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# Smart Campus 5G and IoT network preparations for operational mode: Specification to deploy data and network management

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## Abstract

Digitalization activities have been in process for several years covering most business areas. Enterprises around the globe have been preparing their digital transition by the deployment of novel ICT and IoT systems to strengthen their operational functions on many levels. It is envisioned that most businesses will benefit largely from digitalization. This applies also to research and education sector, where the universities are in role to show the way forward. Specifically, the campuses with ICT, cellular network technology and software research units are probably in the frontline to innovate and pilot sophisticated education and research environments. Utilization of data collected from specific surroundings by sensors, devices, machines, vehicles and individuals is increasingly in the focus of developing new services and applications in campuses. The discussion of data based services and applications has been increasing in recent years and emergence of specific data operators has been anticipated. Prior to the development of services and applications, it is important to specify the platforms for data management process for appropriate handling of data. A proper data management process consists of collection, warehousing, processing, refining and sharing of data while not forgetting privacy and security. Stakeholders like universities, business parks or cities are considering to initiate data operator activity by bringing open data available for service and application developers. Subsequently, another aspect with the data operator is the operation of network infrastructure. The campus discussed in this article has deployed 5G and IoT-sensor test network with edge and cloud computing functionality for research purposes. Complementary functionality like network management will be integrated in the next phase of network infrastructure development. In this paper we define the requirements on how to develop digital smart campus environment for data management and network infrastructure operations to establish an operative 5G/IoT network for research purposes. The requirement evaluation is done based on practical campus network use case in progress. Establishment of experimental 5G/IoT operative functions on campus enables to accelerate procreation of research based innovations specifically when the environment is open for enterprises, developers and innovators like the in the campus presented here. The innovations are piloted in the campus surroundings and the most promising ones are up-scaled to develop city governance or to offer services for smart city inhabitants. The most successful innovations will be scaled nationally and globally. Subsequently, a locally operated experimental 5G/IoT network infrastructure on campus advances to find novel approaches in telecom regulation and models for future telecom market which is foreseen to change significantly.

Keywords: 5G, IoT, data management, network management, smart campus

## 1. Introduction

Many sectors of society have initiated large programs to digitalize their functions. Universities are in a similar process to develop their effectivity, attractiveness and competitiveness [1-2]. In contrast to many others, universities have a specific angle in the digitalization due to research projects, which generate continuously novel innovations. This applies particularly in technical ICT universities but most attractive and surprising research outcomes with high business potential may bounce in universities, which have accomplished cross-disciplinary research activities [3]. To initiate fruitful multidisciplinary co-development between different research units, a specific environment needs to be set up to enable dialog between researchers to outcome novel innovations. For example, the University of Oulu has launched a dividual Smart Campus project to evolve digital infrastructure, in which different research groups can connect with their special research infrastructure to form a multidisciplinary research environment. The target is to

enable to share and compose scientific data produced by research groups, which is believed to have a stimulating effect to the birth of new innovations. Subsequently, the platform can be exploited for data sharing and innovation co-operation with enterprises and the developers of other communities like smart city, who have likewise masses of data in their hands. Finally, the data can be opened for public use following the principles of platform economy [4].

Like several studies show, utilization of data is a growing global business, which have the huge potential to corporates in any business domains [5, 6]. In particular, it is anticipated that particular novel stakeholders called as data operators or local operators will emerge numerously in the coming years [7]. Acting as a data operator requires to deploy a special infrastructure for data collection, storing, refining and sharing. A typical configuration of infra consists of sensors, actuators, devices, robots and terminals producing data, which they send to an IoT platform for processing. The platform is composed of specified functionalities to open the data for sharing [8, 9]. The infra may be equipped also with 5G technology for wireless connections, edge and cloud computing and data analytics. To operate the 5G/IoT infrastructure, some form of integrated network management functionality is assumed to configure, monitor and optimize the network performance [10].

There are lots of various specifications for Smart Campus infrastructures depending on targeted functions and services set for them [11]. Regarding Smart Campus models, the authors in [12] introduce a case where the focus is to define intelligent services and architecture behind them. 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 campus crowd to produce data and to generate contents. The paper emphasized the importance of extendable architecture presenting a model developed by the authors. Another Smart Campus paper [13] 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. Paper [15] describes comprehensively both smart city and smart campus development but finally focuses to present IBM software platform for infrastructure management.

This paper focuses on the specification of data management process and requirements of IoT data platform for Smart Campus use case. The developed Smart Campus case includes 5G and IoT networks, edge and cloud computing and analysis environments where, data from various environments is gathered and analyzed. To meet the requirements and expectations of the campus stakeholders analyzed in [11] using [16], the developed Smart Campus IoT platform assumes that continuously new sensors, actuators, robots, drones and vehicles of different standards can be connected to the platform. Furthermore, to protect the data, to compose and refine it effectively, and to develop it further to campus services it is assumed that the IoT data platform architecture specification is particularly defined for the campus environment. This leads to the first research question of this paper: How should the IoT data platform be defined for Smart Campus case? Moreover, when the digital campus 5G/IoT network is continuously expanding it assumes considering the operational aspects of the network infrastructure. This paper introduces a specification to define which are the most crucial network management functions to be employed for operation in a specific Smart Campus environment. As a consequence, the paper targets answer the second research question: What kind of network management system is appropriate for the Smart Campus 5G and IoT research infrastructure realization?

This research work is of qualitative nature and aims to provide practical guidance on Smart Campus network preparations for operational mode. We first describe the Smart Campus research infrastructure powered by 5G and IoT networks with stand-alone IoT data platforms. Then we conduct an interview campaign among the stakeholders to gather information about their requirements on the data management process. The information is analyzed with respect to the deployment of current IoT platforms. Based on the analysis we determine the specification for the common IoT data platform taking into account the stakeholders' expectations. When considering the Smart Campus network management system, similar research methodology will be applied to define the specification for the network management system to operate the campus digital infrastructure. Finally, we build a comprehensive view on how to realize the IoT data platform and network management system for the Smart Campus 5G and IoT infrastructure.

The rest of this paper is organized as follows. The smart campus framework is presented in Section 2. IoT platform is specified in Section 3 followed by the network management specification in Section 4. Operational smart campus 5G/IoT network is described in Section 5. Finally, conclusions are drawn in Section 6.

## 2. Smart Campus framework

Smart Campus is a framework for evolvement of university campus to offer novel applications and services to the campus community through digitalization [12-15, 17,18]. Based on ICT and IoT technology the digital campus can introduce unforeseen research based innovations for utilization of the campus stakeholders. Together with students, teachers, researchers and other internal groups, the Smart Campus ecosystem activities may involve external actors like property owner, city developers, enterprises and other campuses. Six consecutive process phases can be recognized in the evolution of Smart Campus of University of Oulu: 1) Conducting a stakeholder analysis to compose the definition of multidisciplinary Smart Campus, 2) Specifying the environment and required infrastructure to develop a constantly developing research infrastructure for innovations and open data, 3) Trialing the research infrastructure based on 5G/IoT technology by collecting and refining research data from multiple sources, 4) Opening the data to service and application developers for innovation, 5) Piloting of data based innovations on the campus 6) Scaling-up of the innovations for smart city trials. The process is iterative applying a principle, where the final specification of infrastructure will be determined through trialing and piloting to gain feedback of the system functionality. Firstly, the stakeholder analysis was carried out to recognize the main expectations towards Smart Campus by various internal and external groups. In the second phase an initial definition of the environment was conducted and a specification of the required framework and infrastructure was designated. As third phase the interdisciplinary entity comprised of infrastructures like positioning, air quality sensors, robotics, drones and health terminals connected to the 5G and IoT research test network was trialed to collect data and to gain feedback of system specification. In the next phases the multidisciplinary mass data will be integrated together to open it for service and application developers enabling to launch unforeseen service and application pilots on campus. The most promising ones will be further piloted in smart city digitalization projects.

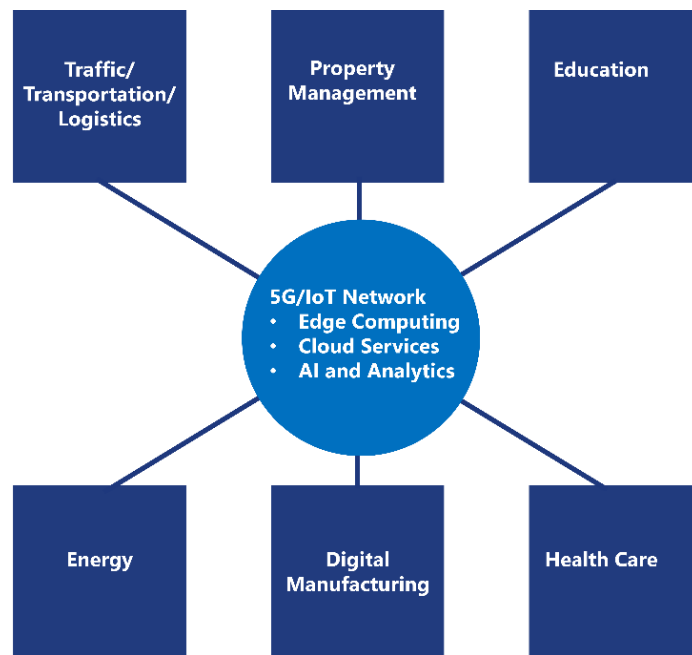


Figure 1. Multidisciplinary Smart Campus research infrastructure

To accelerate birth of technology innovations the Smart Campus framework is unique being open to enterprises, developers, municipalities and to any stakeholder willing to innovate, test and pilot applications, products, services and solutions. The platform enables extensive research and piloting grounded on 5G and IoT technologies and extensive amount of data. On the campus depicted here there has been deployed an experimental research infrastructure composed of 5G network, IoT sensor network, edge and cloud computing capacity, artificial intelligence setup with algorithms data analytics. The research data is collected from manifold sources by the research groups. The campus IoT network is composed of over 2500 sensors and beacons deployed all over the campus to monitor air quality, indoor circumstances and occupancy of rooms by measuring e.g. temperature, moisture, carbon dioxide, illumination, motion, noise and location. Campus-wide positioning system is serving users to navigate to classrooms and meetings. Several drones and robots are equipped with sensors and cameras to gather research data from campus outdoor premises. Smart traffic researchers are able to accumulate data with vehicles and construction machines. Health lab has employed a variety of gadgets and devices to gain health and wellbeing research data. Additionally, strong potential is seen in crowdsourcing of data, which brings highly interesting aspect to enrich the

campus environment by producing data, sharing information and enabling to develop tailored services for individuals. Contemplating the campus community to generate data from the surroundings or to share secured private data for personal service enables to develop a variety of awesome services. It is anticipated that bringing up, refining and combining data from various sources, innovation potential to discover unforeseen services and sophisticated applications is very high. As exemplary case a pilot based on 5G and IoT technology with data analytics was executed in older people's home, where particular data like air quality, water and electricity consumption and motion detection from apartments data was analyzed. Special conclusions could be made about individuals daily behavior. The outcome was used to optimize timing of personnel's intervention for caring the residents [19]. In future pilots it could be discovered if similar data from indoor premises could be used for driving actuators to control the indoor circumstances or to observe how different surface materials could absorb noise in the campus premises.

The university campus of Oulu has up to 25 000 students, researchers and other staff in the coming years. Therefore, it provides an extensive surroundings for piloting research data based solutions. Besides sensors, robots, drones and vehicles the campus offers a comprehensive facility for crowdsourcing of data, when students and researchers are typically eager to commit into pilots and to contribute with personal effort by generating data. In fact, the campus can be considered as small city with similar functions like health care, restaurants, shops, social life premises, energy and water supply, traffic and logistics. Successful campus pilots will be scaled up to be tested by city governance and inhabitants. To establish a solid data management process to advance successful pilots it requires to specify the IoT data platform with specified functionality. The platform permits to collect, store, analyze and share open data for innovators. Furthermore, considering the 5G test network deployed on the campus, it allows to discover enhanced mobile subscriber services for the campus community. Together with open data the campus environment can evolve highly attractive for the daily users. Before delivering mobile subscriptions it assumes though that the 5G network management is in place. Assuming to have thousands of subscribers in the 5G network requires that various network control functions like subscriber management, configuration management and performance management included in the network management system are in place.

### 3. IoT data platform

The Smart Campus introduced here has set up an extraordinary open environment, where external stakeholders like enterprises, application and service developers and smart city innovators can join to develop, test and pilot unforeseen products and solutions together with researchers [20]. The framework has gained wide popularity, which has resulted to high amounts of collected data. Typically data is sent through wireless interface, which is part of the IoT infrastructure configuration. Large amounts of data need secure storing before processing, which includes validation to detect corrupted data and conversion to transform data in specified standardized format. In following phases data is integrated together and shared for the use of applications [21]. Through the entire process data security is ensured. The overall data management process is depicted in figure 2.

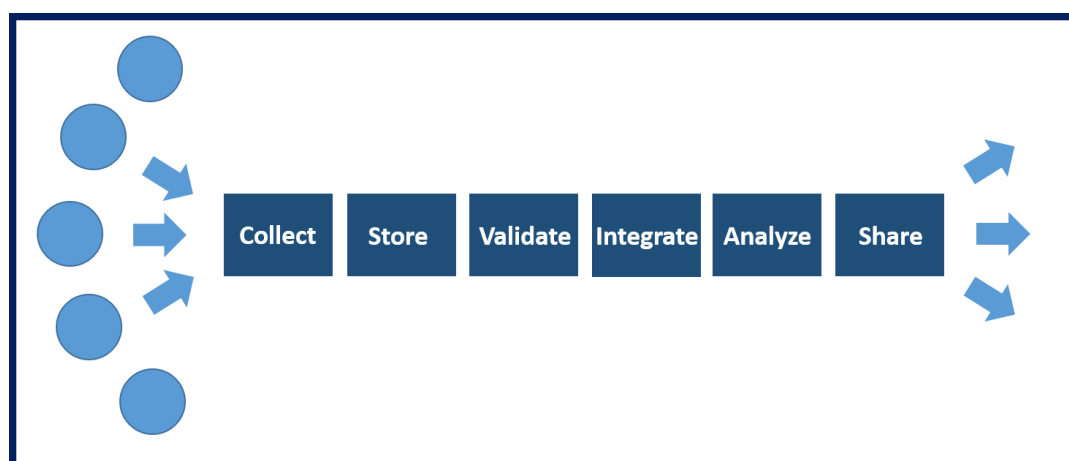


Figure 2. Data management process in IoT data platform

Developing magnificent data based Smart Campus services it is obliged that the IoT platform architecture is specified for research purposes. The researchers of university of Oulu have established a singular interdisciplinary co-operation between research groups, which has set up requirements for the IoT platform. In the architecture specification it necessitates to be observed that the campus multidiscipline environment is continuously changing based on numerous research projects starting and ending. The architecture and platform technology need to support constant emerge of

new sensors, devices, robots and machines which presume flexible and expedient connection to the platform for sending masses of data. Moreover, various devices are controlled over the network connection. To connect or remove devices fluently it assumes to employ an effective device detection functionality. Subsequently, in contrast to business platforms, which are typically closed systems and specified for vertical specific operations the campus IoT platform requires to be specified for multidiscipline research environment, which means open and dynamic system under continuous changes. Moreover, the campus IoT platform specification needs to support a large variety of data standards to connect a versatile set of devices and actuators. Besides the campus community the IoT platform will be open for innovation and testing activities to all enterprises and developers [22].

To offer the services to campus users it requires that the platform environment is steady not to cause interruptions in the service delivery. For setting up the characteristics of nonvolatile system a ‘production grade’ platform section needs to be specified. In turn, the research activities require the platform to be dynamical and flexible for varying research needs. Thus, another section of the platform needs to be specified to be effortlessly reconfigurable for repeating research pilots and experiments and this section is probably under continuous change due to altering phases of research projects. Subsequently, multiple research teams may utilize various IoT and data technologies, which assume a seamless interaction of systems to transfer and process high volumes of data fluently. Similarly, importing and exporting open data from external systems of other campuses, research partner enterprises or from smart city platforms it stipulates undisturbed interoperability of platforms. To make open data available for developers it requires to specify standardized interfaces for various applications. There is variety of options available when choosing the platform. They can be open source based on contribution of community of developers or commercial ones delivered by specific vendors with defined and sometimes limited functionality. Still another option is to develop own platform based on requirements which no other platform can fulfill. The Smart Campus platform architecture described here aims to develop a prodigious IoT platform to allow a mixed combination of open source, commercial and research-based platforms. The following table 1. composes the most essential requirements for Smart Campus IoT architecture.

Attribute	Function
Functionalities to support effective data management process.	Enabling truly open platform of innovation, testing and piloting for campus users and enterprises, developers and other stakeholders.
Device detection functionality	Allowing to effortlessly attach new sensors, devices, drones, vehicles and robots in the IoT platform based on research needs.
Dynamic reconfiguring	Enabling to continuously connect new multidisciplinary platforms or research infrastructures into the system.
Data standards	Supporting large variety of data standards to allow wide selection of device testing by enterprises.
Service delivery section	Offering services to campus users through stabile and fixed system configuration.
Experimental section	Enabling to adapt in changing research needs by easily reconfigurable section.

Table 1. IoT data platform specification requirements

## 4. Network management

Regarding any complex operational system used for production of goods or services the system demands control and management. The Smart Campus 5G test network being fully operational and under intensive research and innovation activity the 5G infrastructure is strongly expanding to fulfill the growing needs arising from research groups and enterprises connecting numerous devices into the network. To maintain control over the network it assumes to deploy

a network management system, which allows to continuously monitor the infrastructure. Typical network management system used by Mobile Network Operators (MNO) contains e.g. the following functionality [11]:

- Configuration Management
- Fault Management
- Performance Management
- Service Management
- Subscriber Management

When the Smart Campus 5G network is growing, it implies to deploy a network management system for controlled and secure delivery of wireless services to researchers, campus users and enterprises. Various commercial systems are available for specific purposes and environments, most of which are developed for commercial business purposes [23, 24]. A question is raised, how should the network management system be specified for experimental university campus network, in which there is no commercial activity? Besides the control and maintenance of the 5G network the network management system serves as research and education environment for wireless system research, development and innovation. Considering the functions above it is evaluated that most of the network management functions are probably needed in the campus 5G/IoT network in long term. The most important functions to employ in phase I are Configuration management, Fault management and Subscriber Management. Complementary functionalities like Performance Management and Service Management will be adopted in phase II when the network has gained more data traffic load along growth of subscribers. The table 2. below presents the key functionalities and their role in campus based 5G network operations.

<b>Network Management Functionality</b>	<b>Purpose</b>	<b>Deployment</b>
Configuration Management	Configuring of network elements  Adjusting of network parameters for optimal performance	Phase I - integration and modification of the growing network configuration
Fault Management	Detection of malfunctions of network units  Fixing the malfunctions remotely	Phase I - monitoring of network faults for immediate corrective actions
Subscriber Management	Control of user subscriptions	Phase I - Configuring and monitoring of the delivered user subscriptions on campus
Performance Management	Recognition degradation of performance  Analysis of network data	Phase II - Follow-up of network performance based on statistical analysis and tuning of parameters
Service Management	Control of network services	Phase II - Operation of the user services launched on campus

Table 2. Network Management functionality in Smart Campus

With the network management functions the campus network environment is similar to commercial operators like MNOs. Subsequently, together with the global spreading of 5G and IoT technology it is foreseen in several studies, that numerous data operators (aka local operators or micro-operators) will emerge [7]. This aspect is fascinating research initiative in the Smart Campus environment and experimental campus operator research would result outcomes for wireless market evolvement. With the open data generated by the IoT sensors, devices and vehicles the infrastructures and control systems allow to launch experimental data operator activity to share data to application and service developers, enterprises and municipal innovators. University cannot operate any commercial actions but the experimental operator trials support research and innovation of campus services and helps to recognize the required stakeholders, when local operators are launched in manifold vertical business environments.



## 5. Operational Smart Campus 5G/IoT network

Operational campus network infrastructure enables to establish a unique innovation environment bringing interdisciplinary research groups together to discover astonishing observations. The network can be compared to any commercial 5G network but being dedicated only for research and innovation activity. In the described case of University of Oulu the researchers have initiated numerous multidiscipline research projects, which are grounded in ICT technology covering 5G and IoT sensor networks, edge and cloud computing, artificial intelligence and data analytics. Together with the researchers the enterprises have actively utilized the network for particular product and service development projects. The framework permits to compose data from various sources to discover surprising and unexpected innovations. Moreover, the research outcomes are piloted in the campus surroundings and the most successful ones are scaled up to city environment to be developed for city governance purposes and to be offered as services to city inhabitants. Some of the research topics have shown potential to promote the sustainability development of smart cities. Typically these innovations are related to traffic, health, property management or city infrastructure. Scaling of smart city innovations will be expanded to national and global level potentially resulting to high economic impacts.

The framework of Smart Campus can be considered as innovation platform to accelerate digitalization development of cities and to advance businesses of partnering enterprises specifically when there is low-threshold access for companies to join the research projects and utilize the infrastructure for testing and piloting of products, applications and services. Moreover, the experimental campus infrastructure operation speeds up to find new approaches in telecoms regulation. One important aspect in the operational smart campus network infrastructure is to define who operates the network which is highly related to telecommunication regulation. The current realization of campus 5G network operates on local license dedicated for research and education purposes obtained from the national regulatory authority giving an opportunity to find novel business models for network operations in the altering telecom market. However, the permission to use the band only for research, testing, and education purposes significantly limits the use of the network as it cannot be used for commercial purposes. At the same time, there are developments in several countries allowing the emerge of 5G networks to introduce local operator models to produce tailored services for various verticals, who need high performance connectivity to run business processes [25]. Operating the live campus 5G network avails to recognize various stakeholders motivated to act as local network operators. There are cases in verticals like factories, harbors and traffic, where group of stakeholders compose an ecosystem to run the 5G infrastructure. Adopting an ecosystem model to operate 5G network advances to find novel business models in telecom markets.

## 6. Conclusions

This article has discussed the Smart Campus case, where a study of campus digital environment has been initiated to accelerate multidisciplinary research-based innovations for creating novel data-based business cases to enterprises and to advance smart city development. Similar developments are of interest in multiple organizations and we aimed at shedding light on some critical factors from the perspective of the required platforms. To enable the evolving of unique business prospects, it is of utmost importance to experiment the potential of 5G and IoT technologies with edge and cloud computing functionalities complemented by artificial intelligence and data analytics functions. Moreover, the Smart Campus framework is remarkably targeted to set open to all enterprises, developers and innovators of future digital services.

The Smart Campus development process has raised continuously new research questions, which have been solved by the interdisciplinary research co-operation. In this article the first research question was set to define specification to the required IoT platform architecture for the digital campus case to enable it to be open for internal stakeholders and to external research partners. The specification of requirements was introduced in the chapter 3 highlighting the flexibility for continuous configuration changes due to increase of sensors, support for wide range of data standards and division to stable section for delivering services and to experimental section for research pilots. Subsequently, when targeting to establish an operative Smart Campus infrastructure for generating IoT-sensor data from various sources and to share the data for developers it necessitates to employ network management functionality for controlling the digital infrastructure. This demand has raised the second research question of how to specify the requirements for network management functions in the campus use case. The minimum requirements have been determined by evaluating the 5G and IoT network development and increase of sensors, devices, robots and drones, which are supposed to generate traffic load in the network. Based on this the specification has been presented in the chapter 4 proposing to deploy first the configuration management, fault management and subscriber management to



allow proper command of daily operations. In later phase functions like performance management and service management are appropriate when the data traffic load has increased in the network and there are large number of services available. By applying both of the defined specifications it allows to launch experimental Smart Campus data operator functions following the growing phenomena of local 5G network operator.

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