ICT for Smart Cities:
Innovative Solutions in the Public Space

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Abstract
In the year 2050, the planet Earth will look different than it does today: Nine billion people will be living here, of which 70 percent will be in cities. Urbanization, globalization, and demographic and climate changes are putting ever increasing demands on our cities. At the same time, however, greater opportunities to manage energy, resources, processes and people efficiently are also being created. It is the goal of smart cities to seize these opportunities. An important basis for this process is the integration of information and communication systems into the various technical systems and infrastructures of a city. This enables the flexible control of supply and disposal networks, especially for electricity, water and gas as well as for goods, and provides novel solutions for mobility, public administration, and public safety in the city. With the help of these smart city solutions, citizens, businesses, social organizations and governmental institutions constantly exchange information. In order to increase the quality of life and work of all parties through efficient and integrated information flows, the city must operate as an intermediate and service provider for citizens, businesses and visitors, and it must aim at keeping things running smoothly through seamless and transparent administration processes. An optimally networked city not only makes everyday life easier in all aspects of life, but it also provides environmentally sustainable solutions. The smart city is an informed, networked, mobile, safe and sustainable city. This chapter discusses different approaches on how to make cities smart and at the same time emphasizes, in particular, the relevance of data, information and communication between various stakeholders, systems and processes in an integrated manner.

1. Introduction

Research and development for “Smart Cities” has been ongoing for almost a decade now. However, only now its rise can be seen in close relation to the newest developments in Information and Communication Technologies (ICT) for mobile broadband communication, sensor technologies, machine-to-machine communication and efficient data and computing resources.

However, what makes a technology smart? According to [7], smart technology comes up to human cognition when it senses and recognizes patterns as humans do. A smart technology recognizes the semantics of patterns it perceives, be it text, speech, special or situational, and it proactively associates and correlates data based on grasped meaning. It leverages real-world and real-time background information to assimilate new data, reasons from what it has just learned , provides common-sense recommendations and predictions, and finally decides and acts on behalf of humans.

Smart cities have, in particular, the ability to acquire components and models thereof through experience and knowledge, and they use these components productively to solve novel problems and deal successfully with unanticipated circumstances. However, there is not a uniform, homogeneous understanding of a smart city. In fact, the following definitions demonstrate that in the worldwide discussion diverse key aspects of a smart city are set:

- According to the California Institute for Smart Communities [1], “Smart Communities” are making conscious efforts to use information technology to transform life and work within its region in significant and fundamental, rather than incremental ways.
- A Korean vision of the “Ubiquitous City” (U-City) [2] focuses on various types of computers/sensors and information systems which are built into houses, office buildings, streets. The prior objective is to get them connected and provide various services (residential, medical, business, governmental) available in a ubiquitous and integrated manner.
- Nikos Komninos, an Athens based professor of Urban Development and Innovation Policy [3] defines “Intelligent cities” as a territory with knowledge-intensive activities and embedded routines of social cooperation. They are characterized by a developed communication infrastructure, digital spaces, and knowledge/innovation management tools; and a proven ability to innovate, manage, and resolve problems that appear for the first time. All intelligent cities are digital cities as well, but not every digital city is necessarily intelligent. While digital cities basically provide services via digital communication, intelligent cities use these services for their problem solving capabilities.

At the same time, these definitions all establish a procedural understanding of smart cities: Smartness of cities relates to urban management and the involvement of the different stakeholders. Smart technologies are used for issue detection, for resolving those issues in an intelligent way and for continuously improving urban processes to advance the quality of live and the attractiveness of the city.

2. The Vision of a Smart City

By managing and constantly improving urban processes, a smart city operates as a service provider for citizens, for enterprises of the region and for tourists and visitors of the city. A smart city is to become a self-sustaining and sustainable ecological urban environment for an increased urban quality of life and city attractiveness. This can be fostered and achieved by interplay of a number of different technical components.

As a basic prerequisite, networked and integrated urban resources are needed that provide data access to and intelligent control of physical urban infrastructures. These technologies enable the necessary information management, information transport, coordination and control, etc. Like in a living organism, the ICT-enriched infrastructures form a nervous system for the smart city that orchestrates the flow of information between its entities.

Smart cities have, in particular, the ability to acquire, through experience, knowledge, and models of itself, its components and its environment and to use them productively to analyse and solve novel problems and deal successfully with unanticipated circumstances.

A smart city platform contributes to sustainable growth and employment in knowledge-intensive industries and it fosters a technology base in future Internet-relevant technology and service industries. Next to that, the platform provides an environment that empowers providers and citizens to develop and deploy services, and it accelerates the development of new networked based services for citizens and consumers.

The future information and communication networks of a smart city will evolve from the networks as we know them today. They will follow a pattern of unbounded growth which leads to even further penetration. But apart from the integration of continuous technological advances, this co-evolution will occur in a complex response to requirements from innovative emerging services and applications. Major technological drivers for these future networks derive from:

- General mobility and wired/wireless network integration
- New solutions for machine-to-machine communication will result from the progressive instrumentation of the living environment with sensors and actuators
- Ubiquity of network connectivity deeply embedded into our living environments following the always best connected (ABC) paradigm of services and the Internet of Things
- Technological heterogeneity with diversity and ubiquitous collaboration instead of a One-Size-Fits-All approach.

The future networks create an underlying technological substrate penetrating and transforming all aspects of society. Networking connectivity is turning into a generic utility and becoming part of everyday life much like machines, electricity and means of transportation did in the wake of the industrial revolution. But along with that role it becomes a critical infrastructure whose uninterrupted availability is a prerequisite for the proper functioning of the whole of society (e.g., cloud computing, eHealth, eGovernment and emergency communication). Complete large-scale outages would lead to disastrous consequences; hence, it is of paramount importance that the communication infrastructure is organized as an autonomous resilient system capable of remaining operational on its own through intrinsic self-configuration and self-healing properties.

Societal, economic and political demands will shape characteristics, deployment and usage of the future ICT. Hence, research in that area must be firmly embedded into a multi-disciplinary context anticipating existing trends and demands that go beyond pure technological engineering. In addition, ICT research must respond to generic strategic challenges for the development of the information society.

3. State of the Art

Research and development for smart cities has been ongoing for almost a decade, however, it is only now that its rise can be seen in close relation to the newest developments in ICT for mobile broadband communication, sensor technologies, machine-to-machine communication and efficient data and computing resources.

Different to the urban trends in developing countries, Europe is facing specific challenges that include:

- Demographic developments: negative growth, aging, differentiation of population
- Weaker economic growth: economic consolidation, diverging work places, financial limitations of public authorities, subsidy reduction
- Postulate for sustainability: economic development in relation to ecologic and social dimensions
- Social change: singling, small families, single parents
- Technological progress: permanency of technical innovation in every sector
- Quest for future: migration disposition and necessity

Furthermore, in Europe special attention must be given to existing urban infrastructures—green field developments for smart cities are possible in rare cases only. For example, according to London's environmental advisor to the Mayor, Isabel Dedring, 80 percent of the buildings that will make up the city in 2050 do already exist today [9]. Another speciality of Europe is that 40% of inhabitants live in medium-size cities with populations of approximately 500,000. Given that, research results for small-size and medium-size cities will be used within Europe, while instead mega-city research results will be relevant for outside Europe.

More and more cities engage in research projects as a partner providing its infrastructures or cities as a "living lab" for technology development. Cities give consideration to the fact that participating in innovative research projects can leverage their status quo and boost their attractiveness and competitiveness as a municipality. Therefore, all over the world, smart city initiatives are gaining momentum. Subsequently, a selection of exemplary initiatives is given:

- Initiatives in selected European cities: Recognizing the importance of going smart, mainly driven by the insight that urban life cannot be sustained in the near future with current approaches, a few selected cities in Europe have taken the initiative of implementing smart technologies for a more sustainable future. Barcelona, for example, is Wifi'ed by a coverage-complete network owned by the city hall with the aim of offering local services to its administration as well as third party services. Barcelona also commences with smart parking, noise monitoring, and the city advocates the use of the Internet to stimulate virtual communities and to promote citizen participation in municipal government. More examples can, among others, be found in Aarhus, Amsterdam, Berlin, London, Lyon, Malaga, Oulu, Paris, Santander, Stockholm, Trento, Vienna or Zurich.

- Selected Multi-City Initiatives in Europe: SmartCity [12] is a European initiative that loosely connects 8 European cities (i.e. Rome, Wroclaw, Cluj, Bruxelles, Istanbul, Novi-Sad, Maribor, and Amsterdam) to promote artistic and technology activities aiming to improve living conditions in urban areas. Another growing initiative is the LivingLabs [13], a "citizen's laboratory" with the aim to overcome the digital gap older citizens suffer, to include elders in the co-design of innovative solutions for their well-being, and to create new professional profiles and jobs for citizens over 55 years of age. At more of a political level, the EuroCities initiative [14] is worth mentioning which unites local governments of more than 140 large cities in over 30 European countries with the aim to influence and work with the EU institutions to respond to common issues that impact the day-to-day lives of Europeans. Finally, EIT ICT Labs [15] was established in 2009 as a new EU instrument for promoting innovation in Europe. It is a consortium of businesses, universities of technology, and research centres in Europe that will use ICT as the key enabler driving the transformation towards the Future Information and Communication Society, with the ultimate goal of transforming ICT innovation into quality of life. Amongst several thematic areas targeted, the digital cities domain aims at creating intelligent and sustainable cities enhanced with innovative and disruptive service-based applications for the citizens of Europe and beyond. In 2011, acatech – the German National Academy of Engineering and Sciences – formulated recommendations for actions on smart cities [16].
- Selected initiatives outside Europe: While at first "smart cities" was an initiative predominantly driven by European stakeholders, there is a growing amount of smart city initiatives worldwide. The Intelligent Community Forum was founded 2004 in the US [19] to study economic and social development of the 21st century community and to share best practices by communities. ITU's Digital Cities initiative [17] acts as an information portal to various but disconnected city initiatives worldwide; it is constantly updated with the latest news and developments. Furthermore, the Massachusetts Institute of Technology (MIT) has launched an initiative on smart cities [18] that offers a range of technology advances to aid urban living. In addition, Australia and Japan advocate the "post fossil living" [20]. Seoul has gone one step further by engaging its citizens in giving them a direct role in running the city by means of contributions to city policies and direct discussions with city officials [21]. China is developing concepts to sense their country, environment and society ubiquitously [22] .

- Commercial initiatives: Although many companies such as Siemens, SAP, Deutsche Telekom, SAP, etc. invest in smart cities concepts, the only notable developments in smart cities at a coherent, international company level are operated by IBM [23]. It unites commercial interests as well as interests of utilities, city halls, and citizens themselves. IBM works with a large amount of large, medium, and small companies—thus constituting an integrator of integrators to facilitate smarter living.

No matter which emphasis a smart city initiative is taking, ICT plays a central role in any development towards or evolution of a smart city. ICT does not make a city smart by itself; however, there is no smart city without a strategic positioning of ICT and substantial investment into it.

The assumption that ICT is evolving towards the fundamental backbone of a sustainable and liveable city, however, inevitably leads to a number of additional questions that are subject matters of current and future "Smart City" research, which we would like to sketch in the following chapters: What should the technical architecture of a city ICT look like? Who are the stakeholders that drive or should drive the smart city evolution? How can we measure and benchmark the ICT-related smartness of a city? Who / what organization is in charge of the network and data security? How can a city's ICT be monitored while at the same time protecting personal data and other privacy issues?

4. The ICT of a Smart City

Urbanization, globalization, and demographic and climate changes are putting ever increasing demands on our cities. At the same time, however, the opportunities to efficiently and sustainably manage energy, material resources and people are increased through the use of ICT. It must be an objective of smart cities to capitalize on these opportunities. An important basis for this process is the integration of information and communication systems into the various technical systems and infrastructures of a city. Such integration enables the flexible control of supply and disposal networks, especially for electricity, water and gas as well as goods. Furthermore, integration enables novel solutions for mobility, administration and public safety in the city. An optimally networked city not only renders everyday life easier in all aspects but also provides environmentally sustainable solutions. A smart city is an informed, networked, mobile, safe and sustainable city.

As a consequence, urban ICT is more and more evolving to become the backbone of smart cities: potentially everything becomes addressable, communicates and can be monitored, controlled and optimized by people with the help of computers. Urban ICT is realized as a system of systems which provides information exchange to urban users (public employees, local businesses, citizens, tourists and others) at any request and need, at any place, at any time and at any preference. The systems collect, exchange, aggregate, analyse and provide data and information of various kinds.

ICT-based systems are used in order to govern the city by automating the control, remote maintenance and optimization of physical infrastructures (e.g., grids, streets, parks, buildings, lamps) that are directly relevant for areas such as energy supply, mobility, logistics, safety and security and by generating and providing information about these infrastructures. Data are automatically generated via sensor networks or interconnected machines and servers. City-related objects (cars, waste bins, etc.) are enhanced to become smart objects and also provide relevant data. Next to their autonomous behaviour and functioning, smart infrastructures/objects provide specific data on their own status and their environment. These data are transferred via reliable and secured (wired or wireless) networks and kept in municipal data stores (public or private). Where needed and possible, data is provided in real time and continuously as streams. Data is visualized on various end devices including personal phones, computers, tablets, but also devices in public areas such as traffic information screens or information billboard.

Furthermore, ICT systems are used by the city to optimize communication and governance processes and facilitate, for example, the municipal administration (eGovernment), but also the enterprises (eBusiness) or the health care system (eHealth) within a city or a metropolitan area. ICT systems are also increasingly used to enhance citizen engagement and political co-determination (eTransparency, eParticipation). The users in a city are in various ways like consumers and providers/producers ("prosumers") of information and data—they act as information and services consumers (e.g., via smart phones, tablets, laptops or desktop computers in private life and as professionals, but as well via public terminals), as data producers (e.g., via smart home sensors) or even as ICT providers (e.g., via shared WiFi).

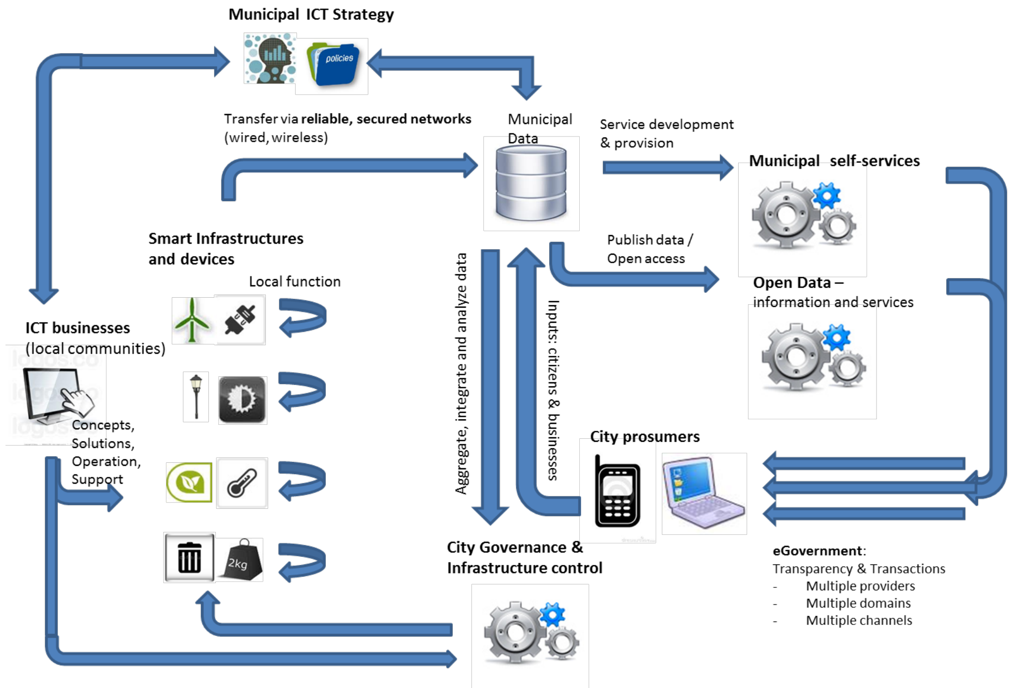

Figure 1: Municipal ICT as a system of systems facilitating governance, infrastructure control, and information exchange

In a smart city, mechanical processes as well as many human activities are continuously based upon, managed or at least influenced by data and information. Value-added services are derived from the mash-up of open, commercial and personal data. Multi-modal information is distributed through various channels according to specific user needs and access rights as well as according to specific situations and devices. Public services increasingly allow for bidirectional communication between the municipal administration and other city stakeholders such as citizens, businesses and non-governmental organizations (NGOs).

Data that are generated in specific urban contexts can be provided in raw or in conditioned form via the Internet. The current worldwide open data initiatives (e.g., [29][30][32]) aim at making even more data available to anyone, any purpose and any use by public authorities, but also by companies, NGOs or the like. If data can be directly accessed by machines as static artefacts (e.g., files) or as dynamic services (e.g., APIs), new kinds of services can be developed and provided to the public and to city professionals.

Thus, ICT has become a critical urban infrastructure - critical in a multiple sense: ICT does not only enhance urban supply, logistics and disposal infrastructures to become smart and energy efficient infrastructures—many safety-critical processes depend on ICT systems today. In hazards, accidents and catastrophes, ICT is an important prerequisite for emergency forces, police and health care organizations to efficiently save lives and minimize damages. In addition, with the use of personal data, there is a specific responsibility and need to secure these data against all kinds of abuse to a high extent. And finally, the ICT infrastructure itself has become that important for the functioning of any urban society that ICT architects and designers have to turn special attention to the protection and the resilience of the systems against damage, destruction, pollution or direct attacks.

ICT systems, at the same time, are a much more dynamic field than most other parts of an urban infrastructure. The quality of the ICT system is a clear advantage in competition concerning the economic performance, but also the quality of life within a city. Therefore, a community of local ICT providers is needed to continuously refine and enhance the ICT infrastructure in a smart city and to provide solutions to the city management. Because of this, urban ICT systems cannot be planned like canalization or rail systems with stable components lasting for decades. ICT systems are systems in constant evolution that demand mechanisms of data integration and constant technical improvement as new technologies are coming to the market. A direct municipal strategy for ICT development is essential to set priorities and—not only technically but as well politically—form a “smart city”.

5. An ICT Architecture of a Smart City and its Elements

Despite the heterogeneity of ICT solutions in urban management, there are basic concepts, layers and interfaces that are required to enable access to and communication of required data and information where needed, to overcome silos of data, information and communication in different application domains, and to provide value-added services and applications to the stakeholders in a city. This multilayer architecture is explained in the following. It has been prototypically used in different reference scenarios which are described at the Fraunhofer FOKUS ICT for Smart Cities Research Portal [24]. Its deployment at larger scale, however, is still subject to research and development work, standardization and adoption.

5.1 Overview

In a smart city, the technical communication infrastructure is the root that provides everlasting data flow. Hardware and software systems convert data into useful information so that it becomes comprehensible and visible to the citizen of the smart city. The urban ICT infrastructure is, often hidden, the basis for the collection and transfer of city data into the municipal data platform. Flexible, safe and robust access provides a framework for seamless data availability and use. In addition, the use of efficient tools leads to new municipal applications that optimize the processes within the city of tomorrow, sustainably and dynamically.

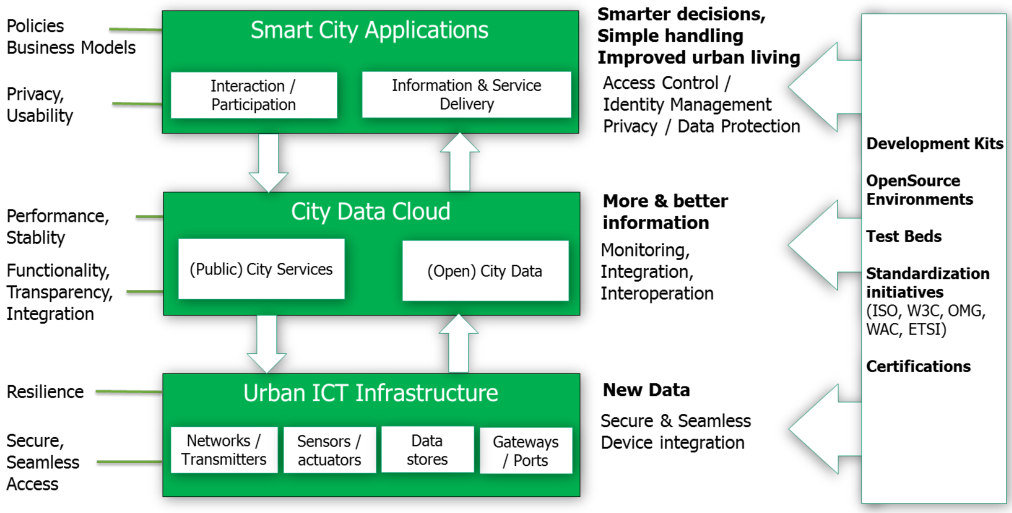

Figure 2. Urban ICT Architecture

5.2 Urban ICT Infrastructure: Sensor Networks and M2M

The city of tomorrow will be shaped by machine-to-machine communication (M2M). M2M communication serves above all the monitoring, control and localization of units that were equipped with M2M technology. It allows for innovative applications for a variety of fields, for example for building surveillance and control, electronic healthcare, and smart metering.

Modern cities, therefore, require a flexible M2M communication infrastructure [53] based on convergent networks that lay the foundation for new applications and their flexible combination. This leads to new possibilities for the use of previously isolated applications and data that are now the basis for new business models. For example, environmental data can be combined with up-to-date values attained from within the building to ensure the more efficient and automatic control of heating and ventilation systems. A uniform M2M communication infrastructure can make those and many other applications possible in both the private and industrial sectors. Sustainable information and telecommunication innovations are supported by the flexible availability of data and applications in all areas of urban life, such as in local electronic marketplaces.

Current research aims for the development of a generic M2M platform that is intended to act as a facilitator between different service platforms and the core network to enable the seamless communication management of different terminals, sensors and actuators. It will thus be a priority to meet the special requirements of the M2M communication and the ability to flexibly adapt the platform for special M2M service domains such as the automotive sector.

5.3 City Data Cloud: Urban Data and Information

In a smart city, urban data, services and applications are bundled on platforms which are required in both a technical and in an organizational sense. On the one hand, a technical infrastructure for the integration and provision of the heterogeneous and distributed data sources is needed. On the other hand, an organizational framework must be established that controls the provision, processing, transfer and use of the data for all actors involved—technologically, legally and economically.

The objectives of a City Data Cloud are to provide enterprises, organizations and citizens trustworthy access to urban and public data for the joint design of urban processes and operations. Commercial and public, current and context-sensitive data together with accumulated information about urban infrastructures and resources in the city are made available making current situations in the city transparent, facilitating decisions and making them comprehensible. Basic requirements for a City Data Cloud include the following:

- Timeliness, accuracy and quality of the data
- Data availability
- Possibilities for data aggregation and data analysis
- Uniform and device-independent access to data
- Data safety and legally compliant use and transfer of data

These demands can be addressed with a multi-layered architecture whose core consists of the infrastructure layer which enables the provision and processing of comprehensive city-relevant data. Basic components of the infrastructure layer include discrete and continuous data sources, data memory, data descriptions and specifications, filters, transformers and aggregators as well as combinable access services.

Such a city data cloud has already been created in Berlin [27] with companies following to support the idea of open data such as Vattenfall [41].

5.4 Smart City Applications and Services

City applications provide the citizens with access to up-to-date information and administrative services. Registration matters, house-hunting, bulky waste pick-up, study opportunities, traffic information, or lack of hygiene in restaurants: These are issues that all cities, communities, municipal companies and citizens must deal with. The time that the appropriate agencies and municipal companies need to address these issues often seems endless, time-consuming and too complicated for the citizen. City applications, no matter if they are provided by public authorities, companies, organizations or citizens, remedy the situation: These applications must combine internal and external resources such as data, functionalities and services and provide users with the opportunity to quickly contact the correct person in the local administration.

The establishment of platform- and device-independent city applications for administrative services and municipal service providers support the (online) involvement of the citizen on the communal level and increases the transparency of administrative processes. With the help of city applications, information and communication technologies can be set up in governmental bodies on a long-term basis. This results in the development of versatile access to administrative services and in providing citizens with up-to-date information about infrastructures and services.

For example, the citizens of a smart city must feel secure when moving around the city and using public transportation. Video surveillance is a key solution for enhancing citizen safety. However, this technology is challenged especially in the case of public and railway transportation. In video surveillance, it is assumed that the cars will be equipped with a set of appropriate cameras for surveillance and the corresponding video streams will be transmitted to a remote control server for investigation purposes. As video streaming is bandwidth demanding, even the use of broadband wireless technologies such as WLAN, UMTS and LTE cannot completely solve the related issues and support from the core network to control the video flows and prioritize them in case of congestion is paramount. In the context of Smart Cities, we will use our expertise in building a wireless based video surveillance solution for railway transportation to enhance the safety of citizens using public transportation.

5.5 Seamless Access

Flexible access to offers, information and services is provided through so-called open service platforms in a smart city. These open service platforms are based on convergent, heterogeneous network technologies, for example, wireless and wired telecommunication networks, next generation networks (NGNs) and the Internet.

Smart City Applications (SCAs) must be available everywhere in the city, implying a strong demand for mobile access (e.g., smart phones). They also must be scalable as the number of concurrent users can reach the millions. Also, in order to enable rapid SCA development and deployment, elementary services and properties such as authentication, authorization and accounting and QoS management must be part of a corresponding communication platform. The 3GPP Evolved Packet Core (EPC) addresses these features in release 8 and higher. The EPC follows the evolution of wired core networks and the occurrence of overlay control networks such as the IMS. Its realization can become an operating system for SCAs.

Moreover, mobile cloud computing can be seen as an infrastructure allowing data storage and data processing outside the mobile device. Therefore, this new computing paradigm will enable the development of rich applications and services, especially in the context of eGovernment, eHealth and urban resource management. Such services cannot be deployed correctly without the support of the network in terms of connectivity, for instance:

- connection reliability: always best connected
- security of the communication with the cloud and
- mobility and resource management

Another aspect of smart cities is the ability to use limited resources efficiently. Widely deployed sensor networks can be used to achieve a better understanding of floating requirements in the city (e.g., vehicular traffic control). Enabling sensor access and control in the EPC is still a research challenge with respect to communication volume, timing, real-time requirements and security.

At the edge of any communication platform for various smart city applications and services there is an obvious need for “capillary networks” mainly based on sensor/actuator technologies enhanced by communication capabilities. These capillary edge networks in the field are responsible for all data gathering and provision functions required, obtaining close to real-time data in order to support all sorts of environmental and utilities-related service and business process optimization.

Technologies for an on-demand establishment and configuration of communication infrastructure provide solutions for emergency communication, temporal peak loads (festival, demonstration, sports) or in providing a backup infrastructure for disaster situations. The goal is the efficient utilization and cooperation of different networks and devices (fixed, mobile, ad hoc) that are deployed in the smart city. Resources provided by users, network operators and authorities should be combined to provide coordinated emergency communication, temporal and backup communication networks as well as security and prioritization policies across heterogeneous environments und administrative domains.

5.6 Engineering Reliable and Secure ICT Solutions for Smart Cities

High-quality, reliable and secure technical systems must constitute the ICT solutions for smart cities. The technical systems of cities include the infrastructure and administrative systems of a city. Municipal task responsibilities such as mobility, resource supply, waste deposal and safety that were in the past most likely separate, are assessed for common interfaces and interactions and linked in a logical way to benefit the city. This leads to increased demands on the information and communication systems that permeate through the various technical systems of a city. Integrated infrastructure and administrative systems raise the city of the future to a new quality level. They allow for analyses, safeguarding and optimization beyond subject, organizational and technological boundaries, whereby the interoperability, effectiveness and the functional and IT safety of these solutions must be designed and realized early on.

It is required to adjust and extend software engineering methods and tools for ascertaining the requirements of the ICT-based solutions as well as their design, specifications, implementation and quality management. Particularly in the area of model-based development of software-intensive systems and the supportive development tool chains, quality management and certification processes are necessary.

For example, techniques for data analysis, privacy, anonymization and other are essential to provide secure reliable communication infrastructures in a heterogeneous environment. In addition, data analysis techniques from the area of network traffic might also be useful in other contexts (e.g., other infrastructures).

Likewise, security and reliability are crucial to support cloud computing or communication networks for critical infrastructures. Solutions are needed to protect communication environments (robustness, availability, security). Network supervision for communication networks help identify and defeat new attacks.

6. Open Data—A Driver towards Smartness

Open data is one of the main urban management trends that have emerged in recent years. It is based on the vision of open exchange of data under free licenses (e.g., CC-BY [37]), thereby providing users, companies, developer communities and other stakeholders with a basis for creating novel services and applications. Thus, open data exchange would also provide opportunities for start-up companies since it fosters novel business models that rely on the availability of data. Correspondingly, open data has the potential to facilitate economic growth and contribute to prosperity. Furthermore, developing countries hope to improve their quality of life based on open data, given that it would allow for monitoring the environment and enable decision making with respect to vital aspects of everyday life, such as water quality.

Open data can originate from different sources. For instance, the data may be provided by a sensor measuring water quality at a particular location. Other data may be collected using certain crowd sourcing principles, or they could be provided by administration, NGOs or science organizations as part of their daily work data collection routines. One of the biggest challenges with open data is trustworthiness: No society can rely on wrong, manipulated or compromised data. One possible remedy for this trust issue is to rely on data that solely come from the public sector, for instance, governmental institutions, different type of authorities etc. These institutions normally keep large amounts of data whose acquisition is financed by the tax payers. Thus, the data belongs to the society since it has paid for its collection. Such data can also be considered trustworthy since it has gone through a lengthy process of collection and verification by experts in the institutions this data belong to. In addition, the institutions, being on the governmental side, have all rights to access different types of raw data which gives them an advantage over data collection enthusiasts from the community (e.g., in case of crowd sourcing).

Institutions from the public sector but also companies and NGOs are intended to publish their data via so-called open data platforms. Such platforms are used to catalogue the data with the help of appropriate metadata. A number of open data portals across the world are already operational—Berlin Open Data Platform [25], Kenya Open Data Platform [28], US Open Data Portal [29] and the Open Data Portal of the United Kingdom [30], to mention some.

Within the EU Project "Open Cities", Fraunhofer Institute FOKUS has developed a platform for publishing open data. The primary benefit of the platform is a "one-stop-shop" experience which means largely reduced efforts of developers and consumers when searching, accessing, downloading and sharing the data. The platform is an integrated solution that utilizes open source software: a data catalogue based on Comprehensive Knowledge Archive Network (CKAN) software, a data portal implemented in Liferay, an optional data store based on the Virtuoso database management system (DBMS) and an integration layer. The integration layer facilitates the interplay between the data portal, the data catalogue and the DBMS server towards an integrated open data platform solution. Technological specifics of the platform are: 1) Java wrapper for accessing the API of the CKAN data catalogue, 2) a metadata scheme for open data based on survey conducted in five major European cities (Amsterdam, Barcelona, Berlin, Helsinki, and Paris), 3) multi-language support and 4) support for linked data.

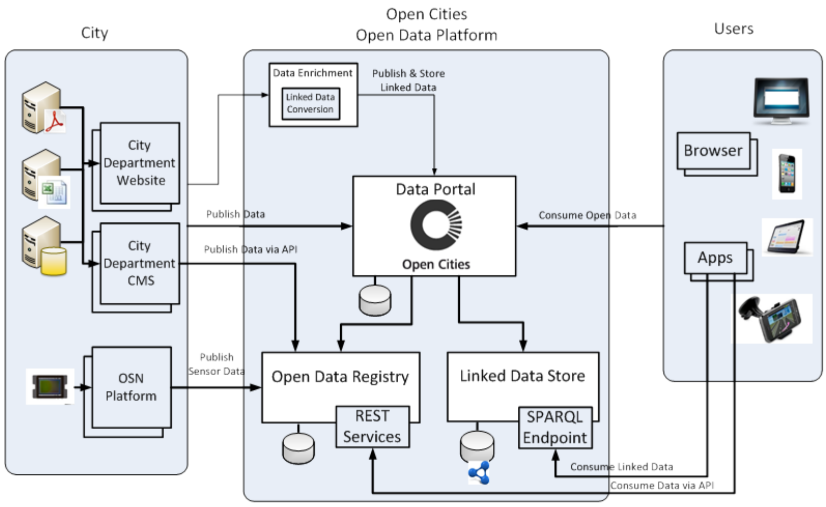

Figure 2: The Open Cities Platform Architecture for Open Data

However, the provisioning of open data still remains challenging for the stakeholders. Even though years ago the European Commission has issued regulations in the European Public Sector Information (PSI) directive [36], the amount of available open data across Europe remains far behind the identified potentials. This relates not only to the number of data sets, but also to the timeliness, completeness and accuracy of available data. Hence, the above-mentioned benefits of open data can be leveraged to a limited extend only.

The reasons are manifold. Above all, the required changes in working with data are that substantial that they require a new mind set and paradigm changes [26] which take time for their implementation in large:

- Public vs. confidential: The decision to publish raw data needs to change from "everything is confidential if not explicitly marked as public" to "everything is public if not explicitly marked as confidential"
- Publication vs. withhold: The timing of publishing raw data needs to change from "an individual decision by administration which often means access on request only" to "a pro-active timely publication of all data that is not subject to security or privacy constraints"
- Free vs. limited use: The license conditions for published raw data needs to change from "availability for private use only, while all other usages need to be arranged separately" to "free licenses according to which published data is available for any use, including reuse and further processing – ideally at no cost"

But also the platforms used to provide open data require improvements: The publication processes, i.e., the way open data is provisioned, versioned and provided address the needs of data providers to a limited extend only. Data providers are required to go through a process of continuously updating the metadata as well as the data sets of static data or the APIs that provide access to dynamic real-time data. This results in situations where after initial data publication the data and their metadata are often not continuously updated since it requires additional efforts from the data provider's side. To maximize the economic and social value of open data, tools for an easy provisioning, continuous maintenance, quality assurance and data provenance are necessary which are subject to current research.

7. Indicators for Smart City's ICT

Because of the growing amount of today's smart city initiatives, and since "Smart City" is becoming a fashionable label, it is justified to raise the bar a little bit higher and to look for methods that will enable a more objective benchmarking. There are various studies and ICT indicator reports, provided for example by the United Nations or the International Telecommunications Union ITU [46][47][48]. However, these studies are basically related to countries, but not to cities. Moreover, while these studies count the number of mobile phone devices or the frequency and speed of Internet access in households, they do not at all reflect on the various urban ICT technologies that we have presented in the past chapters. Therefore, we would like to propose a series of new indicators that will lead to an advanced measurement of the significance of ICT for a smart city. In order to identify such indicators, we have stated the following three basic hypotheses:

- **Hypothesis 1**: A smart city is based on a highly dynamic policy and business-driven community of ICT providers and ICT users. Continuous municipal and private investments but also ICT-related revenues for the city are the ground floor for flourishing urban ICT developments.
- **Hypothesis 2**: In smart cities, many aspects of urban systems and lifestyle (traffic, public transport system, public security, health care, eGovernment, etc.) are supported by ICT. Citizens, businesses, public and private organizations and visitors rely on secure and attractive services that are used in day-to-day routines and available wherever needed.
- **Hypothesis 3**: Smart cities are characterized by continuous growth of connectivity and integration. People, objects, vehicles and assets are connecting to the diverse subsystems of a city ICT infrastructure for private, business or public purposes. In parallel, there is a continuous trend of integrating systems and data in order to receive a consistent stream of data, an acceptable system performance and, finally, added value through information and services.

We used these three hypotheses as a basic structure to identify and group related indicators. As a result of our work, we would like to propose the following:

Indicator group 1: ICT policy & business. Urban ICT innovation is policy- and business-driven with a broad variety of objectives. A sustainable city ICT policy will encompass continuous long-term developments, but also short-term projects heading for concrete solutions and addressing the specific key performance indicators (KPIs) of a city. As a specific part of urban planning, ICT innovation must include numerous stakeholders, may they be politicians or ICT professionals from the city municipality, local provider businesses and organizations or local users (citizens, businesses, tourists) that influence the processes of ICT innovation in a city. A vital local ICT user and provider community helps to implement and quickly adopt the latest technology within the city, but also to refinance municipal investments in technology innovation and thus contribute to the economic growth of a city.

Indicators: ICT policy & business
ICT-1.1: Existence of a roadmap for long-term ICT evolution in the city ICT-1.2: Percentage of municipal investments in innovative local ICT projects as compared to the total investments (in the city infrastructure). ICT-1.3: Municipal investment in ICT development relating to explicit objectives from city development plans as compared to the total amount of municipal ICT investments. ICT-1.4: Percentage of private investments in innovative local ICT projects as compared to the total investments in such projects ICT-1.5: Share of the ICT sector in the economy of a city (% of GDP) ICT-1.6: Share of workplaces in the ICT sector as compared to the total number of jobs in a city.

Indicator group 2: ICT implementation rate & services adoption. In a smart city, ICT is implemented to realize a broad variety of purposes that relate to the city and its inhabitants. First, ICT can be used to optimize and automate typical urban processes. One example is a smart traffic system that helps avoid traffic jams and at the same time fosters the use of the public transport system. Furthermore, ICT is used to support innovation through the creation of new products, services and markets (e.g., trading energy in neighbourhoods). Other technologies aim at raising the empowerment of citizens, businesses and organizations by providing information transparency and participation options. For example, open data portals allow for the development of services in wide-spread ecosystems including large ICT providers and small- and medium-size enterprises and in a highly dynamic way. Last but not least, ICT plays an important role in governing a city by collecting and providing relevant data necessary for long-term urban planning, decision making and for control of sustainability.

Smart city services provide added value and a positive user experience to businesses, organizations, authorities, citizens, tourists and other users. Services that are perceived as safe, simple and user friendly will lead to a higher overall acceptance and adoption rate of ICT infrastructures and ICT services. With the growing use of smartphones and other mobile network devices, the demand for ad-hoc access and service continuity is rising and the provision of these technologies is increasingly anticipated as normal.

Indicators: ICT implementation rate & services adoption
ICT-2.1: Percentage of individuals using local ICT services/information services via mobile broadband Internet every day or almost every day (private & work)
ICT-2.2: Percentage of individuals trading (selling or buying) goods & services in local malls or on service platforms
ICT-2.3: Percentage of local enterprises routinely exchanging data with public authorities via the Internet
ICT-2.4: Percentage of municipal procurements managed via the Internet
ICT-2.5: Number and usage rate of local health online services fostering access to health care, improved quality of care (e.g., health monitoring), illness prevention and health care efficiency.
ICT-2.6: Number and usage rate of online services relating to the local public transportation system (e.g., real-time timetables, commute planning assistants, car sharing services).
ICT-2.7: Number and usage rate of online services relating to the local traffic systems (e.g., fostering traffic jam prevention, street safety, environmental protection, parking lot finders)
ICT-2.8: Number and usage rate of transactional[1] online services fostering data exchange between local governments, citizens, businesses and other organizations
ICT-2.9: Number of eGovernment services based on open databases from the public sector
ICT-2.10: Share of households equipped with a smart metering solution
ICT-2.11: Share of households connected to a local Smart Grid

Indicator group 3: ICT connectivity & integration. Urban ICT usage is based on a high level connectivity. Connectivity relates to the municipal infrastructure itself by mounting resilient, secure and data protecting ICT systems to the physical infrastructures (buildings, streets, electricity, public transportation vehicles, etc.). The term connectivity also relates to citizens or tourists that ubiquitously connect through their mobile or static devices. It finally relates to vehicles, objects and assets owned by citizens and

[1] Transactional eGovernment services are eGovernment services on a higher maturity level. They are directly integrated in processes of the municipal government and thus go far beyond a pure information provision or the download of documents. Transactional services, such as the German tax return software ELSTER, provide direct interaction between the client of a citizen/enterprise and a relating server of the municipal government. http://bura.brunel.ac.uk/bitstream/2438/4486/1/250740082c.pdf

businesses as well as by the municipality. Since connectivity always aims at the provision and the exchange of data and information, a concrete notion of data protection and the management of sensitive data are necessary.

The growing amount of enabling devices and platforms as well as the huge volume of data emerging from the physical world calls for the integration of data and information from various subsystems. For example, monitoring noise, pollution, structural health and waste management demands data integration from different subsystems of an urban ICT infrastructure. These subsystems have grown into silos in the past. Data integration is not only a question of data protection and controlled data access, but also puts numerous challenges on the stability and the performance of the system as well as on the data management (consistency, integrity, redundancy).

Indicators: Connectivity & Integration
ICT-3.1: Percentage of individuals accessing the internet through mobile devices every day or almost every day ICT-3.2: Density of free WiFi hotspots provided by the city ICT-3.3: Number of sensors and cameras that are integrated into the physical infrastructure of the city[2], per inhabitant ICT-3.4: Amount of data streaming into municipal systems by time unit (MB/s or TB/s) ICT-3.5: Share of municipal applications that aim at integrating data from various municipal subsystems / total amount of municipal applications ICT-3.6: Percentage of local authorities & public service organizations that exchange data or access shared and integrated data pools

The indicators will be used in an analysis of selected cities and their ICT strategies as part of the Fraunhofer Morgenstadt initiative [52].

8. Conclusion

Smart cities are to be addressed by cross-sectorial, multidisciplinary approaches and are to be understood as a continuous process of improvements in urban management.

This chapter discussed the central role of ICT for smart cities. While ICT itself does not make a city smart, there is no smart city without a strategic positioning of ICT and corresponding substantial investment.

[2] This encompasses static elements (buildings, streets, street lamps) as well as mobile elements of the city infrastructure (city buses, metro trains).

A generic architecture for ICT of a smart city was presented, consisting of the city network infrastructure that provides ubiquitous access to environmental, urban management, supply and disposal, etc., data in raw, machine-processable form. The city network infrastructure reports into the city data cloud in which data is filtered, stored, aggregated and processed into information and value-added services. These services are visualized and presented by dedicated urban applications to end-users in business, administration, science, education, etc. In particular, value-added services for specific user groups become possible by the use of real-time information which is adjusted to the preferences and requirements of the users. The actions in response to the various needs can then be realized by interconnecting the different actors by means of ICT.

Subsequently, open data as a driving force for smartness in cities was discussed. Recent work in Berlin, other European cities and broadly across Germany was presented. In September 2011, the first German Open Data Portal was launched for Berlin. A study for Berlin [25] about the status and potential of open data for the city in early 2012 was followed by a similar study for Germany [38] in summer 2012. The German study is more exhaustive in terms of quantitatively analysing open data candidates, discussing legal issues along the data lifecycle and providing options for the operation of a German platform [32]. This study is the foundation for the ongoing pilot realization of that German platform. The German platform will offer data sets from German ministries, states and municipalities as well as from domain-specific offers on statistical, environmental and geo data. It will result in a joint cross-level, cross-disciplinary platform that provides a centralized access to various open data offers in Germany. In a first phase, existing data offers from, for instance, Bremen or Berlin and from PortalU (environmental data sets) or GDI-DE (geo data sets) are brought together into this German platform.

Finally, 23 ICT-related indicators for smart cities were presented. They were classified into indicators for ICT policy and business, for ICT implementation rate and services adoption and for ICT connectivity and integration. These indicators can be used for the determination of ICT readiness of selected cities worldwide in order to measure the adoption of smart cities concepts, and they will be evaluated as part of the Fraunhofer Morgenstadt initiative [52].

The concepts and approaches described in this chapter already resulted in new deployed solutions (e.g., in Berlin [27]) and will be further elaborated as part of the Fraunhofer FOKUS strategy towards ICT for smart cities [24].

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