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DIGITAL TWIN AS CITY MANAGEMENT TOOL

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Abstract

The new communication technologies, such as 5G, will be acting as enablers for new kinds of services and applications, with advanced requirements especially in terms of latency, resilience, coverage and bandwidth. Cities in developing countries struggling with challenges such as traffic control, water and sanitary management and urban security may turn rapidly developing ultra-high speed data transmission infrastructure into agile and easily reconfigurable solutions to local urban issues.

Questions regarding practical implementation of the new immaterial information infrastructure (or 3i for short) are being studied in a Finnish state-funded LuxTurrim5G project that is being carried out by a research consortium led by Nokia Bell Labs and including prominent Finnish companies and research institutes.

Key Words: City design, 5G, digital twin, digitalization, integrated city management

INTRODUCTION

The wave of digitalization has reached the traditional infrastructure assets of urban environment. Soon all built city elements such as buildings, streets, cars and infrastructure assets are interconnected in a mesh of sensors and other data sources. This will be the framework where civil and commercial processes take place, gaining from and adding to the flows of information.

At the same time, the cities of developing countries face the dilemma of fundamental and fast evolving urban challenges in traffic management, sewage, urban ecology and providing everyday services to their dwellers, this with limited human and financial resources available for urban management and traditional planning services.

We see the potential of digitally enhanced city environment not only in rich developed cities, but also as a tool for bypassing some of the bottlenecks of traditional urban management in developing countries.

New 5G technology offers a disruptively new approach in cities in form of agile, local application tools and solutions, utilizing machine learning algorithms to readjust themselves to local conditions and situations at hand.

RESEARCH DESIGN

Our ongoing research project, LuxTurrim5G, will solve critical challenges developing and demonstrating concrete technical solutions for 5G smart city infrastructure, and business and service innovations based on that (LuxTurrim5G, 2017). The project brings different highly committed stakeholders to close collaboration to create new ecosystem building key enablers and solutions utilizing modern 5G networks for smart city environment needs. Research is based on the multiple case study method (Yin, 2003). Additionally, literature findings enrich case study findings and the experts from the consortium partners' have given their experiences and insights to make in-depth understanding of the 5G smart city infrastructure challenges (Eisenhardt, 1989). This paper concerns the development of city design tool, which will be used for the simulating different parameters in context of future smart cities. These parameters are for example air quality, traffic flows, outdoor lightning and 5G network coverage in smart city environment. Ultra-reliable low latency connectivity enabled by mobile 5G network is an essential platform for developing services for smart cities. Emerging urban services such as self-driving cars, delivery drones and security solutions require continuous data flow with high reliability and low latency. Paper defines the utilization of the proposed tool and platform concept that we call "immaterial information infrastructure" or 3I in short. In our view, this concept calls for unprecedented ways of public and private urban interaction and opens totally new opportunities for businesses in field of infrastructure management.

This study has its basis in the two main concepts, which are 1) digital twin, and 2) integrated city management. These concepts are defined in following sub-chapters.

A digital twin is a digital representation of a physical object as promoted by Gartner (Shetty 2017). It includes the model of the physical object, data from the object, a unique one-to-one correspondence to the object and the ability to monitor the object. Adapted to urban scale, the digital twin of a city represents the different urban assets and processes as well as their interaction.

City management or integrated city management is a term widely used in connection with smart cities, combining the capabilities of the existing agencies for mobility improvements (private and public transport) energy efficiency (lighting, irrigation, buildings) environmental issues (emissions, weather) and risk management (floods, rain/snow/ice, outage) (Riveira 2016).

STATE OF THE ART 5G TECHNOLOGIES, BACKGROUND

The World is facing an unprecedented pace of urbanization stressing the current and future land and geospatial systems. The upside is that the increasing urban areas also provide growth and jobs as 80% of the economic activities globally center to cities. However, the challenge is sizeable. Capitalizing the cities' potential will require accommodating 2 billion new urban residents and planning of 1.2 million square kilometers new urban space by 2030. Totally new levels of support and solutions are needed for managing this dynamic and constant change. At the same time with urbanization, the need for mobile connectivity increase and today cities are becoming smart (Smart City) with the digitalization of services. While the 4G networks have been driven by the need to deliver consumer video content and internet connectivity, the coming years will be characterized by the explosion of machine-to-machine connections generated by the increase of IoT traffic and services. This field will be dominated by several new vertical business segments, e.g., automotive and mobility, factories of the future, health care, media and entertainment, and energy.

The new communication technologies, such as 5G, will be acting as enablers for new kinds of services and applications, with advanced requirements especially in terms of latency, resilience, coverage and bandwidth. Next generation communication systems are expected to integrate different technologies such as mobile, fixed, satellite and optical to offer a more seamless experience to users as they move between locations served by networks of different capabilities. With this increasing demand of new functionalities, new requirements and new use cases, next generation communication networks will need to possess intelligent mechanisms for network orchestration and efficient processing methods of large amounts of data. This study focuses on the development of 5G connectivity and its relation to future smart city services.

5G is, quite literally, the fifth generation of mobile networks. Despite the huge interest, 5G development is in the very early stages and there are as yet no standards or specifications, but first standards should be agreed during the year 2018. In December 2014, the GSMA outlined eight criteria for 5G. A network connection should meet a majority of the eight in order to qualify as 5G (5G.co.uk):

- 1-10Gbps connections to end points in the field (i.e. not theoretical maximum)

- 1 millisecond end-to-end round trip delay (latency)
- 1000x bandwidth per unit area
- 10-100x number of connected devices
- (Perception of) 99.999% availability
- (Perception of) 100% coverage
- 90% reduction in network energy usage
- Up to 10 year battery life for low power, machine-type devices

5G will be much, much faster than previous generations. A full HD movie will be able to be downloaded in under 10 seconds, compared with a similar number of minutes over 4G. And that time for 4G is contingent on having peak rates for the duration of the download, which is very rarely the case. The response time will be significantly better, at 1 millisecond compared with the current rate of around 50 with 4G. Because of the substantial improvements to speed and latency, the user will have the perception of limitless bandwidth and continuous availability, wherever they are. 5G will provide the bandwidth that will be needed to enable the billions of devices that will be connected to the internet to communicate with each other. 5G will need to be cost effective for users and operators, hence the need to achieve significant reductions in energy usage. The three major design objectives for 5G are listed as follows (Huawei, 2013):

- Implementation of massive capacity and massive connectivity
- Support for an increasingly diverse set of services, applications and users – all with extremely diverging requirements
- Flexible and efficient use of all available non-contiguous spectrum for wildly different network deployment scenarios

As a summary of previous technological developments, the European Commission have presented the next figure for indicating new ecosystem related to 5G development.

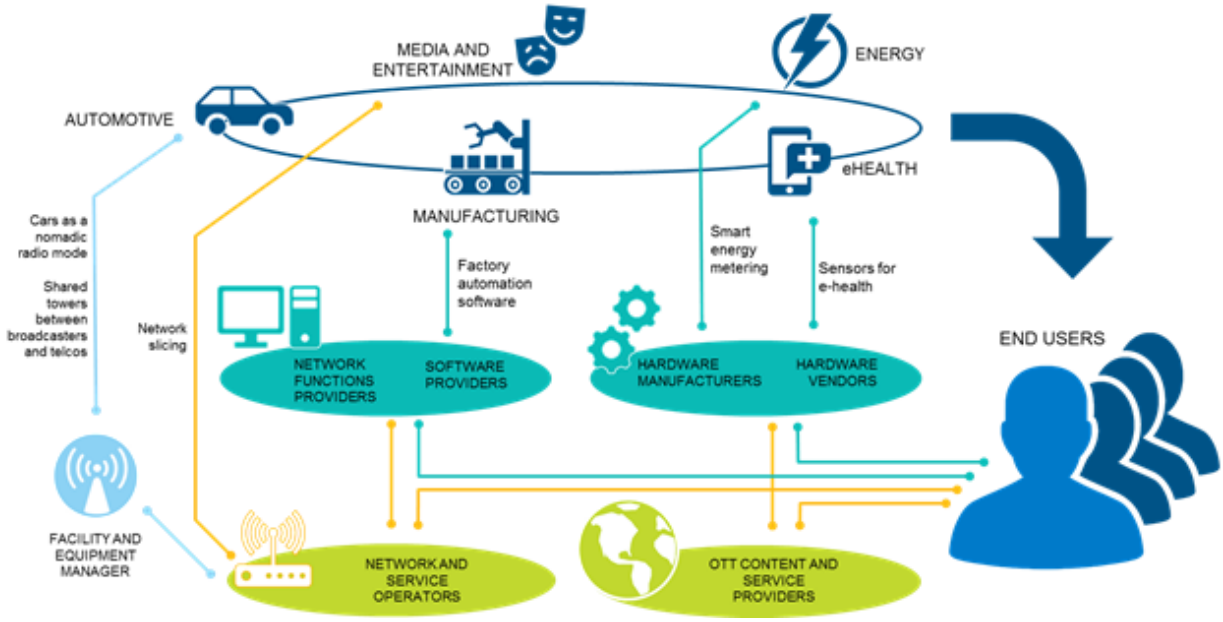

Figure 1: According to the estimates of European Commission, the new 5G ecosystem is an evolving value chain of both existing and new players (modified from European Commission, 2018)

Most of the vertical sectors have strong requirements on geographic and/or population coverage, but also in other technical terms (latency, reliability and data rate). That is the main motivator for this research of 3I tool and simulation usage of Smart City design. The Smart City infrastructure design is a complex process in the future, when combining people flow, logistics, city lighting, data connectivity and other design flows together.

THE "3I" AS A BUSINESS SERVICES PLATFORM

In our view, the immaterial information infrastructure or 3I will be an integral part of any urban economy, acting as a mediator platform between data network technology and urban social and managerial processes. Essentially it consists of three ecosystem layers:

- **technological network base** with hardware and software components: backhaul, core network, base stations, software network functions enabling management and slicing of network capacity;
- **service layer** and interface with business enablers: processes and market functions for secure exchange of domain- and provider-specific data; and
- **smart urban vertical domains**: eg. mobility, utilities, security, energy, e-health and entertainment.

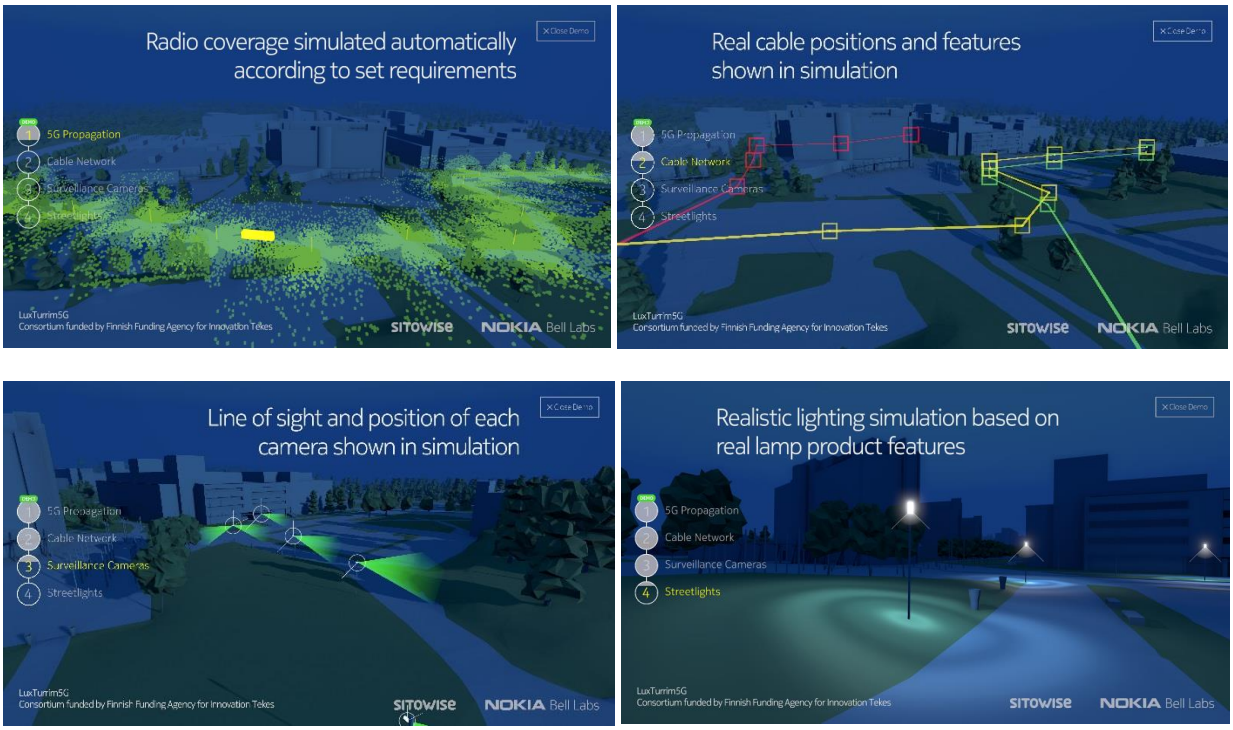

Figure 2: Examples of smart urban services supported by the 3I and studied in the LuxTurrim5G project: automated radio coverage simulation and base station optimization, utilities network layout and management, security infrastructure as well as outdoor lighting. (Sitowise and Nokia Bell Labs, LuxTurrim5G project 2018)

5G solutions in developing cities

To relieve pressing urban challenges in dense conurbation areas, ultra-high speed data networks and extensive IoT sensor infrastructure enable rich array of possibilities highlighted by the following examples:

- **Traffic control:** real time data from optical sensors, lidars and cameras may be combined with device information from moving cars to create a dashboard data background on the dynamics of traffic in the city. This backdrop of information may be used for eg traffic light optimization, dynamic route recommendations, smart dynamic signage and smart route consultation. The gathered situational data may also be used in analyzing the traffic flows during the day and for creating advanced traffic simulation algorithms.
- **Flood control**: IoT sensors may be used to monitor the flow and quality of water in floods and streams as well as storm water. This cumulative data may be used for advanced simulations for water management, crisis management in severe flooding situations as well as management of fresh water assets, just to mention a few potential examples.
- **Fresh water asset management and sewage**: wireless IoT sensors maybe used to track use and distribution of fresh water and management of sewage water. Combined with online data on

water quality, this information base caters for a smart and agile water management and more economical use of fresh water assets.

- **Increased resilience in data distribution**: 5G technology provides multiple data channels and dispersed MEC (edge computing) technologies and dramatical decrease in use of energy per data delivered (x1000). Combined with advanced device-to-device technologies, the architecture of a highly dispersed local network significantly increases the reliability and resilience of local wireless data exchange.
- **Urban security and crisis management**: online situational data forms the basis of security measures in cases of accidents, natural disasters, fires etc. Data from static IoT sensors maybe complemented by ad hoc data sources such as drones, mobile devices and cars to provide situational data for rescue personnel over ultra-high speed and reliable 5G network architecture.
- **Data exchange needs for large public gatherings**: ultra-high capacity 5G networks may be set up for large venues in an agile and configurable manner. The first major use of this technology has been showcased in the Pyeongchang Olympic games. This kind of ad-hoc architecture may rely on a combination of static core network and mobile temporary elements.
- **Replacement of vulnerable cable installations by wireless connections**: a dynamic urban environment is a challenging context for agile equipment installations that need ad hoc reconfiguration. With a large number of IoT data sources it requires approach similar to manufacturing industry halls or logistic areas (such as ports and airports). Major difference is that cityscape if fundamentally multi-user and multi-managerial compared to a closed controlled ecosystem. A 5G network architecture is the solution for this kind of very complex playground of extremely heterogenous data formats and use cases, where the installation of cabling and hardware hindered by rigid permission and management processes.

We see the “3i” concept as a way for bridging the technology gap in developing countries that have moved straight to mobile technology and wireless data infrastructure in cities.

The key element in managing the new digital urban context is the virtual platform infrastructure where the communication and interaction of manually operated and automated elements takes place. Enabled by ultra-high speed 5G network, the traditional ideas of a “map” or a “3D model” evolve into live low latency virtual presence and self-awareness of the cityscape, creating unprecedented opportunities to reform governance and business processes.

This kind of virtual infrastructure features extreme agility and resilience, as its nodes (sensors, cars, mobile devices, local data servers, etcetera) act autonomously and network in an arbitrary way. New ways of conduct enabled by digital data, tools and applications help in resolving some of the immediate management problems in cities of developing countries.

For example, a driving car or a flying drone in the city streetscape keeps in continuous contact with multiple devices and servers, allowing one lost connection to be bypassed by other devices in the network. An individual element of the cityscape, a car, a pedestrian or even a sewage pump gets

constant live feedback from its environment and other relevant actors and is thus able to adjust its action accordingly. All kinds of anticipatory simulations maybe run parallel to the live action, and this background data could be processed by machine learning algorithms to make the various urban actions smoother and more efficient.

An ultra-high speed 5G network acts as a platform for a wide range of solutions and tools, including various simulations, both anticipatory and real time, on air quality, security issues, radio signal propagation and other urban issues. Urban environment is typically characterized by a combination of low to ultra-high latency data flows, from static or slowly evolving 3D building data to live pointcloud data produced and shared by automated cars and drones. The 5G network supports a management ecosystem for development and maintenance of physical and virtual data infrastructure.

We recognize that critical steps on the path to an integrated digital urban environment include an efficient and affordable way for setting up and maintaining an ultra-high speed network. The traditional way of mobile operators investing in a network of base stations will be challenged by the sheer number of transmitters required by high-frequency networks. Setting up a 5G network, typically combined with other urban services such as street lighting, will require the interference and support of city administration, possibly combined with an eventual “neutral host” that acts as a moderator between city administration, different mobile operators and eventual other actors in the “3i” ecosystem.

We see that the new information infrastructure eventually overlaps and integrates with traditional concrete elements of urban infrastructure, and will form a platform for integrated city management also in cities of developing countries, offering a novel set of tools in the numerous challenges that they face in gain of both city administrations and their citizens.

CONCLUSIONS

The immaterial information infrastructure (3i) and a digital twin of the city environment will help developing countries to design, manage and reconfigure urban and city infrastructure much faster and more cost effectively. Ultra-high speed 5G networks will reform many urban processes and services, and their implementation is a fundamental opportunity also in developing countries.

Requirement for the effective adoption of 3i is a proactive role taken by cities in promoting the development of the three enabling elements: technical infrastructure base, market structures and verticals representing a variety of service domains.

Different aspects of smart city environment enabled by ultra-high speed 5G network are being studied and developed in Finnish LuxTurrim5G project by Nokia-led consortium. Learnings from this national development project should be adopted through international pilot projects with cities in developing countries.

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