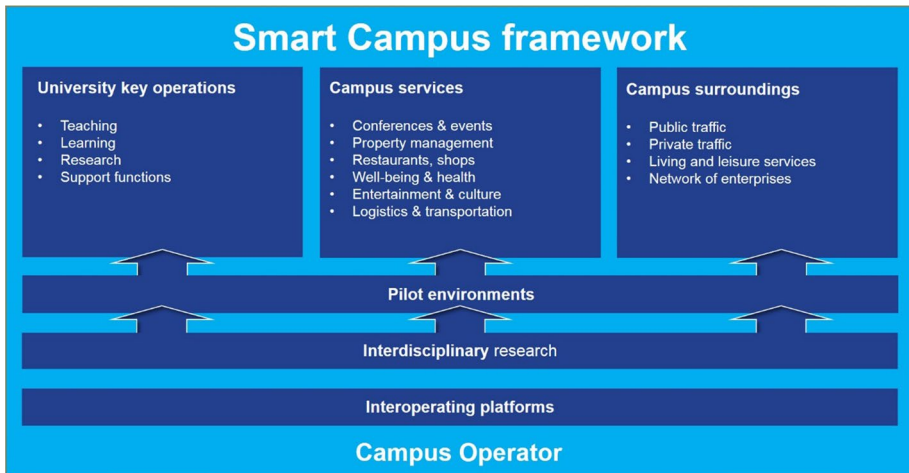


Fig. 2 Smart Campus framework

systems to enable seamless offering of services. Interdisciplinary Research depicts the targeted co-operation of research units. Co-operation of different research groups working on education, technology, medical and economics has the potential to result in unexpected findings allowing to predict unforeseen evolution of Smart Campus. The most promising findings will be verified with pilots and successful pilots will be developed in services for different vertical segments. Finally, the realization of the Smart Campus framework calls for the establishment of a Smart Campus Operator who is the key actor to operate the Smart Campus digital infra and services.

4 Practical Realization

4.1 Operational Aspects

While most of the Smart Campus descriptions demonstrate significantly increasing amount of infra, devices and terminals, very few—if any—of those descriptions consider the operational aspect of Smart Campus. Therefore, it is suggested that the operational challenge will be raised in discussion. Smart Campus deployment will multiply the amount of ICT and IoT infrastructure, devices, machines and robots compared to what has been implemented as existent IT infrastructure in campuses today. Therefore, it is justified to present a question about the management and operation of Smart Campus infra and services i.e. ‘Who will operate the Smart Campus?’ Typically, the IT infra has been managed by university IT administration. Based on the interviews, it is anticipated that IT Administration is not eager to adopt the Campus Operator role. Moreover, when MNOs have implemented and operated wireless networks in campuses and may have deployed an indoor network, they might be regarded an appropriate actor for Smart Campus. However, MNOs are yet commonly profiled as providers of connectivity or ‘bit pipe’ to end-users for which their business models have been tuned. Additionally, MNOs business is focused on national and regional level but not on local networks. For this reason, MNOs are not seen as the most appropriate partners to operate local campus

infra and services. Based on dialogue with verticals in similar circumstances than campus e.g. factories, hospitals or ports intending to deploy smart technology environment they have strict opinions, that a particular new actor needs to emerge to operate increasingly demanding smart environments. Similar outcome has been concluded in 5G technology research. Based on the research about the micro operators described earlier the ecosystem concept can be considered as the most promising actor to operate the Smart Campus digital infrastructure and services. The ecosystem stakeholders are illustrated in Fig. 3 and introduced in the following by applying the Smart Campus case when appropriate.

University functions: Education, research and support functions represent university stakeholders setting requirements for the smart campus operator.

Network infrastructure vendor: Vendor delivers the required network equipment to be deployed by local smart campus operator.

Facility owner: Owner is required for permitting the implementation and potentially to define service requirements. In this special campus case the owner is enthusiastically developing the campus.

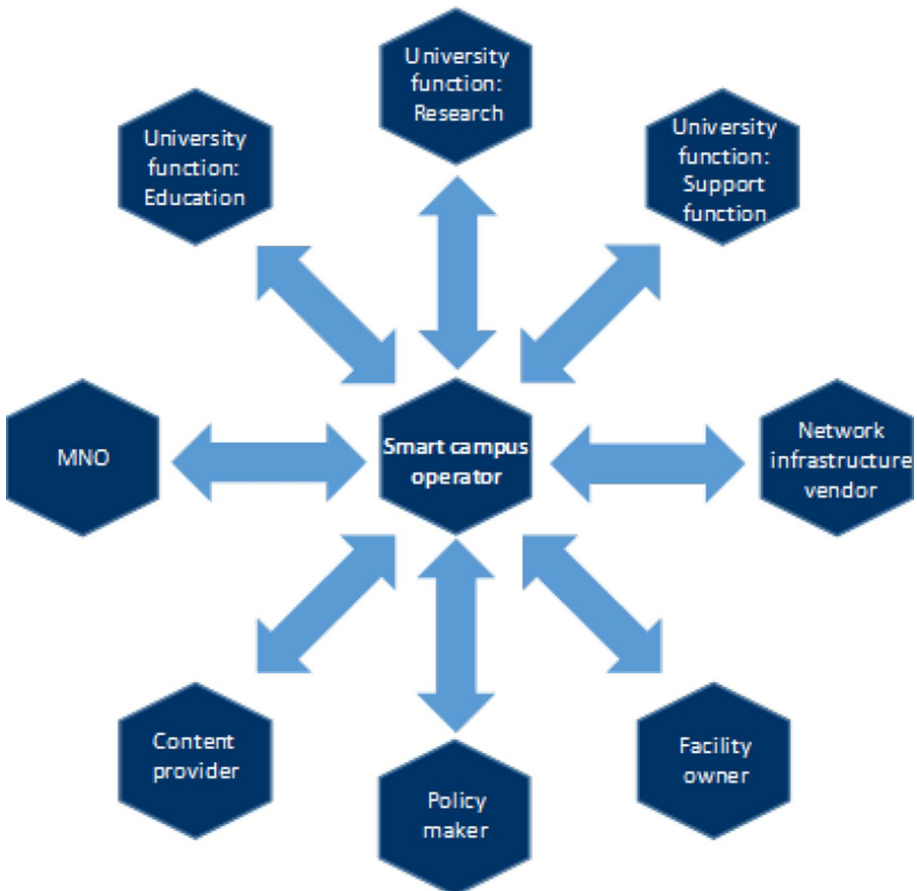


Fig. 3 Smart Campus micro operator ecosystem

Policy maker: Collaboration with the regulator is essential for local frequency licensing. In campus case the license has been granted for research and education purposes and will be applied on the limited geographical district where the campus is located. The regulator’s duty is also to supervise the competition equality in a market.

Content provider: Content provider’s role is to develop meaningful and attractive local context specific services and applications to the campus society. The campus case has special characteristics from the point of view that the society groups like students or researchers may also develop applications and services to the Smart Campus operator as part of their studies and work.

MNO: Smart Campus operator is in collaboration with MNOs to agree about the usage of infra and to offer local services to MNO’s subscribers, who are supposedly campus students, teachers, researchers and other staff.

4.2 Realization of Smart Campus

In the following we depict the actual campus case, where the 5G network, IoT sensor network, MEC (Multi-access Edge Computing) and cloud computing and analysis environment have been realized [31, 32]. The proposed Smart Campus 5G network architecture is illustrated in Fig. 4.

In the proposed model the terminals are smart phones, wearables and AR/VR glasses with special applications for data visualization. In addition to this, the IoT sensors such as CO (Carbon Oxide), measure environmental parameters in the campus premises. The sensor data is sent to the MEC and cloud servers where it is further analysed. Different technologies have been employed to realize the wireless access interface in the campus outdoor and indoor

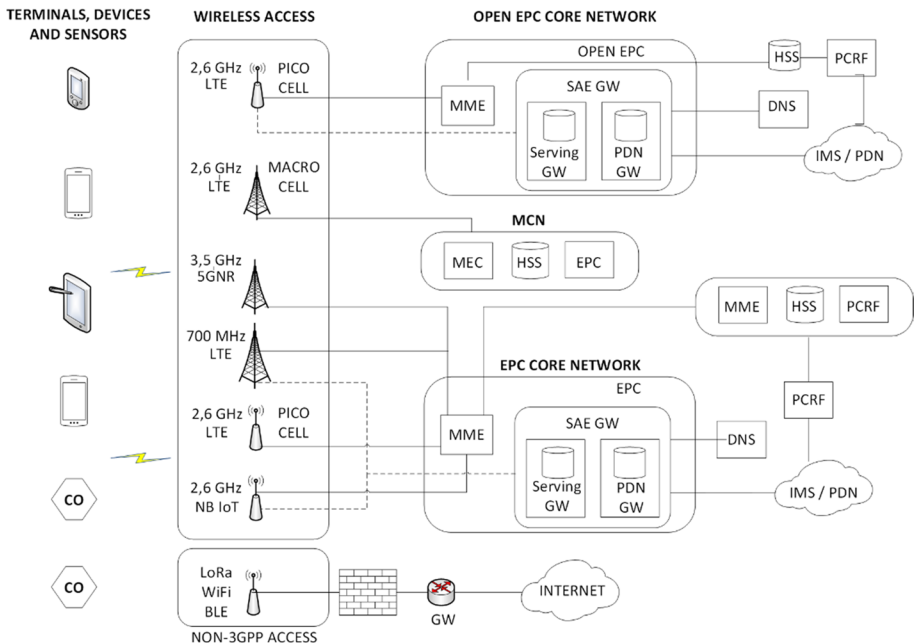


Fig. 4 Realization of Smart Campus 5G Architecture

premises. The interface consists of cellular access based on 3GPP standard technologies LTE (Long Term Evolution), NB-IoT (Narrow Band-IoT) and 5G NR (New Radio). For research purposes, non-3GPP technologies Bluetooth, WLAN and LoRa (Long Range) technologies are deployed in the indoor premises [32]. The 3GPP technology base stations are deployed both indoor and outdoor premises of the campus. Outdoor macro cells make use of 700 MHz (LTE), 2.6 GHz (LTE) and 3.5 GHz (5G NR) frequency bands with combined bandwidth up to 80 MHz. The construction is utilized both for low volume and high volume data transfer of mobile terminals, devices and sensors in the campus area and in larger surroundings. The indoor pico cells are exploiting in 2.6 GHz (LTE, NB-IoT) frequency and having bandwidth of 10 MHz. They are used for data transfer of smart phones, AR/VR devices and indoor sensors. The Bluetooth, WiFi and LoRa systems are likewise used for indoor sensors data transfer. Moreover, the radio network includes additional base stations in remote locations, such as in the city centre and at the university hospital test lab.

Three types of core network configurations are deployed in the realized network architecture. They are EPC (Evolved Packet Core), Open EPC and MCN (Micro Core Network) core networks. The EPC network describes a configuration based on vendor specific solution to implement virtualized network functions. The gateways Serving GW and PDN GW (Packed Data Network) have been illustrated independently, but vendors may integrate them together in SAE GW (System Architecture Evolution), which is connected to DNS (Domain Name System). The Serving GW is the interconnection point between the radio network and the EPC and serves the terminal by routing the incoming and outgoing IP packets [31]. The PDN GW is the point of interconnect between the EPC and the external Packet Data Networks and routes packets to and from the PDNs. The MME (Mobility Management Entity) unit takes care of the signalling related to mobility and security for LTE access network and the HSS (Home Subscriber Server) unit acts as central database containing user-related and subscription-related information. Other functions of the HSS include functionalities such as mobility management, call and session establishment support, user authentication and access authorization [31]. The PCRF (Policy and Charging Rules Function) unit functions as a policy decision point for policy and charging control of service data flows or applications and IP bearer resources. The IMS (IP Multimedia Subsystem) system conceives all core network elements to provide IP multimedia services when the MCN entity accommodates the MEC to enable low latency services and data analytics at the network edge [31]. The upper right section describes the configuration of open EPC network with the same functional elements than the EPC network. When a typical 5G infrastructure by MNO is based on existing 4G network topology to provide wide area outdoor service to offer higher data rate for subscribers, the campus deployment differs with the dense small cell indoor 5G and sensor network in the campus premises. Moreover, three types of core network configurations are deployed in the realized network architecture for research purposes. The configuration supports to connect multidisciplinary research infrastructures in the same framework allowing to compose together scientific research data from several sources. When multidisciplinary open data from several research areas is composed together, it creates high innovation potential to develop unforeseen new services [33].

5 Conclusions

The global trend of digitalization sets challenges to all levels of society. Each entity from nations even to the smallest enterprises need to plan and prepare the agenda for digitalization to survive in global competition. ICT and IoT technologies are seen as the key factors to enable this evolution. Specifically, sensor technologies, 5G and IoT networks, and computing and data analytics with MEC and cloud computing technologies play a key role in the development of transformational applications and services for the university society. This paper has discussed Smart Campus environment, which many universities are willing to set up. This paper has introduced technology architecture for the Smart Campus. A realization of the proposed architecture has been developed in a campus, where real 5G, IoT, MEC and cloud computing infrastructure has been deployed during the past few years. The network is used widely for special 5G services development for verticals like health care, education, industry campus and traffic. The transformation is not only single exercise but the increased technical infrastructure assumes also to decide how to maintain and operate complex systems to get the best benefit out of it.

The outcome of the interviews conducted in this study demonstrate, that in a multidisciplinary university campus there are several interest groups who are capable and willing to contribute to the Smart Campus development. The findings support the university to evolve the intelligence of a campus environment. The actions can advance e.g. digital education, campus services, property management or campus merging with the surrounding smart city society. Additionally, the study shows that a particular new actor is expected to emerge to operate the Smart Campus infrastructure and services, when IT Administration and MNO cannot be regarded appropriate actors. For this reason, a model of Smart Campus micro operator ecosystem is proposed to operate the complex digital infrastructure and to offer sophisticated services for the various instances in the campus society. The target is to find an operational model for the Smart Campus infra and services in the growing complexity, where the traditional university IT administration or MNO are not considered as the most potential actors. The proposed solution is based on a specific vertical specific service provider (micro operator). The research outcome shows that a local micro operator would be an essential actor to respond to vertical's increasing needs and the local Smart Campus operator would fit also excellently for Smart Campus expected needs.

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References

- Jiang, L., & O'Neill, B. C. (2017). Global urbanization projections for the Shared Socioeconomic Pathways. *Global Environmental Change*, *42*, 193–199.
- Zhuhadar, L., Thrasher, E., Marklin, S., & Ordonez de Pablos, P. (2017). The next wave of innovation—Review of smart cities intelligent operation systems. *Computers in Human Behavior*, *66*, 273–281.
- Arditoo, L., Ferraris, A., Petruzzellid, A. M., Brescianib, S., & Del Giudice, M. (2019). The role of universities in the knowledge management of smart city projects. *Technological Forecasting and Social Change*, *142*, 312–321.
- Bruneo, D., Distefano, S., Giacobbe, M., Minnolo, A. L., Longo, F., Merlino, G., et al. (2019). An IoT service ecosystem for Smart Cities: The #SmartME project. *Internet of Things*, *5*, 12–33.
- Kim, T., Ramos, C., & Mohammed, S. (2017). Smart City and IoT. *Future Generation Computer Systems*, *76*, 159–162.
- GPPP. (2016). *5G empowering vertical industries*. Roadmap paper. The 5G Infrastructure Public Private Partnership. Retrieved from 15 July 2016 https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf.
- Rendón Schneir, J. J., Whalley, J., Amaral, T., & Pogorel, G. (2018). The implications of 5G networks: Paving the way for mobileinnovation? *Telecommunications Policy*, *42*, 2018.
- Sejzi, A. A., Aris, B., & Yahya, N. (2012). The phenomenon of virtual university in new age: Trends and changes. In *International conference on teaching and learning in higher education (ICTLHE 2012) in conjunction with RCEE & RHED*, 2012.
- Van Merode, D., Tabunshchyk, G., Patrakhalko, K., & Yuriy, G. (2016). Flexible technologies for smart campus. In *13th international conference on remote engineering and virtual instrumentation (REV)*, 2016.
- Nguyen, D. (2018). The university in a world of digital technologies: Tensions and challenges. *Australasian Marketing Journal (AMJ)*, *26*(2), 79–82.
- Cerratto-Pargman, T., Järvelä, S. M., & Milrad, M. (2012). Designing Nordic technology-enhanced learning. *The Internet and Higher Education*, *15*(4), 227–230.
- Chen, C., Chen, C., Lu, S.-H., & Tseng, C.-C. (2016). Role-based campus network slicing. In *IEEE 24th international conference on network protocols (ICNP) workshop on control, operation and application in SDN protocols*, 2016.
- Wang, F. (2017). Research on the application of smart campus construction under the background of big data. In *2nd international conference on computer, network security and communication engineering CNSCE*, 2017.
- Nie, X. (2013). Constructing smart campus based on the cloud computing platform and the internet of things. In *Proceedings of the 2nd international conference on computer science and electronics engineering (ICCSEE)*, 2013.
- Adamkó, A., Kádek, T., & Kósa, M. (2014). Intelligent and adaptive services for a smart campus - visions, concepts and applications. In *CogInfoCom, 5th IEEE international conference on cognitive infocommunications*, 2014.
- Díaz-Díaz, R., Muñoz, L., & Pérez-González, D. (2017). Business model analysis of public services operating in the smart city ecosystem: The case of Smart Santander. *Future Generation Computer Systems*, *76*, 198–214.
- Walia, J. S., Hämmäinen, H., & Matinmikko, M. (2017). 5G Micro-operators for the future campus: A techno-economic study. In *Conference internet of things business models, users, and networks*, 2017.
- Jurva, R., & Matinmikko-Blue, M. (2019). Stakeholder analysis for digital campus development with 5G micro operators. In *ITS Europe conference*, Helsinki, 2019.
- Matinmikko-Blue, M., & Latva-aho, M. (2017). Micro operators accelerating 5G deployment. In *12th IEEE international conference on industrial and information systems (IEEE ICIS) 2017*.
- Matinmikko, M., Latva-aho, M., Ahokangas, P., & Seppänen, V. (2018). On regulations for 5G: Micro licensing for locally operated networks. *Telecommunications Policy*, *42*, 2018.
- Atif, Y., Mathew, S. S., & Lakas, A. (2015). Building a Smart Campus to support ubiquitous learning. *Journal of Ambient Intelligence and Humanized Computing*, *6*(2), 223–238.
- Yu, Z., Liang, Y., Xu, B., Yang, Y., & Guo, B. (2011). Towards a smart campus with mobile social networking. In *International conference on internet of things and 4th international conference on cyber, physical and social computing*, 2011.
- Valeroa, A., & Van Reenenb, J. (2019). The economic impact of universities: Evidence from across the globe. *Economics of Education Review*, *68*, 53–67.
- Connecting universities to regional growth: A practical guide. European Commission, 2011.

25. Appioa, F. P., Limab, M., & Paroutisc, S. (2019). Understanding Smart Cities: Innovation ecosystems, technological advancements, and societal challenges. *Technological Forecasting and Social Change*, 142, 2019.
26. Hoeger, K., & Christiaanse, K. (Eds.). (2007). *Campus and the City. Urban Design for the Knowledge Society*. Zurich: gta Verlag.
27. de Jesús Curvelo Magdaniel, F. T. (2016). A study on the relation between innovation and the built environment at the urban area level. No 12 (2016). *Technology campuses and cities*, 2016.
28. Ferrarisa, A., Belyaevac, Z., & Bresciani, S. (2018, in press). The role of universities in the Smart City innovation: Multistakeholder integration and engagement perspectives. *Journal of Business Research* (**Corrected Proof**).
29. TechVision Group of Frost & Sullivan. (2017). Technologies impacting the future of education—AI, mixed reality, XaaS, Wearables Will Shape the Classroom of the Future, 2017.
30. Wang, S., Zhao, Y., Xua, J., Yuana, J., & Hsu, C.-H. (2019). Edge server placement in mobile edge computing. *Journal of Parallel and Distributed Computing*, 127, 2019.
31. GPP TS 23.002 V15.0.0. (2018). 3rd generation partnership project. Technical specification group services and system aspects; Network architecture, 2018.
32. GPP TS 24.302 V16.0.0. (2019) 3rd generation partnership project. Technical specification group core network and terminals. Access to the 3GPP Evolved Packet Core (EPC) via non-3GPP access networks- Stage 3, 2019.
33. Latva-aho, M., & Leppänen, K. (Eds.). (2019, September). *Key drivers and research challenges for 6G ubiquitous wireless intelligence*. 6G Research Visions 1.

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