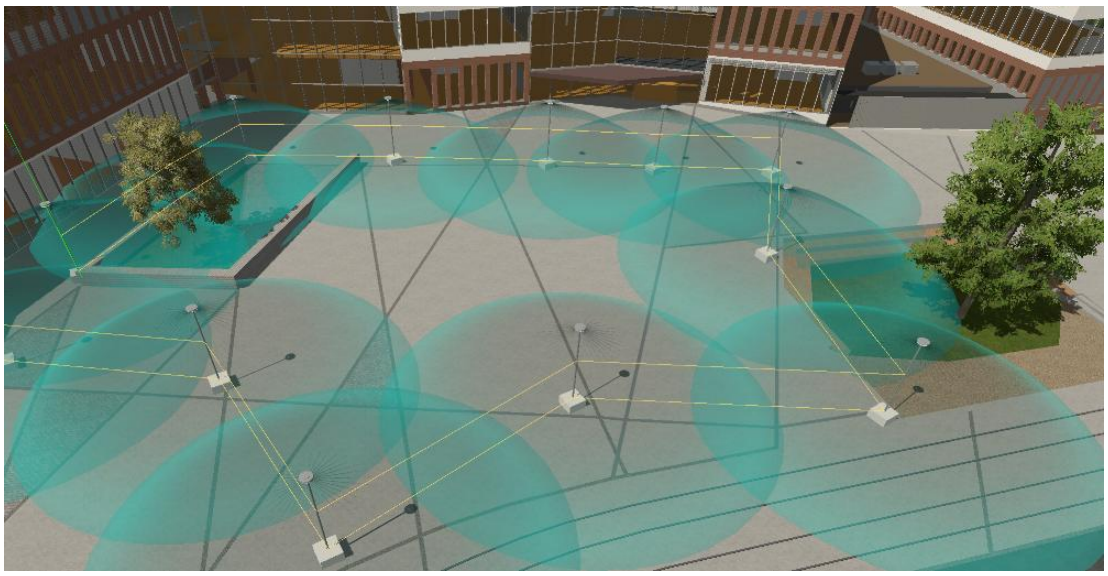
LuxTurrim5G

D1.1.1: State-of-the-art analysis



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1 Preface

LuxTurrim5G is developing and demonstrating fast 5G network based on smart light poles with integrated antennas, base stations, sensors, screens and other devices. This joint project opens new digital services and business opportunities for a real smart city.

LuxTurrim5G Key Challenges:

- Smart cities need digital service infrastructure to improve safety, energy efficiency, air quality, effectivity of transportation and quality of living
- However, the capacity of mobile networks will be far too insufficient due to the increasing traffic volume and new digital services built and planned
- The problem can only be solved by using small cell 5G radio frequency technology & higher frequencies; this requires dense networks of antennas setting new requirements for the network infrastructure

The project is a great technical challenge, but also a global service and business opportunity for the consortium members and Finnish industries. Identification of new innovative service concepts and business models are essential for the Finnish companies' success in digitalized global economy. The goal of WP1 is to define new service and business opportunities and next generation business models for flexible and scalable outdoor 5G small-cell high-speed services utilizing light pole infrastructure.

This deliverable is the state of the art analysis for setting the base line for the research and development within the LuxTurrim5G project. The deliverable is presenting the State-of-the-art in relevant telecom & light pole global markets, as well as relation to past and ongoing projects. This study identifies what are the key market areas in smart city context related to LuxTurrim5G project. This deliverable is based on the literature findings, consortium partners' case studies, and individual expertise.

LuxTurrim5G is a 2.5 year project started 2017 including 9 companies and 3 research institutes. The project is funded by the consortium partners and Business Finland.

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2 Introduction

While 4G networks have been driven by the need to deliver video content and internet connectivity, the coming years will be also characterized by the explosion of M2M connections due to the increase of IoT traffic and new services. Several new vertical business segments, e.g., automotive and mobility, factories of the future (sometimes referred also as Industry 4.0), health care, media and entertainment, and energy are the examples of forthcoming dominating developments. The development of new communication systems, such as 5G, will be thus acting as enablers for new kind of services and applications with advanced requirements especially in terms of latency, resilience, coverage and bandwidth. From this perspective, the Web is now widely recognized as a powerful platform to provide highly intuitive and user friendly applications.

The capacity of mobile networks will be far too insufficient already in a few years due to the increased number of users and new digital services built and planned. This creates a serious bottleneck and threatens realization of the important smart city digital services which will be vital only if they are connected and distributed through an effective and reliable telecommunications network. This problem can be solved only by taking into use small cell RF technology and higher frequencies.

LuxTurrim5G will solve these critical challenges developing and demonstrating concrete technical solutions for smart light pole based 5G infrastructure, and business and service innovations based on that (Project scope in Figure 1.). This is a key element to bring the effective novel data networks available and open real business base for a variety of services.

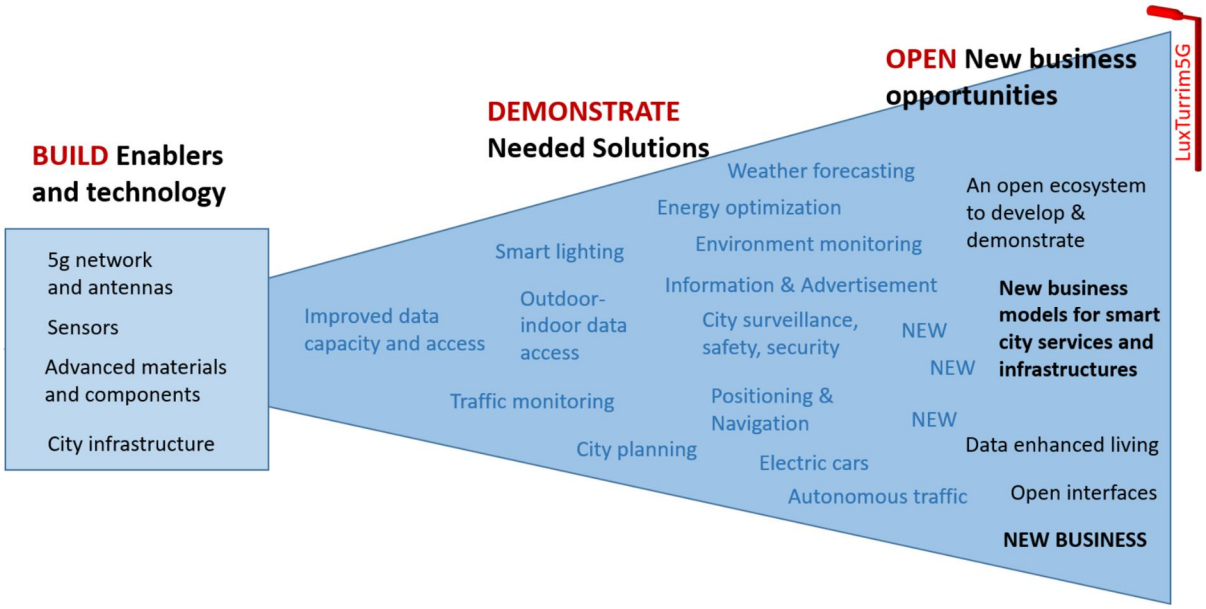


Figure 1 LuxTurrim5G Project scope

LuxTurrim5G project will develop a new light pole with 5G capability. 5G small cell will be integrated to light pole mechanics. Small cells will enable over 10Gbit/s traffic and below 1ms latency. New 5G light pole includes also the needed data transport from access points to core network. Transport is done by fiber or meshed wireless self-backhaul or dedicated backhaul. From 5G light poles' the coverage areas are street level outdoor and also indoor using propagation through new selective

glasses. The smart part of the light pole can be used also as a separate box in walls, inside billboards or related places, in case the light poles are not giving the needed coverage.

The project will develop open interfaces for service platform to be used by operators, micro-operators and vertical industries. This enables to use a single 5G network for all different services made by different providers and makes relevant smart city applications as well as 5G mobile network applications economically feasible.

This document is the state of the art analysis for the LuxTurrim5G project, and it is for setting the base line for the research and development. The focus of the document is in the project context, 5G and smart light poles in future smart city environment.

3 Selected technologies related to LuxTurrim5G context

3.1 5G communication technology

5G as the first network designed to be scalable, versatile, and energy smart for the hyper-connected internet of everything world. The small cells, Spectrum and Fiber are the key enablers of the upcoming 5G technology. There are many available definitions ad descriptions for 5G. EU-Charisma project have defined 5G and the need for 5G networks as follows in this chapter (Charisma D5.4):

5G is a compact two-lettered word encapsulating a very large concept. Indeed, capturing a definitive understanding of 5G (short for "fifth generation") networking is elusive, since 5G covers so many different aspects. For example, there are the technical aspects, which are easily quantified, such as the expected end-user high bandwidths (e.g. 1-10 GB/s to end-users), low latency (1-millisecond access times), and the ability to network very high numbers of devices in a small geographic location. This final aspect is an example of where the boundaries between 5G and other emerging concepts such as Internet of Things (IoT) or cyber-physical systems (CPS) and "Big Data", become blurred, and exemplify the problem of a precise definition of 5G.

Other features of 5G, which are the reason there is such a global interest in 5G research currently occurring are:

- Fixed-mobile convergence, i.e. seamlessness between the traditional fixed access network (e.g. fibre-to-the home, FTTH) and the mobile communications network;
- Device-to-device (D2D) communications and ad-hoc meshing (e.g. for sharing of content and social media in localised public spaces)
- Open Access, such that multiple network operators and service providers can share the same physical infrastructure, and therefore achieve useful CapEx and OpEx cost savings;
- New network services, i.e. such a higher performance 5G network infrastructure will allow entrepreneurs the freedom to be creative in developing new network services functions and applications
- Software defined networking (SDN)
- Network functions virtualization (NFV)
- Security and privacy (including issues such as reliability, trustworthiness, and robustness);
- Network dynamicity
- Cloud and fog computing
- Environmental impact, i.e. energy efficiency
- The visual impact of 5G technology on the urban and rural landscape, potential health issues due to possible electromagnetic smog issues, life-cycle disposal of old (legacy) communications and ICT equipment, as well as the design of 5G equipment with its end-of-use disposal already in mind

Charisma project has identified that 5G create a very complex technology landscape, with many possibilities for successful innovation and new business opportunities. This is one of the main

motivations also for LuxTurrim5G project to identify how to create successful business around 5G infrastructure.

3.1.1 Background for 5G infrastructure development

Our society and cities face great challenges to improve safety, energy efficiency, air quality, effectivity of transportation and quality of living. There is a need for a new generation service infrastructure, which enables new digital ecosystem in smart cities. 5G will have to provide solutions for a broad range of devices, operating in a fully heterogeneous environment.

- Enables development of new smart city infrastructure and services
- Enables improved data capacity for citizens
- Enables new service and business opportunities for companies
- Enables opportunities for new micro-operators in the systems
- Uses one common flexible total cost optimized network

3.1.2 Small Cells

Small cells or small cellular base stations encompass several different technologies but one could describe them as anything that is not a typical macro site. With mobile data traffic expected to double annually, small cell base stations are set to play an important role in expanding the capacity of wireless networks. Small cells provide flexibility and increased QoS capabilities at an attractive cost. Implementing a small cell infrastructure is also more environmentally friendly as it will reduce the number of cell towers (maybe even eventually eliminate them) and it provides a cleaner signal with less power. The main benefit of macro/small cell cooperation is that cooperative schemes outperform conventional unicast and multicast schemes in terms of energy efficiency. Although many works in the literature deal with this topic, 5G multicasting requirements of low-latency and low-energy need to be further investigated (Araniti, et al. 2017).

3.1.3 Spectrum Regulations

Topics such as massive MIMO and small cells, which address the efficient use of spectrum, must also be considered important issues in spectrum policy. Spectrum allocation and policy is an essential topic for 5G, which they are different approaches to spectrum regulation in that context (Andrews et al. 2014).

1) *Exclusive Licenses:* The traditional approach to spectrum policy is for the regulator to apply an exclusive license to a particular band for a particular purpose, subject to limitations (e.g. geographic coverage). Exclusive access gives full interference management control to the owner and allocates investments in infrastructure, allowing for quality-of-service guarantees.

2) *Unlicensed Spectrum:* At the other extreme, regulators can designate a band to be “open access,” meaning that there is no spectrum license and thus users can share the band provided their devices are certified (by class licenses). Examples are the industrial, scientific and medical (ISM) bands, which are utilized by many devices including microwave ovens, medical devices, sensor networks, cordless phones and especially by WiFi. With open access, barriers to entry are much lower, there is enhanced competition, and innovation, as the incredible success of WiFi and other ISM-band applications makes plain.

3) *Spectrum Sharing:* It includes options from both exclusive licenses and open access, such as the opportunistic use of TV white space. While the potential of reusing this spectrum is enticing, it is not clear that reliable communication services can be delivered that way. Alternatively, Authorized Shared Access and Licensed Shared Access are regulatory frameworks that allow spectrum sharing by a limited number of parties each having a license

under carefully specified conditions. Users agree on how the spectrum is to be shared, seeking interference protection from each other, thereby increasing the predictability and reliability of their services (Andrews et al. 2014).

3.1.4 Standardization

5G has been referred to as''IMT-2020'' in many industry and telecommunication forums. The main goal of 5G technology is to be released by 2020. With investigation on 5G characteristics, it has been concluded that LTE is not sufficient to meet the predicted 5G requirements. However, many standards for 5G like massive MIMO has been covered by 3GPP which indicates that 3GPP has been identified some standards which the entire standards will be released in upcoming years (Andrews et al. 2014). Standardization regarding spectrum is started to be analyzed especially for spectrum under 6 GHz and technical aspects such as channel modeling, semiconductor readiness, coverage, mobility support, potential deployment scenarios and coexistence with existing networks have begun within the International Telecommunication Unit (ITU). It is envisioned by''IMT-2020'' that 5G technology will be a collaboration between 3GPP and IEEE to having unified standards (Andrews et al. 2014).

3.2 Modern lighting technologies

The most common luminaries for street lighting nowadays are HPS armatures with a characteristic yellow light. The armature has satisfying light yield but the reflection of different colors is unsatisfactory because of the yellow light. White light gives the best ratio for sight because of the thorough reflection of colors, which makes the LED light a good alternative. LED are small diodes with high efficiency, long lifetime, and a wide range of color temperatures. For reasons such as energy, environmental and economic savings, it can be an advantage to regulate the intensity of the light from the armature. The LED module uses a proprietary method of transferring heat to the heat sink which features wings to take advantage of cross ventilation. This heat dissipation ensures the usable life of 50,000 hours of the LED, which based upon 12 hours working each day results in a life span of over 10 years. When compared to a conventional sodium light, an equivalent LED light can use 70% less electricity. With no adverse glare or flicker, LED light eliminate vision fatigue and distraction when compared to traditional lights, thus providing a safer lighting solution to drivers. Unlike traditional high-power streetlights, which require time to achieve full power, LED streetlights feature instant on at full power and instant off. LED lights are environmentally friendly both in production and in use. LEDs do not contain lead or mercury, argon, xenon or krypton gases. Nor do they emit infrared or ultraviolet radiation. LED lights are a big save in terms of money and energy. LED streetlights are known for their minimal energy consumption feature. This helps in illuminating the roads brightly with minimal utilization of the electricity.

3.3 Digital technologies transformation

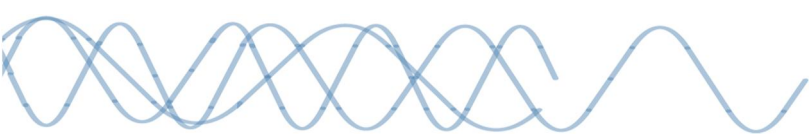
3.3.1 M2M communications

Device-to-device (D2D) communication commonly refers to a type of technology that enables devices to communicate directly with each other without communication infrastructures such as access points (APs) or base stations (BSs). In the 2020 timeframe, 4G LTE will remain an important technology for massive M2M due to its wide area network, mature ecosystem, high reliability, high performance and robust features. We will describe the LTE path to serving low data-rate and delay-tolerant M2M services, including the introduction of low-cost devices and features to enhance coverage and battery life. In addition, we will discuss how a 5G system using spectrum above 6 GHz

can be used to serve mission-critical M2M services that require ultra-low latency, ultra-high reliability, and extremely high throughput. (Beltran et al. 2016)

3.3.2 IOT

The Internet of Things (IoT) refers to the widespread use of systems, heterogeneous technologies, and the evolving paradigm of the interconnectedness of devices, using TCP/IP protocols, around our physical environments. The internet of things generally means connection of everything to everything, which is a similar form of M2M communication without direct human intervention. However, IoT encompasses not only M2M but also humans, home appliances, vehicles, machinery, pets and how they interact with one another. IoT includes a new wave of sensor devices and it interoperates with the growing cloud network infrastructure. On the long run, it is envisioned that an IoT ecosystem will evolve which will not be too different from the internet. It will facilitate the interaction of devices (mobile or fixed), smart objects and other real-world devices just as humans interact nowadays using internet-based applications. When 5G, the fifth generation of wireless communications technology, arrives in 2020, engineers expect that it will be able to handle about 1000 times more mobile data than today's cellular systems. It will also become the backbone of the Internet of Things (IoT), linking up fixed and mobile devices—vending machines and cars alike—becoming part of a new industrial and economic revolution. (Beltran et al. 2016)



4 Existing businesses around Smart Cities from the perspective of LuxTurrim5G

LuxTurrim5G project aims to the creation of a new light pole with 5G capability for next generation smart city infrastructure. Identification of a new innovative service concepts and business models are essential for the project and Finnish companies' success in digitalized global economy. This deliverable is part of work package defining new service and business opportunities and next generation business models for flexible and scalable outdoor 5G small-cell high speed services utilizing light pole infrastructure. This state of the art study is for introducing and evaluating the existing businesses around smart cities, from the perspective of LuxTurrim5G consortium. Because of the project perspective, these presented businesses are not covering all smart city businesses known today.

4.1 City design business

Urban design is the process of designing and shaping cities, towns and villages. In contrast to architecture, which focuses on the design of individual buildings, urban design deals with the larger scale of groups of buildings, streets and public spaces, whole neighborhoods and districts, and entire cities, with the goal of making urban areas functional, attractive, and sustainable. (Boeing et al. 2014). Urban design is an inter-disciplinary subject that utilizes elements of many built environment professions, including landscape architecture, urban planning, architecture, civil and municipal engineering.

Urban design is about making connections between people and places, movement and urban form, nature and the built fabric. Urban design draws together the many strands of place-making, environmental stewardship, social equity and economic viability into the creation of places with distinct beauty and identity. Urban design draws these and other strands together creating a vision for an area and then deploying the resources and skills needed to bring the vision to life.

In city design business, there are many service providers with slightly different offerings. Global consultant, engineering and design companies are offering basic design. Some service providers are expanding their offerings towards mobile network design. Today, urban and city design can be done in computer-modelled 3D format. In the LuxTurrim5G project point of view, city design should include:

- City design
- Mobile network design (network coverage in cities, etc.)
- Data model combining two previous areas

Cities are having own expertise, but in many cases lack of resources. Offering the competent resources is the main business motivator for city designing service providers.

4.2 City outdoor lighting business

Frost&Sullivan (2017) estimates that outdoor led lighting market revenue would be approximately globally 10000 ($ Million) and in Europe 2700 (year 2017) / 2960 (2015). These figures are not comparable but they give a good estimate of the market potential and relation between total street lighting market and the share of LED.

Smart lighting systems are not yet applied at larger scales (Enigma, 2014). LED is commonly purchased for new projects, but adaptive lighting is still not widespread. Most of the cities are still

in the pilot phase for smarter lighting solutions, often enabled by European projects. The experience is still limited, but overall it seems to be more complex than anticipated. This complexity is due to:

- The required ICT knowledge, which is not commonly available within municipalities
- The required cross-departmental collaboration that is needed in municipalities for smart solutions (e.g. including traffic management)
- Solutions should be context specific, creating more diversity in applied solutions and required testing procedures
- The lack of standardization and open systems that allow easy integration of solutions from different suppliers

Despite the complexity, the cities believe that the developments towards smart city solutions are important and necessary, and provide new opportunities.

4.3 City air quality monitoring

According to the World Health Organization (WHO), more than 5.5 million people worldwide die each year as a result of air pollution. Many of these deaths occur in large cities, where masses of people are exposed to heavy emissions from traffic, domestic heating and local industries.

For monitoring purposes, Air Quality has traditionally been measured by government or municipal authorities using methods defined in applicable regulations such as EU Air Quality Directive or US EPA Federal Regulations. Characteristic for these methods is a high degree of accuracy and traceability obtained by using carefully defined analyzer technologies combined with intensive calibration and maintenance programs. Due to the high cost (~150 – 200 k€) and large size (see Fig. 2) of this type of stations they are typically installed in small quantities in locations requiring specific attention rather than network deployments targeted to characterize the air quality distribution in a geographical area.

Figure 2 A typical regulatory air quality monitoring station (http://www.bbc.com/news/uk-scotland-26592819)

In recent years, technological advances in miniature sensors, sensor networking and atmospheric modelling have made it feasible to envisage dense networks of air quality sensors that complement the regulatory network by providing a grid-like network of data points, which optimally supports high resolution atmospheric models. With adequate sensor data and modern modelling techniques air quality data and forecasts can be obtained over extended areas with city block level spatial accuracy.

High resolution air quality data and forecasts may find many applications in urban setting in areas like traffic management, health management, urban planning and consumer applications. The needs in these areas are driven by global megatrends such as urbanization, health consciousness, smart cities and even climate change.

The benefits and potential of dense supplementary air quality networks has created a large number of research projects and piloting trials globally. Among others, projects like CITI-SENSE (http://www.citi-sense.eu/Project.aspx), Chicago Array of Things (https://arrayofthings.github.io/), US EPA Smart City Air Challenge (https://www.epa.gov/newsreleases/epa-announces-smart-city-air-challenge-awardees) or Singapore Airscapes (http://eoe.airscapes.io/front.html) have studied different aspects of dense air quality city networks and data and brought valuable insight into practical uses of this type of networks. In these projects with limited duration, the sensing hardware has typically been constructed as a part of the research project with emphasis on low cost and functionality for the duration of the project.

For operational air quality networks sensing solutions with verified performance against reference analyzers and reliable low-maintenance operation are needed. With the emergence of this market a number of mostly startup companies have been established to develop and offer gas and particle sensing solutions to meet the demanding needs for a price/performance suitable for urban air quality networks. One such solution is the Vaisala AQT420 Air Quality Transmitter (Figure 3.).

Figure 3 Example of Air Quality Transmitter (Photo by Vaisala)

4.4 City video monitoring and video surveillance

As cities and towns expand, security in common areas like parks and downtowns becomes more and more important. A constant stream of consumers and visitors are vital for the success of restaurants and local businesses, and video surveillance is a great security tool to keep consumers safe and towns thriving. Already in widespread use in Britain, more and more cities and local governments in the US and Canada are installing surveillance cameras in public areas. (VideoSurveillance, 2017).

Benefits of Municipal Surveillance (VideoSurveillance, 2017):

- Increased business – Cameras posted in high-traffic and risky areas can help reduce street crime and encourage more consumer traffic to stores and restaurants, increasing business and local revenue.

- Reduction in crime – Security cameras in public places can help reduce crime and vandalism, and assist law enforcement in apprehending criminals whose malfeasance is caught on camera.
- Improvement of public areas – By bringing in additional business and encouraging use of public spaces, public surveillance cameras can help make parks, public squares and city sidewalks better and more hospitable for everyone.
- Increased cooperation between businesses and government – One unexpected benefit of surveillance cameras in public places is improved relationships between businesses and local governments. An example of this is Morgantown, West Virginia. There, the city government has begun to offer incentives to businesses who install surveillance cameras. Agreements like this one may foster better relationships between businesses and governments while boosting security.

Risks of Downtown Security Cameras (VideoSurveillance, 2017):

- Privacy – Make sure that your public surveillance cameras do not point into any private areas – like apartments, businesses or offices, or other areas where the owners wish not to be recorded.
- Damage – Outdoor cameras can be damaged by a number of factors – including weather, car accidents and vandalism. Store your cameras in environment-controlled housings that can protect them from rain and extremes of heat and cold.

VideoSurveillance (2017) is just one generic example of serviced provider in surveillance area. However, from the LuxTurrim5G point of view it is important to figure out business opportunities related to video surveillance. The HW deliveries, installation, maintenance can be challenging, as the amount of locations are extremely high. In side of HW, surveillance systems include SW, which need also updates and operations. Service providers should develop service processes or on the other hand make collaboration with other technology providers. Service Level Agreements (SLA) should be managed with municipalities. In Finland, there are separate surveillance systems in some locations, as Police forces have own system, Traffic management its own, maybe real estate owners have own system. Typically, these systems are individual without integration to each other.

4.5 City communications

Today the core technology in city communications is 4G mobile networks and fixed networks. Not yet small cells widely in use, while those are too expensive to build for mobile operators. The basic business concept for city communication is that mobile operators make the services to users. There is not yet real service ecosystem available for other service providers.

From the city communication perspective, following customer segments can be identified:

- Transport
- Energy
- Consumers/Citizens
- Cities itself maintaining and building the city-infra

Today, the main regulatory issue related to city communication is the spectrum licensing policy, especially for higher spectrum frequencies (e.g. 3.5 GHz). Higher frequencies will enable local licenses and micro-operators in the future. There is already research related to micro-operator model.

City communication is the main driver for the LuxTurrim5G project, but the 5G based business will be very different than existing business settings. Because of the new forthcoming technology (5G) and related new business environment, we do not present more about the current city communications in this deliverable.

4.6 Selected material sciences related to city infrastructure

Within the LuxTurrim5G concept, our project consortium is interested about selected material sciences, which are radome material for base stations, material for the light pole, and facade materials in smart cities (especially windows).

4.6.1 Material manufacturing: radomes for base stations

Today, the majority of the mobile network base stations belong to 3G and 4G (LTE) technologies, which work in the frequency range below 6 GHz. These frequency bands require large antennas and thus also large antenna radomes. To ensure proper mechanical properties, the radomes are typically made of, e.g., glass fiber, reinforced thermoset composites or polycarbonate. However, the signal attenuation of such materials is significant when moving to higher frequencies. The manufacturing methods include, e.g., pultrusion. Radomes are basically service-free, since their lifetime should be in the order of several decades. The most prominent service associated with radome manufacturers is the readiness for product development.

The main actors and competitors consist of other materials manufacturers as well as other materials. Several materials can be treated as competing materials, such as glass fiber reinforced (GFR) thermosets, polycarbonate (PC/ASA), and polyurethane (PU) foam.

The largest demand for radomes and radome materials comes from the global network vendors such as Nokia, Huawei, Ericsson, ZTE and Samsung.

There are different regulations and standards for radomes depending on whether the base stations are deployed indoors or outdoors. In indoor use cases, the fire safety is the most significant issue, requiring strict levels for flammability. Outdoor base stations should have sufficient mechanical strength and tolerate a wide range of weather conditions, meaning that the antenna radomes should keep their mechanical properties from -40 °C to +85 °C and be UV resistant.

4.6.2 Material manufacturing: light pole materials

Despite LuxTurrim5G concept is related to light pole, this study looks challenges in more broader view. A utility pole is a column or post used to support overhead power lines and various other public utilities, such as electrical cable, fibre optic cable, and related equipment such as transformers and streetlights (Wikipedia, 2017). It can be referred to as a transmission pole, telephone pole, telecommunication pole, power pole, hydro pole, telegraph pole, or telegraph post, depending on its application. Utility poles can be made of wood, metal, concrete, or composites like fiberglass (Wikipedia, 2017). The most relevant technology from LuxTurrim5G consortium point of view is the composites. Composites industry in general is very fragmented. There are a few main technologies represented, but hundreds of players within those few technologies and only a few big companies within the industry. Core technology today is pultrusion for manufacturing the poles from composite. Pultrusion was developed to enable continuous production of composite parts for mass volume applications. For composites currently the customers within city infrastructure have been construction companies, architecture companies, utilities and other.

Many times, in different applications, composites are not considered as market-de-facto products, and as the industry is very fragmented, there can be sometimes regulations that are in favor of alternative materials like metals or wood.

4.6.3 Material manufacturing: Façade materials in smart cities

The increasing interest from companies and academia in smart cities, it became more compelling to envision the built environment as a connected, sensitive and responsive system (Savic, 2017). Connectivity gradually became a central requirement in these systems, networking tangible and intangible components with interfaces and people. Yet, designers and architects rarely consider connectivity outside of its functional paradigm (Savic, 2017). The most dominant design trend in façade materials selection has focused on energy efficiency, but the focus is turning more and more towards “Wireless Friendly” materials in buildings (Savic, 2017).

Finnish Federation for Communications and Teleinformatics (FiCom) is a co-operation organisation for the ICT industry in Finland and looks after its interests. FiCom influences on ICT-related regulatory issues, promotes the development of information and communications technology, manages ICT statistics and business indicators, openly communicates current professional issues to various target groups and contributes the ICT industry's public image. In September 2017, FiCom made a statement to the Committee on Transport and Communications on amending the Land Use and Building Act. There, FiCom's key messages (FiCom, 2017):

- The quality and coverage requirements for telecommunications operators' general communications networks and communications services are laid down in the information society framework. The telecommunications operator does not own and manage the internal networks of buildings, but only has access.
- The architectural design solutions for interior lighting must be the responsibility of the developer. Internal space is critical for emergency situations and for public authorities, so indoor space should not be dependent on the discretionary cost-effectiveness of the developer.
- Costs for indoor costs are not included in telecom operators. Indoors should be equated with heat, water, electricity and sewage as the basic responsibility of the developer.
- FiCom is in favor of a proposed model in which technical issues would be regulated by a ministerial decree. Obligations and costs should be regulated at the law level.

FiCom (2017) has stated that effective communication links are a necessity in society, the basic need for users and the authority network is a prerequisite. Most of the use of telecommunications is done indoors, so mobile and mobile broadband networks must be able to use anywhere inside buildings, regardless of location.

FiCom (2017) argues that the setting up the mobile network inside the building, its construction and maintenance, and the responsibility for the property and the owner of the building, not the telecommunications companies. As is the case with other construction technology costs, such as heat, electricity, water and drainage networks, the construction cost of indoor furniture for mobile devices should also be allocated to the project.

There are already research and development activities related to window technology, which is enabling indoor/outdoor connection through the building façade. In the LuxTurrim5G project, window technologies are on the focus of the development, not other façade or building materials. However, the 5G radio signal penetration loss investigation concerns also other construction materials of a building external wall.

5 Ongoing and past projects related to LuxTurrim5G context

The current social impact of modern technologies has produced major changes in all areas of society, creating the concept of a smart city supported by an electronic infrastructure, telecommunications and information technology. In general, this chapter covers the literature review from various sources related to the smart street lighting system – invention of other's project, technology and current industrial product. Observation and findings about their advantages and recommendation from the studies are also discussed. The aim is to collect and prepare information set of different projects with details of their planned activities in terms of business goals and business case study for the light poles and the communication technology used. This will help to monitor the health of street light pole projects available globally.

Below mentioned are the chosen four projects among many, which are closely linked to the LuxTurrim5G project, remaining project details can be found from references and appendix section.

1. Smart Poles Pilot Project (2015-2020) lead by Ericsson & Philips in San Jose & Los Angeles (USA)

This project is trying to implement the same idea for the smart street light poles as for LuxTurrim5G project. The project aims to achieve and provide energy efficient solution, better infrastructure opportunities for mobile communication services and good business opportunities for existing and new service provider companies. The concept is to integrate small cell solutions with street light poles to provide optimal urban coverage with minimum visual impact (Ericsson Network, et al. 2017). The base station technology used is fully integrated 4G wireless broadband technology mounted on each light pole (Raaijmakers, et al. 2017). The ecosystem build is based on the 3GPP standards. Trials conducted include 150 smart city poles covering applications as sensors, video monitoring, RFID, emergency Call, Wireless Networks such as Wifi Hotspot, Charging Pile, information Display for Advertising and Political News Information, etc. The project goal is to make streetlights as wireless digital hubs, which would help to provide digital services that will benefit the cities and citizen. From project solution, the municipalities and utilities can explore multiple opportunities for fresh revenue streams from site lease to operators and other utilities (Kanter, et al. 2015). Although, the major difference lies is in the technology used here which is 4G LTE instead of 5G as in LuxTurrim5G. For more detailed information, please visit the content from attached references.

2. The ENIGMA project (Sunshine 2014-2017) lead by Philips in Bassano del Grappa & Rovereto (Italy)

This project is piloted in cities of Eindhoven, Malmö, Stavanger, Espoo and Bassano del Grappa, where the goal is to address and define the common public lighting challenges. The communication technology used here is smart lighting photocell control. The connection from the remote server to the streetlight system for data transfer and processing is identified to be mostly optical fiber. At some locations it can be wireless also depending on the area and capacity environment per site, this will then act as a control unit which is able to control, manage light points and collect data from the sensors. In addition, also acting as an interface for data and commands transformation between different interoperable formats (Giovannini, et al. 2015). The Project aims to provide energy efficient solution, reducing operational cost and CO2 emission. The business model aims to improve remote public lightning management and to install innovative lighting solutions in European cities. The base station technology used is integrated base stations, the technology allows possibility of remote lightning network by means of proprietary integrated management and control systems. This is done

by using two systems between light poles for communications i.e. power line carriers or wireless (Cipriano, et al. 2015). The information linked to ecosystem standards are not public yet. Project pilot size was of 71 light poles deployed in different areas with LED technology where most of the sites are still in the pilot phase to have smart lightning solutions (den Ouden, et al. 2014). The project is targeted to provide applications as sensors, digital display, smart parking control, weather forecast, on/off dimming of streetlights and improving remote safety during nights, etc. The difference between ENIGMA and LuxTurrim5G is based on the advance small cell technology and 5G network, which is not implemented in the Enigma project yet. For more detailed information please visit the content from attached references.

3. SECE Smart Street Lighting System (Silver Spring) lead by Panasonic and Silver Spring in Chicago, London, Miami, Paris

This project has similar piloting plans as of LuxTurrim5G project. The project aims at replacing existing streetlights with LED based lamps, which would help utilities and other streetlight operators to reduce the energy and operations cost by 50 percentage or more and taking the payback period down to 6 v/s 8 years. The idea is to deploy network based lighting solution (LED Lights) to provide platform for multiple smart city services. By leveraging Silver Spring's unique communications infrastructure and expertise, cities and utilities can deliver ongoing value and build a lasting competitive advantage for their community. New energy efficient LED-based streetlights will have a life span of up to 20 years, enabling lower energy and operations costs. The communication technology used for this project is Wireless Starfish Mesh (IP) technology. This technology proves to be a great solution to connect intelligent devices and sensors to address energy, traffic, transportation and safety issues. It is targeted to deliver up to 2.4Mbps in speed, 10ms latency, up to 50 miles in point-to-point range along with industrial-grade security, reliability and scalability (Silver Spring Networks, et al.). Base station (integrated radio) installed on the street poles have open, standards-based IPv6 network that integrates and connects all utility's or city's infrastructure, software and services to provide a flexible foundation with future proof capability to support emerging needs of the smart cities, which is targeted to improve the operational efficiencies while providing superior and reliable services. The project pilot program has replaced around 3 million LED streetlights which are equipped with Digital networks, embedded sensors, light controllers, charging stations, Pollution/Weather/Air Quality sensors, Traffic IP cameras, Water and Gas Metering which helps to detect traffic congestion & parking space, remote control to turn on/off/flash/dim the lights, improving pedestrian and bicyclist safety, reduce crime, automatic outage detection, remote monitoring and management, etc. (Silver Spring Networks, et al.).

The company has used SLV6 smart city management platform designed with open architecture, which helps to control a vast ecosystem of smart city devices from best-in-class manufacturers for their equipment. For more detailed information please visit the content from attached references.

4. Smart Street Lighting Solution and LPWA Network (2015-2020) for Singapore Smart Nation & Smart Cities lead by Municipality of Singapore

This Project solution includes Ultra-Narrowband Radio technology, a long-range low-power wireless network that provides an ideal platform for city-wide multi-sensor applications, all covered under the street lighting cost savings. The project has developed CMS (Control Management System) tool

enabling full remote control and monitoring capability (IPI Singapore, et al. 2017). Solution enables smart city applications by enabling smart sensors to the streetlights, and smart parking through such a remote-control network. The Project aim to provide energy efficient solution which will have reduced operation and maintenance cost.

In addition, like in LuxTurrim5G Project, the light poles are equipped with availability of small cells technology, wireless network which is targeted to support both specialized transportation solutions (e.g., vehicle-to-vehicle communication) and specialized public safety solutions (e.g., gunshot detection sensor communication), all while ensuring the best quality of service to other highly critical applications, such as a nearby hospital which requires highly reliable communications (e.g., for remote surgery) (IPI Singapore, et al. 2017). The information linked to ecosystem standards are not public. This smart streetlight solution has been deployed globally in more than a million lights. The project is said to be successful in terms of making future-proofs LED investment, which serves two basic functions: first providing light energy to the cities and second enabling communication channel to meet the future demand for high data consumption. For more detailed information please visit the content from attached references.

6 Discussion about current Smart City and Smart Lighting developments

6.1 Smart City Initiative Evolution

The diversity of the Smart City Initiatives or the projects related to and connected to these is large. The transition from the traditional street lighting business and technology to smart LED lighting systems and services is ongoing and the new normal in the business remains to be seen.

This said the ongoing Smart City and Smart Lighting projects are not suitable as examples of business models or long-term city strategies. The current lighting initiatives, except those focused purely on energy saving and basic lighting control, are pilots in the nature and usually based on heavy external funding like Horizon 2020 in the EU. Therefore the common business rules and axioms do not fit in these cases and they cannot be used as examples to design new sustainable business activities. However these projects are also doing research and experimenting with the new business models and are thus valuable living labs and provide learning through case studies. However, one has to remember that these are not authentic business ecosystems but special cases of this transition period.

It is challenging to define a concept of ”Smart City initiative” even from the street lighting perspective. The level of smartness is very different in the cases. If we talk about ”Smart Lighting”, smart often refers to the controllability of the lighting itself, how and when to turn it on and off or to dim it. The simplest case of smart lighting is one that is controlled by a dusk or sunset switch. This type of projects are common and driven by energy efficiency goals.

However, the remotely controllable lights can be a part of a Virtual Power Plant. This demand control capacity can then be sold on the flexibility market. This type of a solution is much less common, usually a pilot project and requires platform approach both on the technology and business level.

Adding the communication technologies usually refers to the IoT type of a solution where the data channel is used to control and monitor the lights or to enable separate video surveillance just mechanically attached to the light pole. This is still very different from the LuxTurrim5G where the idea is to use base stations located into the light poles to provide 5G access for the integrated services and to the nearby mobile users. Thus, the pole will no longer be a support structure for different pieces but a physical part of an open platform for service business ecosystems.

In the table 1. a simple classification of initiatives is presented from the LuxTurrim5G point of view.

Table 1 Classification of initiatives from the LuxTurrim5G point of view.

	Business as Usual	Complexity	Systemic technology novelty	Challenges	LuxTurrim5G interest
Energy efficient street lighting	Yes	Low	Low	Delivery costs, dying market	Subtarget, added value
Smart (control) Lighting	Yes in most cases	Medium	Medium	Delivery costs, LCCA argumentation	IoT experience, data channels
Smart Lighting + VPP	No	Medium	Medium + High	Business model, maturity of the market interoperability	Business models, data platform
Smart Lighting Poles (LuxTurrim5G)	No	High	High	Technology verification, integration, interoperability, business case justification	Benchmarking, co-development, standards, procurement
Smart City	No	High	High	Complexity, interoperability, scale of transition, funding	Business end technology co-innovation, roadmap, vision

In principle the bottom ones are more modern but in practice they all exist parallel and the Smart City is a combination of various, not only lighting related but also many other interconnected developing initiatives. The speed of transition is apparent also in the initiatives related to lighting. In the early 10's they focused on "energy efficiency" of lighting, next became the "smart lighting" and now the context of discussion is "smart city". Also "safety" and "empowering" have higher priority in the present discussion as citizen needs have become centric in the discussion.

This change reflects well the change that takes also place in the political discussion during the initiatives preparation when separate systems, like lighting, are being replaced by higher level or more generic topics like "smart city" or "smart society". This has both good and bad impact when systemic challenges become visible but at the same time focus on the subsystem level can be lost and complexity in decisions making requires simplification.

6.2 Smart City Initiative Drivers in Transition

An important change takes place in the drivers. When the dimensions and players in the systemic planning increase, what is the driver that sets the process in motion, directs the planning and convinces the public and private investors? The cost-benefit relations change and become fuzzy, they cross the city operations and change the whole initiative ecosystem. This change has a huge impact on initiative development mechanisms and on related decision making.

This said one has to remember that the ownership and thus the motivation / drivers differs from case to case. Traditionally the street lighting has been owned by the municipality or an utility company that can be either municipality owned or a private company. Maintenance has usually been

bought as a long term service from an electric outfitter company. The drivers are different for a municipality or a private company. In the future when lighting is connected to ICT and IoT ecosystems the needs, interests and drivers will be different and much more complex.

In the ENIGMA project http://www.enigma-project.eu/en/ cities were asked (2013) what are their most important needs defined in the lighting development projects (Figure 2.). At the same time they were also asked who participated into defining the needs. This is an excellent example of the diversity of needs and the multitude of city functions connected to the initiatives. However, these needs are still very much focused into energy and safety. The communication dimension is not on the list. If this same research would be done today asking about the current initiatives planning the communication and data related needs would be there.

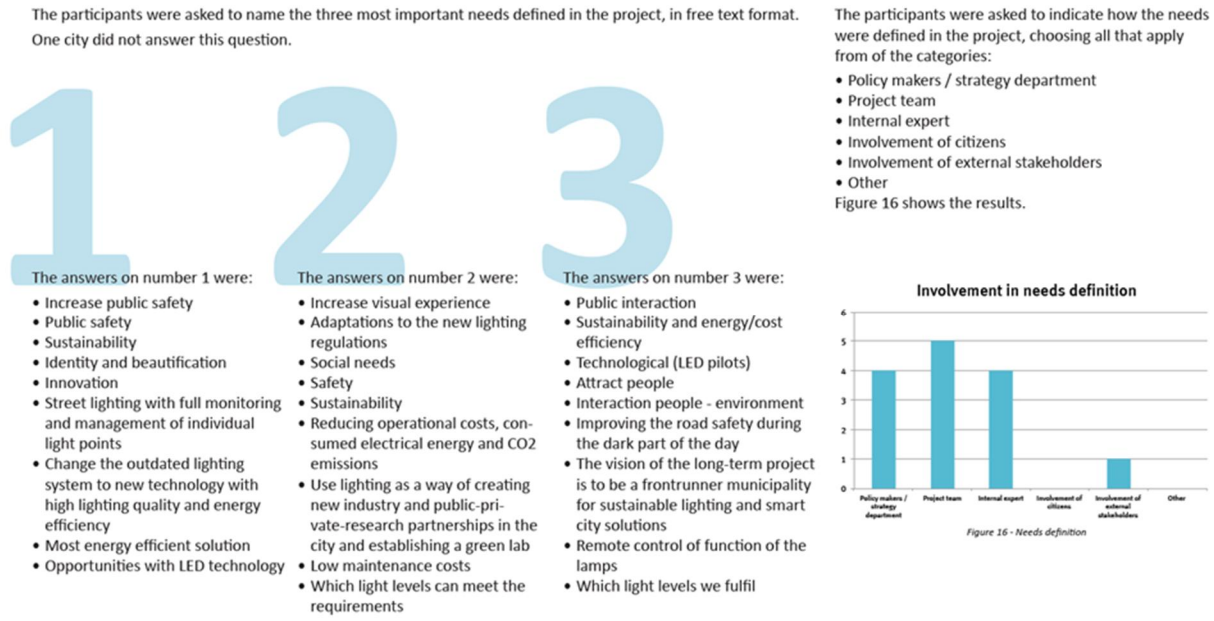


Figure 4 Important needs defined in the lighting development projects (ENIGMA project, 2013).

Overall the conclusion (ENIGMA, 2013) is that smart lighting systems are not yet applied at larger scales. LED is commonly purchased for new projects, but adaptive lighting is still not widespread. Most of the cities are still in the pilot phase for smarter lighting solutions, often enabled by European projects. The experience is still limited, but overall it seems to be more complex than anticipated. This complexity is due to:

- The required ICT knowledge, which is not commonly available within municipalities
- The required cross-departmental collaboration that is needed in municipalities for smart solutions (e.g. including traffic management)
- Solutions should be context specific, creating more diversity in applied solutions and required testing procedures
- The lack of standardization and open systems that allow easy integration of solutions from different suppliers

Despite the complexity the cities believe that the developments towards smart city solutions are important and necessary, and provide new opportunities.

Below (Albino, et.al, 2015) is a list based on two studies (2012-2014) that shows examples of initiatives promoted in three smart cities. This shows that many of the initiatives are either energy or ICT related.

Table 2 Smart city initiative examples (Albino, et.al, 2015)

Cities	(Smart City) Initiatives
Seattle, US	Seattle.gov portal with 20+ language support
	data.seatle.gov allows open data and open government
	Community Technology Planner
	Equitable Justice Delivery System
	Communities Online
	Puget Sound-Off
	Smart Grid
	Automated Metering Infrastructure
	Pacific Northwest Regional Demonstration Project
	Fiber to the premise
	GigU seeks to accelerate the deployment of ultra-high-speed networks to leading U.S. universities and their surrounding communities
	Supervisory Control and Data Acquisition
	Drainage and Waste Water System
	Rain Watch Program
	Field Operations Management System
	Common Operating Picture
	IT Cloud
	Electronic Plan Review System
	Digital Evidence Management System
Quebec City, CA	Zap Quebec providing Wi-Fi internet access
	Text messaging service of snow cleaning information
	Snow cleaning management project: providing sensors at each snow cleaning machine
	Inter-cities network: connecting with major cities of the province of Quebec
	Mobile homepage: developing a mobile version of the city's website
	Infrastructure management system: integrating different information systems to coordinate activities related to infrastructure management
	Open data initiative: making city data open
	Online transportation control system
Friedrichshafen, DE	GPS distress signal, in an emergency, people can send a signal by touching their cell phone
	Mobile Clinic system enables the interactive remote monitoring of patients with chronic heart conditions
	KatCard E-ticketing project enables the non-cash purchase of tickets
	Edunex is a web-based educational platform for schools
	Secured EduKey allows secure access to Edunex biometrically
	Smart Metering provides customers with information about their electricity and gas consumption.
	Digital picture frame has an integrated wireless module and receives digital photos via the Deutsche Telekom network
	CityInfo allows requesting short info on various topics via the SMS information service.
	Multimedia Stations provide information and services free of charge in the areas of city

	Hearing impaired telephones for deaf people access to a sign language interpreting service, using special video telephones
	SZ News adds a local dimension to the Internet Protocol Television information services.
	Tourism portal friedrichshafen.info compiles all important information required for a stay in Friedrichshafen.
	With G/On, employees can access their work stations securely from anywhere in the world.
	dDesk allows applications and data are stored on the cloud on a central server.
	T-Mobile emergency number supports the coordination of rescue services in Friedrichshafen.

Cities current role in the Smart City initiatives is that of an enabler. There has been two different approaches, one for the research type of pilots and another for the more commercial pilots. In the commercial pilots, a competitive bidding approach has been commonly used. Since an average city has no knowledge or experience in this type of initiatives, the knowledge of the solution providers has been harnesses through competitive bidding process.

The nature of city development has changed from a siloes one to an integrated one over the last decades. Different functions and technologies have become more integrated and linked thus adding new complexity into the system. Earlier city lighting was quite an independent function that was connected only to the power system, owned by the city and maintained by an electrician. The poles were only for the lighting purposes and the only control was a switch in the control center. Nowadays the control has moved closer to the luminaires, the energy saving and power demand control potential enabled by the LED technology has linked lighting system to the larger energy management platform, street lighting has become an important part of city image and buying services is replacing ownership. The modern platform economy and product-service system approach has already changed the way cities plan street lighting initiatives and will continue to do so even more in the near future.

6.3 Smart City Initiatives as a Market Ecosystem

Cities already plan for the “new normal” though the transition period is still ongoing. During the transition period, the concrete projects are pilots in nature both technologically and economically. Therefore, it is very challenging to identify the current “norm” since procurement policies vary from traditional to forward-looking ones. It is typical that initiatives are planned and initiated in collaboration. The initiative can originate from the city, solution providers or third parties like research organizations. Public funding has been a strong driver both on national level and on regional level. Horizon 2020 has been one of the biggest drivers that promotes LED and smart lighting through programs and funding calls.

At the same time, it has been challenging for public procurement to keep up with the pace of transition. A good example is the price of LED luminaires that has exceeded the limits set. New ways of calculating the costs have been needed that are based on life cycle costs instead of purchase price. In addition, the rating of tenders has to take into account the total cost approach to direct the bidding process into more economical solutions.

One solution to this has been the Energy Performance Partnership (EPP), Energy Performance Contracting (EPC) and Energy Service Company (ESCO) approaches. Basic idea is to move the street lighting costs form CAPEX to OPEX by buying the lighting service from the service provider instead of owning the luminaires. The service provider takes the responsibility of financing, delivery and maintenance of the system. Service provider’s income is related to the verifiable energy saving as

agreed in the contract. Traditionally these are seven years contracts and after the contract period the ownership is transferred to the city or the contract can be renewed.

This type of energy efficiency contract model is good both for the service provider and the customer when the rate of change is predictable and the complexity of the system covered by the contract is not too high. During a transition period, it is a political challenge to make decisions that can prove to be more expensive to the city than the alternative option. Though it is a fact that money was saved the alternative option might have saved even more. This political dilemma delays the transition and makes technology companies business risks more difficult to estimate.

However, this is a situation under development like Streetlight-EPC project (http://www.streetlight-epc.eu/) has put it:

“Most European regions have not yet seen a significant development of energy performance contracting (EPC). Apart from legal barriers, this can be attributed to the lack of understanding and trust in EPC and the absence of experienced ESCOs and organizations facilitating the EPC market development.

Street lighting is a good "learning and testing ground" for EPC due to its lower technical and economic complexity (compared to building-related EPC). Furthermore, the recent market introduction of LED technology for street lighting offers high energy and cost savings with comparatively short pay-back times. Energy performance contracting can be a very good solution to make street lighting refurbishment happen: guaranteed energy services in the form of EPC work best in cases of high energy and costs savings potentials.”

Another business model that is very interesting from the LuxTurrim5G point of view is to incorporate the street lighting. Cities have traditionally incorporated e.g. health services and energy production and distribution. The motivation to this has usually been purely political or either making profit or preparing to sell the facility. It is difficult to say what is the case with street lighting but it enables new type of business models to be used and product-service systems to be developed on the market. This will be elaborated further in the future business models part of LuxTurrim5G.

There are several ways to realize the street lighting projects. Financing is a key component in the decision making and has become even more so during the recession as cities aim to optimize their CAPES and OPEX expenditure balance. Energy efficiency as a goal actually combines the environmental, economic and financing dimensions in the investment planning.

Smart lighting approach is common nowadays as well as getting ready for the needs of a Smart City concept. However, the current level of technological requirements does not include wireless communication between and from the light poles. Wireless communication is used but it is for the light control purposes not to provide an access point for the end users. The common presumption is that data cables are required to meet the future high speed data service requirements of a Smart City but a wireless pole-to-pole 5G network has the potential to provide same level of service.

This all makes the street lighting market a complex business environment in transition. In the Figure 5. the distribution channels for different customer segments of LED lighting is presented. Currently 80% of the Architectural and Outdoor Applications sales is direct sales (Frost&Sullivan, 2017). With increasing complexity, the Wholesalers share is probably going to grow. Cities are to by product-service solutions that cross several city functions thus creating markets for the “turn-key” type of solution providers. An important part of this are the life cycle services that enable reliable operations of the complex integrated systems.

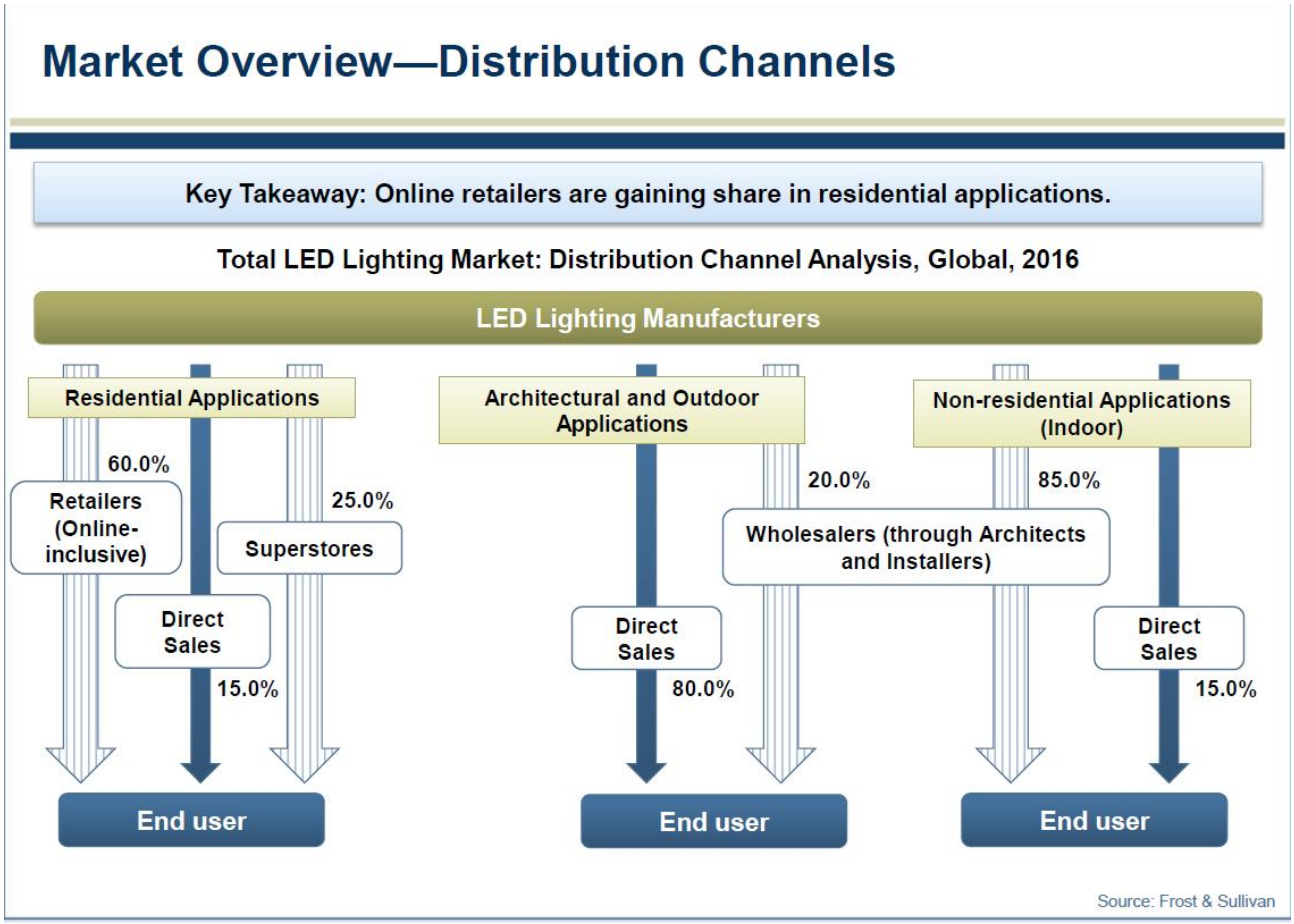


Figure 5 Direct sales in Architectural and Outdoor Lighting Applications (Frost&Sullivan, 2017)

A critical factor in the business that one has to remember is that the street lighting, and basic lighting business and technology is global in nature. The big providers in this business are international giant companies like Philips, Osram and GE. It has fit well into their business to develop the technology more efficient and to replicate these changes into their mass production. Now that the new business comes from the services and platforms it is much more challenging to combine this and the large scale mass production. Customer needs, distribution channels, key partners and practically all parts of business models change. This provides new players from outside the lighting business or novel technologies an opportunity to enter the established lighting market. However, one has to remember that the existing players have the market connections and they have established a position that is difficult to break. In addition, the best of them are able to adapt into the new product-service ecosystem.

7 Conclusions

Smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality (Bakıcı et al. 2012). Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centers that are at once integrated, habitable, and sustainable (Barrionuevo et al. 2012). A city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance (Caragliu et al. 2011). Until these days, there have been many initiatives related to Smart Cities and related technologies.

Current situation in digitalization of cities:

1) Mobile network small cells are a challenge for mobile operators because the site cost and backhaul transport cost are high. Small cells with higher frequencies are needed to get enough capacity for new smart city ecosystems.
2) City infrastructure planning and management tools are quite automated, but the cellular networks are not yet included. Macro cell and small cell site and infrastructure planning are so far a separate exercise done by mobile operators.
3) Specialized smart lighting solutions for streets are already available from Finnish companies, but the control network is not yet standardized.
4) Smart city digital street level ecosystem is limited while good enough common data transport network does not exist.

To make the transformation to the new generation smart city infrastructure possible, proof of concepts is needed to test the technological opportunities and economic feasibility of this digital ecosystem. This digital ecosystem requires open interfaces and data access for different stakeholders and service providers. The LuxTurrim5G project aims to create the environment by joining companies, which are ready to create the basis - from pioneering proof-of-concept solutions to building new export business for Finnish companies.

The European Commission have presented a 5G Action Plan, which foresees a common EU calendar for a coordinated 5G commercial launch in 2020 (European Commission, 2016). EU encourages a joint work with Member States and industry stakeholders to identify and allocate spectrum bands for 5G, organize pan-European 5G trials as of 2018, promote common global 5G standards and encourage the adoption of national 5G deployment roadmaps across all EU Member States. (European Commission, 2016). The Commission and investors in the telecoms sector also consider providing venture capital to start-ups developing 5G solutions for innovative applications and services across industrial sectors.

At the beginning of the LuxTurrim5G project, many expert group and practitioners meetings have been organized for identifying challenges related to current development. The following questions are the most relevant for the LuxTurrim5G research:

- Who will take the lead in the investment of 5G networks in the future?
- Role of mobile operators in the LuxTurrim5G ecosystem?
- Time frame of 5G deployment -> can there be an early start with 4G?
- Cost of the network implementation, how to share the costs?

Although the LuxTurim5G project is focusing highly on technical innovations, the business opportunities are the key underlying driver for the innovations. The business environment in the digital smart city ecosystem is very complex, with a large number of different public and private organizations. Thus, it is crucial to understand the value proposition for the market. Companies should identify their own role in business context and finally in the entire ecosystem which will be formed around the LuxTurrim5G platform. In the end the main concern is: how do individual companies create value to ecosystem and make a successful business case? From a scientific perspective the question is twofold. Firstly, how to understand the individual technology value proposition and its relation to other technologies in the forthcoming platform. Secondly, what kind of business model is needed for competing in global market? LuxTurrim5G research will tackle these issues in two work-packages WP1 and WP3, by analyzing the case studies but also by generalizing the results for better understanding of the future directions of LuxTurrim5G platform and the ecosystem.

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9 Attachment 1 - List of Key terms

3GPP	3rd Generation Partnership Project
CapEx	Capital Expenditures
CO2	Carbon dioxide
CDMA	Code Division Multiple Access
CR	Consistency Ratio
CMS	Control Management System
CPS	Cyber Physical Systems
D2D	Device to Device
E2E	End to End
EPC	Energy Performance Contracting
EPP	Energy Performance Partnership
ESCO	Energy Service Company
EDGE	Enhanced Data GSM Environment
ETSI	European Telecommunications Standards Institute
ENISA	European Union Agency for Network and Information Security
FO	Fiber Optics
FTTH	Fiber To The Home
FC	Fog Computing
GPRS	General Packet Radio Service
Gb/s	Giga Bits per Second
GSM	Global System for Mobile Communications
HW	Hardware
HSPA	High Speed Packet Access
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunication
ITU	International Telecommunication Union
IoT	Internet of Things
IP	Internet Protocol
IPv6	Internet Protocol version 6
KPI	Key Performance Indicators

LED	Light Emitting Diode
LTE	Long Term Evolution
LDPC	Low Density Parity Check
LPWA	Low-Power Wide-Area
M2M	Machine to Machine
Mbps	Megabits Per Second
ms	Millisecond
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
MMS	Multimedia Messaging Service
MIMO	Multiple-input and Multiple-output
NFV	Network Function Virtualization
OpEx	Operational Expenditures
PPP	Public Private Partnership
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RFID	Radio-frequency identification
SDN	Software Defined Networking
TCO	Total Cost of Ownership
TVO	Total Value of Ownership
V2V	Vehicle to Vehicle
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
VM	Virtual Machine
VR	Virtual Reality
WP	Work Package

10 Attachment 2 - Related further readings

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