Luxembourg 5G Strategy

Expert Report

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Created by:

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THE GOVERNMENT
OF THE GRAND DUCHY OF LUXEMBOURG
Ministry of State

Department of Media, Telecommunications
and Digital Policy

Luxembourg’s vision for 5G

In September 2016 the European Commission published its Action Plan for 5G in Europe. The Commission insisted on the need for a coordinated approach to ensure timely deployment of 5G throughout the European Union. The European Ministers of telecommunications responded by agreeing in December 2017 on a common 5G roadmap with a view to position Europe as the global leader in 5G. The roadmap foresees making more spectrum available in a timely and predictable manner to enable the fast deployment of 5G networks. The overarching aim is to make 5G available in the first cities by 2020 and enable the so-called ‘Gigabit society’ by 2025, with 5G deployed in all major cities and along important transport networks.

5G will be a crucial component of our national infrastructure. 5G is not merely an extension of existing telecommunication networks, but rather an integrated network that supports the ever growing data requirements and enables new consumer experiences based on seamless and ubiquitous connectivity. Apart from the advantages related to new and improved consumer experiences, 5G will also improve the life quality of its users.

Luxembourg’s vision is to be amongst the leaders in 5G, while seeking to make the most of the new technology towards improving the wellbeing of its citizens and driving economic prosperity for the country. The Government aims to put in place the appropriate regulatory and policy framework that will allow an efficient 5G network rollout and induce investments in the digital economy. The Government’s mandate will be to support the timely development of 5G in Luxembourg as per the European connectivity targets.

Rollout and adoption of 5G has the potential to produce long-term economic and social benefits for the economy and the entire country. 5G is expected to change the way we interact with other people and machines, paving the way for new and revolutionary use cases across a number of verticals. For instance, use cases related to autonomous driving and connected vehicles will improve road security while making traffic management more efficient. This should lead to a reduction in road accidents and time spent in transportation that could, in turn, contribute to a cleaner environment. 5G use cases in healthcare, like connected ambulance or remote personalised care, will contribute to a more reactive and less congested healthcare system and improve the feeling of safety for people living in remote areas. Furthermore, 5G will also be the enabler of smart home applications, improving the users’ life quality by providing increased privacy and security at home, amongst other enhancements.

While the first four generations of wireless networks mostly served our communications and digital content needs, 5G networks will serve more diverse needs of the economy, integrating the physical industries with the digital world. The Government considers that 5G networks are vital in enabling the next wave of productivity and business innovation across different sectors in the Luxembourg economy.

The present strategy report is based on a number of discussions with a wide range of stakeholders from the Luxembourgish ecosystem that will be directly or indirectly involved with 5G network deployment. The report examines various aspects of 5G networks, such as business models, market demand, regulatory considerations and possible funding schemes and it also identifies several potential candidates for 5G pilot testbeds across the country.

The purpose of these pilots would be to research, develop and pre-commercialise those 5G networks, aiming to simulate the operations of a live mobile network to the greatest extent. The pilots should provide significant lessons, address technical challenges, facilitate the creation of a 5G ecosystem and ensure the cost-effective and timely deployment of the future nationwide network. Efficiency and productivity of the end users are expected to improve through this exercise, and new applications and services are expected to arise. To that end, all existing ecosystem players will have to play an active role and collaborate during the pilots' implementation and new players will join the value chain. Municipalities and other public sector organisations are expected to be interested in the opportunities that those pilots will reveal, as they could play a significant role in the 5G era, as issuers of permits, infrastructure owners and possible network neutral hosts.

The Government aims to work with the 5G stakeholders to coordinate the development of 5G services and applications within Luxembourg and to create the conditions necessary to drive innovation and investments in the 5G ecosystem. This strategy report presents the Government's current thinking on how Luxembourg could benefit from 5G and overcome any bottlenecks. The Government understands that as 5G evolves some of the issues that are pertinent today might be less relevant in the near future, as many questions around 5G networks are still unanswered. Therefore, by no means should this strategy report be perceived as set in stone. The Government is dedicated to maintain an ongoing dialogue with all stakeholders towards the promotion of 5G in Luxembourg.

The Government would like to thank all the entities (listed in Appendix II) who agreed to provide their views on the different issues related to the introduction of 5G in Luxembourg. The Government would also like to thank inCITES Consulting for preparing this strategy report.

Xavier Bettel

Prime Minister
Minister for Communications and Media

Luxembourg 5G Strategy

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1. 5G overview

1.1. What is 5G ?

5G is the next generation of wireless technologies as this has been defined by the International Telecommunications Union (ITU) in the IMT-2020[1] release. 5G promises enhanced capabilities across all technical specifications compared to its predecessor, IMT-Advanced[2], or 4G as it is more colloquially known. More specifically, the ITU has identified the specifications that are presented in Table 1 as the minimum requirements related to the technical performance of IMT-2020 radio interfaces.

Technical specifications		ITU definition
Peak data rate	1-20 Gbit/s	Maximum achievable data rate under ideal conditions per user/device
User experienced data rate	10-100 Mbit/s	Achievable data rate that is available ubiquitously across the coverage area to a mobile user/device
Spectrum efficiency	15-30 bit/s/Hz	Average data throughput per unit of spectrum resource and per cell
Mobility	350-500 km/h	Maximum speed at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/-RAT) can be achieved
Latency	1-10 ms	The contribution by the radio network to the time from when the source sends a packet to when the destination receives it
Connection density	10^5 - 10^6 devices/km^2	Total number of connected and/or accessible devices per unit area
Network energy efficiency	90% more efficient than IMT-Advanced	Energy efficiency has two aspects: - on the network side, energy efficiency refers to the quantity of information bits transmitted to/ received from users, per unit of energy consumption of the radio access network (RAN) - on the device side, energy efficiency refers to quantity of information bits per unit of energy consumption of the communication module
Area traffic capacity	0.1-10 Mbit/s/m^2	Total traffic throughput served per geographic area

Table 1 - Technical requirements of IMT-2020 radio interfaces, (ITU[3])

Specifically, 5G is expected to provide enhancements in the peak data rate, improved spectral efficiency and reduced latency in an environment-friendly way. Put into context, these specifications promise major enhancements versus 4G (Figure 1) that will enable a variety of new services and capabilities for 5G network users, which cannot be realised with existing technologies. For instance, these enhancements will allow 5G networks to unlock the potential of the so-called Internet of Things (IoT) industry, by enabling the seamless connection of a large number of devices without human intervention.

[1] https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx
[2] https://www.itu.int/pub/R-REP-M.2134-2008/en
[3] http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

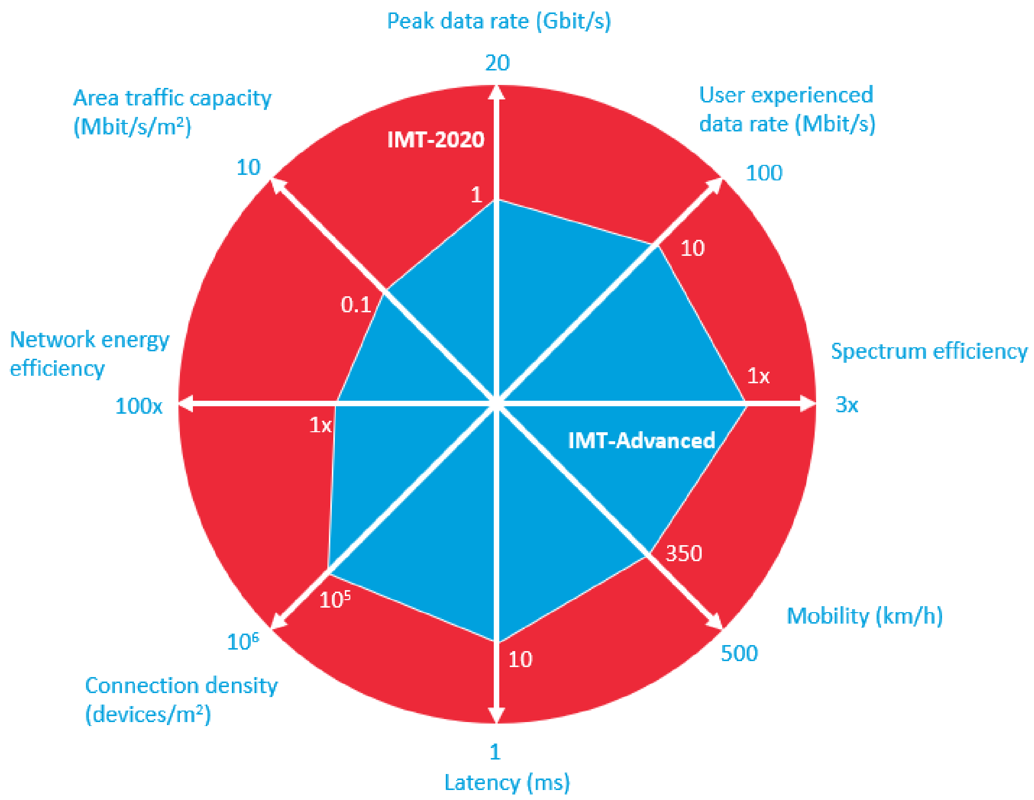

Figure 1: Enhancement of key capabilities from IMT-Advanced to IMT-2020, (ITU[4])

In addition to the substantial enhancements in the technical capabilities that 5G will enable for mobile broadband, which are really important to help mobile operators address the ever-growing data traffic, a decisive benefit that 5G will bring is the so-called network slicing. Network slicing allows the network operator to 'slice' the physical network into smaller virtual networks, each of which can have different specifications, using a common shared physical infrastructure. These network slices can become Pan-European and vary greatly between them in terms of latency, security, quality of service, bandwidth and so on, having the flexibility to support a variety of users. The key benefit of this technique is that it provides an end-to-end virtual network to the tenant that encompasses a range of functionalities outside connectivity, such as computational power and storage functions. Being able to tailor the network slices according to the tenants' needs allows a single network to support a range of networks with different requirements, such as an IoT network, Mobile Broadband (MBB) applications and ultra-low latency applications (e.g. e-surgery, autonomous driving) at the same time. The main purpose of this technology is to allow the network operator to partition the network in such a way that allows for optimal traffic management, isolation from other tenants and managing the network resources seamlessly at a high level (Figure 2).

[4] http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

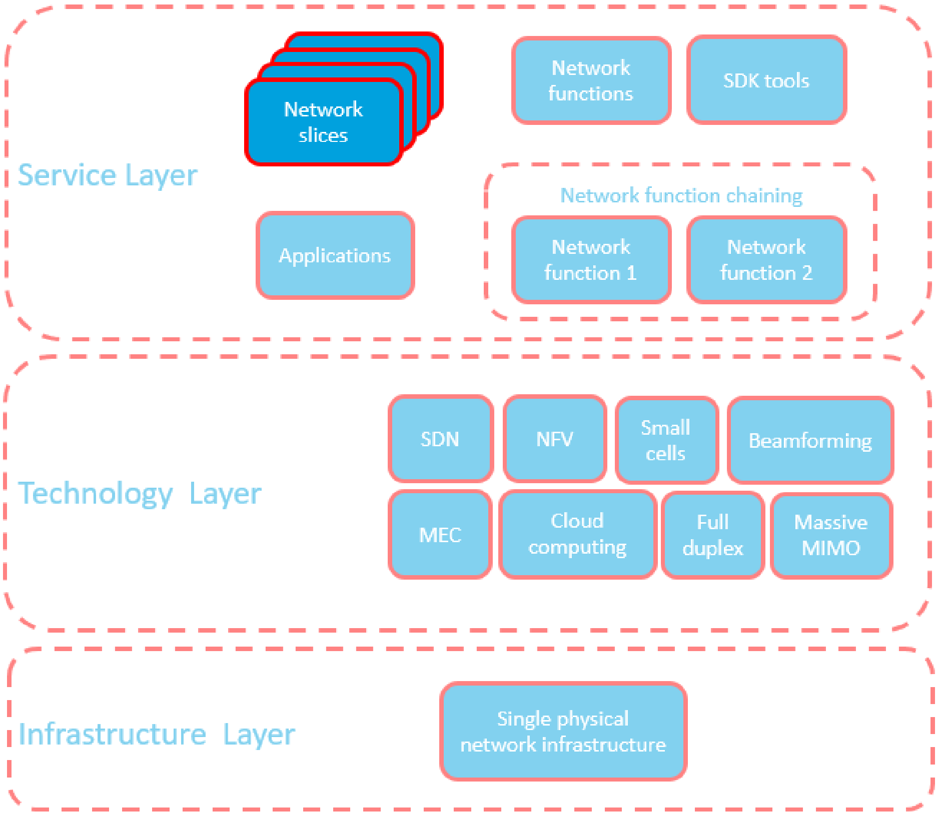

Figure 2: Network slices as part of the 5G network architecture, (inCITES Consulting)

1.2. 5G use case families

In order to take advantage of the enhanced capabilities that 5G networks will offer, the ITU has identified three broad families of usage scenarios (Figure 3), namely, enhanced mobile broadband (eMBB), massive machine type communications (mMTC) and ultra-reliable and low-latency communications (UR-LLC). 5G will be an evolutionary, rather than a revolutionary technology for most of the applications that these use cases will support and which already exist with 4G and 4.5G (LTE Advanced) networks. 5G will, however, be essential to unlock some mission-critical applications that require ultra-low latency, advanced security, high reliability and ultra-high speeds, such as e-surgery, autonomous driving and various industrial applications.

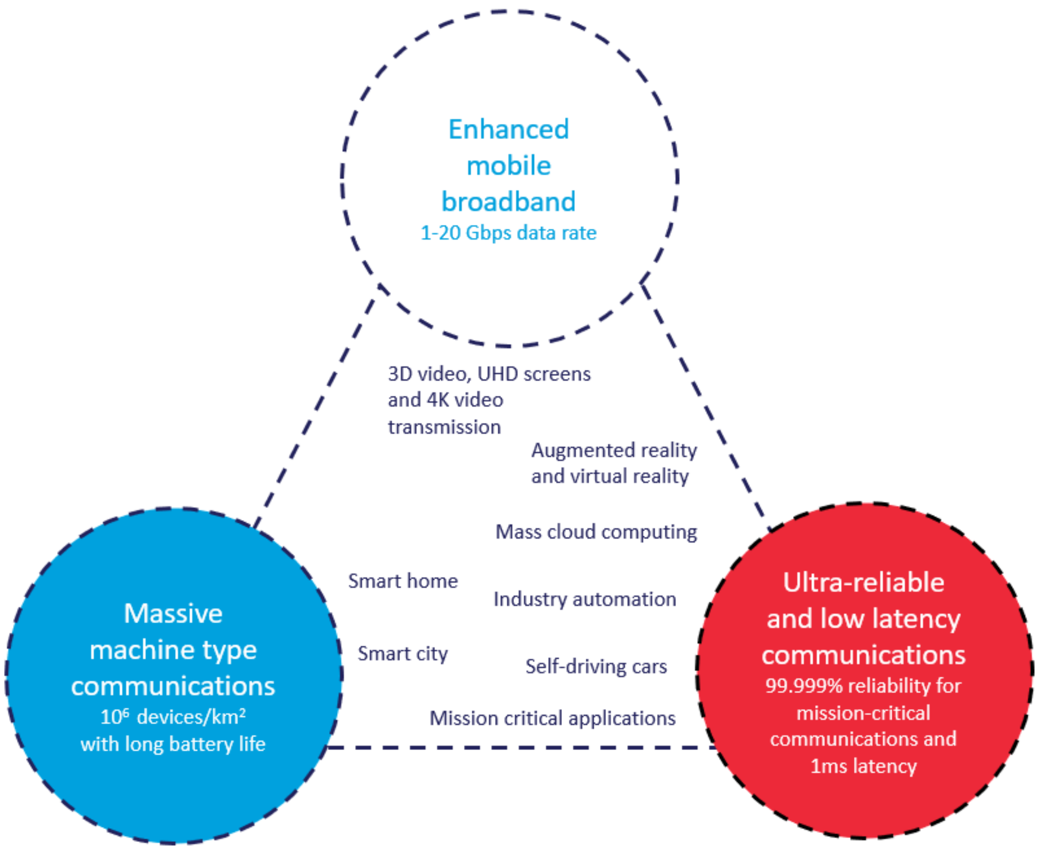

Figure 3: Usage scenarios of IMT-2020, (ITU[5])

Each of the three broad use case families encompasses applications that already exist today but which are expected to see major improvements with 5G. The mMTC use case refers to networks which typically have a very large number of devices but each device may have very low bandwidth requirements. These networks connect devices that are low cost, low-power and have a long battery life, typically over 10 years, hence latency and throughput are generally not too important for this application though security and network resilience are essential. This will unlock a variety of IoT applications, such as smart homes and smart cities.

The eMBB use case family includes applications which typically support a much smaller number of devices versus mMTC, each of which though has high bandwidth requirements. The eMBB usage scenario covers a range of cases which have different specifications for mobility, latency, bandwidth, data rate and coverage. Applications such as Augmented Reality (AR), Virtual Reality (VR) and wide area coverage are included in this category.

The UR-LLC use case includes applications that have very strict requirements for specifications such as latency, reliability, security and throughput. The number of devices that these networks would typically support varies greatly, though connection continuity and low latency are of utmost importance. Applications such as remote surgery, industrial automation, Public Protection and Disaster Relief (PPDR) services and self-driving cars are part of this use case scenario.

[5] http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

1.3. 5G enabling technologies

5G networks will not only be faster than any previous mobile technology family, but they will also be more agile and easier to manage, catering for a range of use cases and requirements under a single unified physical network. The following technologies have been identified as the key enablers of 5G networks that will accommodate a plethora of services efficiently (Figure 4):

- Software Defined Network (SDN)

Software Defined Networking is an emerging technology that allows the separation of the network management from the physical network infrastructure for applications and network services. SDNs are agile, cost-effective and highly adaptable, which enable seamless network management regardless of the underlying network technology and hardware. Due to their advanced characteristics, SDNs qualify as the prime candidate technology to meet the dynamic needs of the future 5G network applications and as such they will be the cornerstone of those networks.

- Network Functions Virtualisation (NFV)

Network Function Virtualisation is a technology which allows network operators to virtualise network functions such as firewalls, intrusion detection and caching so that they can run on standard general purpose computers and network platforms instead of customised purpose-built hardware. This architecture allows for significant Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) cost benefits for the network operators since they are not dependent any more on dedicated costly hardware to run their network functions. Outside the cost benefits, NFV:

  - reduces the complexity and time-to-market when introducing new network services
  - improves the return on investment from new services
  - gives greater flexibility to scale up, scale down or evolve services
  - provides openness to the virtual appliance market and pure software entrants
  - gives opportunities to trial and deploy new innovative services at lower risk

- Mobile Edge Computing (MEC)

Mobile Edge Computing is a network architecture which enables cloud computing capabilities at the edge of the mobile network, physically closer to the end user of the mobile service. This technology aims to provide reduced latency, high network efficiency, high bandwidth, location awareness and improve the experience for the end user. The main concept behind this technology is that network congestion issues are alleviated by running processing-heavy applications closer to the mobile network user. MEC also allows network operators to give access to application developers and content providers enabling them to tailor their offering to the mobile users and create additional revenue streams and new business models across the telecoms value chain.

- Cloud Computing

With the increase in the sophistication of the mobile ecosystem, consumers tend to run mobile applications that consume large amounts of the smartphone’s computational resources, eating up the available battery power more quickly. Hence, to overcome this obstacle, mobile devices could offload the most computationally-intensive tasks to nearby servers. This process has been supported strongly through cloud computing which enables users to use resources on demand. Cloud Computing is a technology that enables ubiquitous, on-demand access to shared pools of configurable system resources, such as networks devices, servers, storage, platform and applications, that can be rapidly provisioned and released with minimal management effort or service provider interaction. 5G networks will allow Cloud Computing systems to have higher level performance in offloading computationally-intensive tasks by migrating data processing and data storage to the cloud.

- Small Cells

Small Cells are radio access points that require minimal power to operate and they complement the macro cells to improve coverage, capacity and support new services for the mobile users. While the performance of macro cells is expected to improve in the future, to achieve 5G performance will require the deployment of Small Cells networks in areas with high population density, where capacity needs are the greatest. Small Cells networks are expected to also provide more efficient use of spectrum.

- Li-Fi

Li-Fi is a wireless communication technology that uses the infrared and visible light spectrum for high speed data communication. Li-Fi is gaining popularity as a supplement and substitute for radio frequency communications and is expected to play a significant role in future 5G networks. New types of Light Emitting Diodes (LEDs) were invented thanks to the lighting industry efforts. In the last few years, the cost of LEDs has decreased by two order of magnitudes, whilst the energy efficiency and average lifetime have increased by roughly the same amount. The key advantage of Li-Fi technology is its ability to provide high bandwidth to users in high density areas, supporting cells as small as $1m^2$. Another key feature of the Li-FI technology is that performs well indoors, i.e. where around 80% of data traffic is currently produced. In the case of Visible Light Communications (VLC), the intrinsic confinement of light also allows for physical security of data, a feature that is becoming increasingly important for various use cases, such as IoT. For bandwidth-hungry applications, high data rates have been achieved by combining commercial LED chips with suitable modulation bandwidth with adaptive multiplexing techniques. Another benefit of VLC, is that it can be installed in the lighting fixture of a building and in any other environment where excess radio frequency cannot be used, such as airplanes and hospitals. Finally, the infrared version of Li-Fi can be used in outdoor use cases and as an alternative solution for backhauling.

- Massive MIMO

Massive Multiple Input Multiple Output (MIMO) is a technology that allows a base station to send and receive more data packets at once. Although MIMO is already available with 4G networks, Massive MIMO will help to increase the capacity of base stations by multiple times, an essential property of 5G networks so to support the growing data traffic needs.

- Beamforming

Beamforming is a radio wave technology which allows the base station to transmit data in the direction of the mobile network user in the most efficient way, creating a stronger, faster and more reliable network. Given the sheer amount of data packets sent by 5G base stations using Massive MIMO technology, beamforming will be essential in order to reduce interfering signals and use the available spectrum in an optimal way. Additionally, beamforming can reroute signals that get weakened by physical objects by focusing the transmitted signals towards a specific direction that will minimise interference.

- Full Duplex

Full Duplex transmission is a technology that allows a transceiver to send and receive data at the same time using the same radio frequency band. By doing that, this technology has the ability to effectively double the capacity of the traditional half-duplex systems.

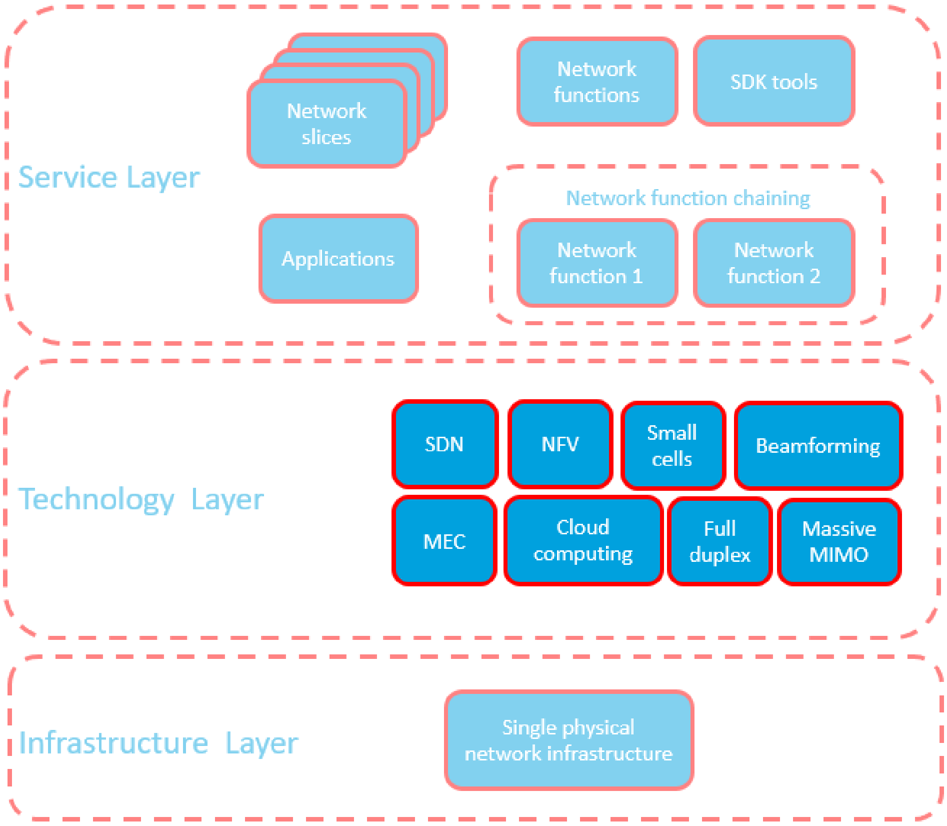

Figure 4: 5G-enabling technologies, (inCITES Consulting)

1.4. 5G spectrum requirements

For 5G to deliver on its promise to support the wide range of new applications, it will require to use spectrum across three different frequency ranges, depending on the nature of the application. More specifically, the European Union's Radio Spectrum Policy Group (RSPG) has identified the following bands for initial deployment of 5G in Europe (Strategic Roadmap Towards 5G For Europe - Opinion on spectrum related aspects for next-generation wireless systems (5G)[6,7]):

- 700 MHz: this band should be liberated by digital terrestrial television by 30 June 2020, or 2022 the latest, in accordance with Decision (EU) 2017/899 of the European Parliament and of the Council of 17 May 2017 on the use of the 470-790 MHz frequency band in the Union and will be used for providing wide 5G coverage, suitable for IoT/M2M applications

[6] http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf
[7] https://circabc.europa.eu/sd/a/fe1a3338-b751-43e3-9ed8-a5632f051d1f/RSPG18-005final-2nd_opinion_on_5G.pdf

- 3.6 GHz (3400-3800 MHz) will be the first primary band for 5G to offer higher bandwidth for new 5G services
- 26 GHz (24.25-27.5 GHz) will give ultra-high capacity for innovative new services, enabling new business models and sectors of the economy to benefit from 5G

The swift clearing and award of 5G frequency bands is essential to the timely deployment of 5G across Europe.

Luxembourg has conducted several consultations and has defined a roadmap[8] to make available spectrum in the 700 MHz band for 5G. Discussions and studies about the 3.6 GHz and 26 GHz bands are also under way to ensure the timely spectrum allocation as per the EU mandate and avoid possible interferences with existing spectrum users.

1.5. 5G standardisation timelines

The technical specifications of mobile technologies are primarily set by the ITU and 3rd Generation Partnership Project (3GPP). ITU is the United Nations organisation responsible for coordinating global initiatives around the telecommunication industry. ITU conducts studies on a number of topics in telecoms through its Working Party 5D, which is also responsible for the research around radio frequency of international mobile communications. Working Party 5D has been heavily involved in the efforts to standardise 5G (IMT-2020) as it did earlier this century when the 4G technology (IMT-Advanced) was standardised. 3GPP is an industry body that comprises standardisation bodies, industry players, industry associations and public organisations and it is responsible for developing and updating technical specifications for mobile telephony standards, in-line with the objectives set by ITU.

Regarding 5G specifications, ITU is working closely with 3GPP to complete the standardisation process as early as possible. Phase 1 of the standardisation, or Release 15, was completed in June 2018 and the most important elements it included were the standards for both Non-Standalone (NSA) and Standalone (SA) 5G new radios. NSA new radio refers to a 5G network which uses a 4G core and radio anchor with a 5G small cell MBB capacity boost. while SA new radio refers to a 5G network which only depends on 5G technology both for its core and radio anchor. Phase 2 of the standardisation, or Release 16, will achieve full compliance with ITU's IMT-2020 requirements and it is expected to be completed by end-2019 (Figure 5).

5G-compliant networks are expected to start launching in early-2019 and will be based on NSA 5G new radio standards. NSA standards will enable the eMBB use case family to come to life as they will be relying heavily on existing 4G core network. This type of network is expected to be very popular in the early years of 5G as mobile network operators demand backward network compatibility. Subsequently, the industry will start launching SA 5G networks to support the strictest criteria regarding the technical specifications, such as latency, data rate, capacity, spectrum efficiency and mobility, to support mMTC and mission-critical applications.

[8] https://smc.gouvernement.lu/dam-assets/Luxembourg-Roadmap-700-MHz.pdf

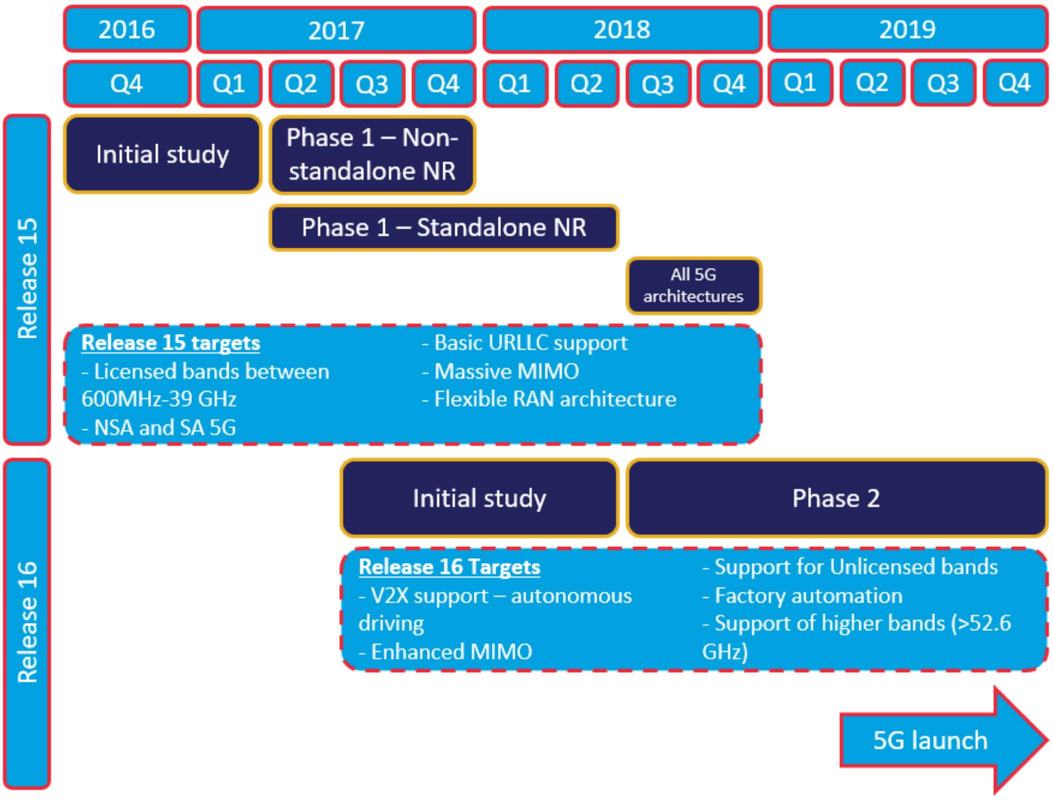

Figure 5: 3GPP Work Plan for 5G, (ITU, inCITES Consulting)

Hence, technology migration from 4G to 5G is expected to happen gradually and 4G will be complementary to 5G initially. In fact, some of the 5G requirements will be met due to specifications set in prior standards releases (Releases 13 and 14) and the new network launches will effectively be evolutions of 4G networks rather than pure 5G networks. This is consistent with what happened when the industry migrated from 3G to 4G, the latter of which initially used some of the advanced characteristics of the former in the early years after launch.

2. Business models

2.1. Introduction - Monetisation of 5G networks

As network operators are striving to identify profitable use cases for the next generation of mobile technology, eMBB appears to be the use case that will drive the initial 5G deployments as a means to accommodate the explosive growth of mobile data traffic. A growing trend towards streaming video in higher resolutions and streaming of immersive video formats will drive significant demand for data traffic.

Network operators are expected to initially deploy NSA 5G NR networks, those that use the existing 4G core to operate, and subsequently to upgrade their networks based on the SA 5G NR standards, which will be relying on a 5G core and will be able to deliver the cutting-edge properties that 5G networks promise. Hence, NSA 5G networks will support only a limited number of applications and services initially. This will create a negative gap between the required network investments and anticipated revenue from the network in the early years after launch, since consumers will likely not be willing to pay a premium just to enjoy higher connection speeds. Similarly to 4G, the main driver of 5G deployment for eMBB will be the reduction in the unit cost of enhanced services provision, as a result of increased capacity and spectral efficiency. However, in the medium term, revenue streams from new use cases will arise and customers from other domains will be interested in entering the 5G value chain, such as the vertical industries.

Since it is currently uncertain which new use cases will generate incremental revenues for operators and when those use cases will be introduced, it would be preferable for operators to focus on applications that require 5G capabilities to run (such as low latency, reliability, high data rates) and target users spanning across many industries. Attractive 5G services, however, is expected to be coupled with differentiated charging schemes. For instance, industry clients that will be interested to connect many devices to the network, could be charged in a tailored way and offered incremental benefits compared to competing technologies so to use 5G services.

Another expected monetisation source is that of connectivity provision to indoor networks in private areas, such as manufacturing sites, shopping malls and concert venues. Such venues will probably not be served by the macro-cell network due to the use of higher frequencies for 5G and the energy efficient materials used in modern buildings, preventing signals from penetrating indoors. Hence, the vertical players will have to deploy their own private networks to address that need. Due to their market expertise and spectrum holdings, MNOs will be able to act as network developers and operators for those private networks, creating new revenue streams for them. Nevertheless, the vertical players could also build and operate their own networks, though this option would add to the complexity of the venture.

It can thus be expected that massive network deployments will not happen in the early years after 5G networks launch. Operators and other connectivity providers will likely follow an evolutionary approach of deploying islets of public and / or private networks in the beginning, and subsequently expand their coverage to other territories. The introduction of new innovative services and applications that will rely exclusively on 5G networks, coupled with the data traffic increases to such levels that cannot be accommodated by existing networks, will drive the expansion of the initially deployed islets.

2.2. 5G Business models

5G networks promise to provide increased capabilities able to support different use cases in a number of vertical industries. It is also interesting to note that these use cases have different performance characteristics such as high data rates (media), low latency (autonomous driving or industry 4.0), large number of connected devices (IoT) etc while using different spectrum bands from very low frequencies (e.g. 700 MHz) to very high frequencies in the area of 26 GHz (or even higher at a next phase).

In order to accommodate this wide range of requirements, 5G networks are designed with advanced management capabilities and increased flexibility stemming mainly from the use of SDN and NFV technologies, network slicing and sharing. Future networks can be configured properly enabling the provision of differentiated services for different verticals using a single physical infrastructure. This also provides opportunities to both new (function developers) and existing players (service / application developers) to cost-efficiently launch innovative services.

Introduction of 5G networks is expected to bring several changes in at least two aspects of the telecom landscape, namely, a) service provisioning and charging models and b) network deployment models.

2.2.1. Service provisioning and charging models

The technological advancements of 5G will enable mobile operators to offer differentiated services based on the customers' requirements, shifting away from the traditional model of providing bundles of undifferentiated mobile broadband services. Service differentiation will benefit vertical industries and provide operators the ability to sell service plans that meet the verticals' unique connectivity needs (Figure 6).

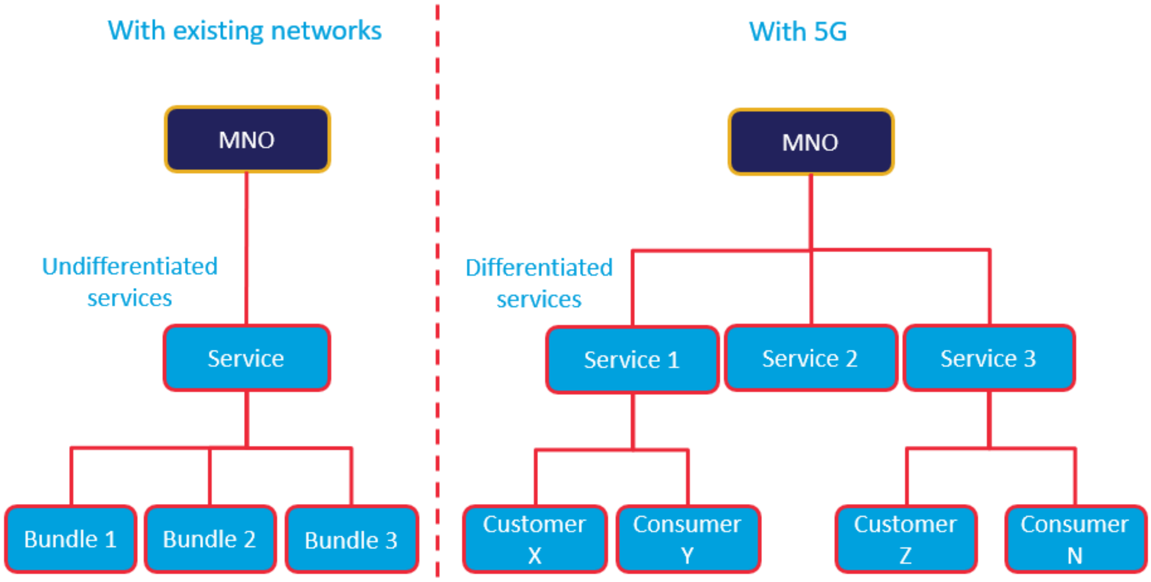

Figure 6: Service differentiation with 5G networks

The changes of service provisioning models will also influence the associated charging models which will be 'smarter' to reflect service differentiation and dynamic enough to lead to benefit maximisation for both the service provider and consumer. It should also be highlighted that the flexibility that the new charging models will have, will enable operators to adjust the service cost according to each customer's unique connectivity requirements in terms of data rate, latency, bandwidth etc. Changes are also anticipated in the service provisioning / connectivity provisioning domain, with new options coming to the picture about who the connectivity provider will be.

In the traditional MNO model, the network operators acquire spectrum from the regulator and then negotiate their contracts on a bilateral basis with other virtual network operators, vertical players and equipment vendors before offering their services to the end users (Figure 7). In the 5G era, this business model will likely become obsolete, as more relationships between the different stakeholders are identified and new players enter the 5G value chain.

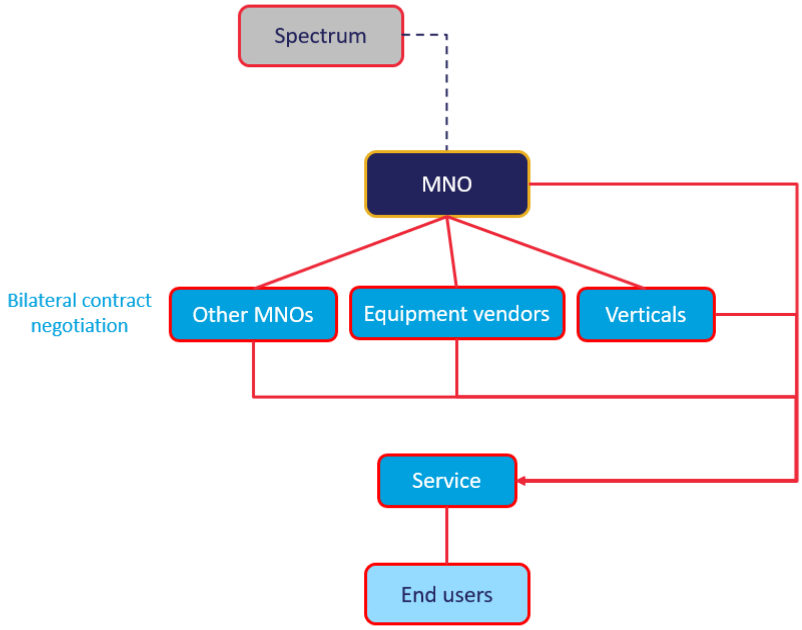

Figure 7: Connectivity provisioning - MNO model

Three new connectivity provisioning models have been identified as the most promising ones to exist in the 5G era, namely, Vertical, Collaborative and Broker models.

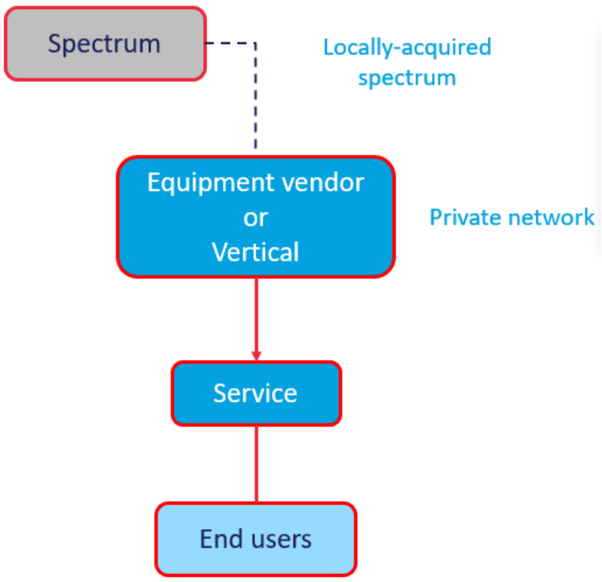

Figure 8: Connectivity provisioning - Vertical model

One of the new service provisioning models that will arise with 5G is the **Vertical model**. This will meet the demand that specific verticals or vendors have to deploy their own private networks to satisfy their unique connectivity requirements and ensure increased network reliability. In this model, the vertical player, or equipment vendor, uses its own spectrum locally for its premises, builds its own network and provides differentiated services to its users. It is worth mentioning that the mobile network operator's role in this model's value chain will be limited to backhauling and interconnection (Figure 8).

Another promising model that will arise with 5G is the **Collaborative model**. In this model, the mobile network operator will co-invest with a vertical player and/or equipment vendor to build a network that will meet the needs of the involved players (Figure 9). The main benefit of this network is that it leverages the expertise and customer base of all stakeholders.

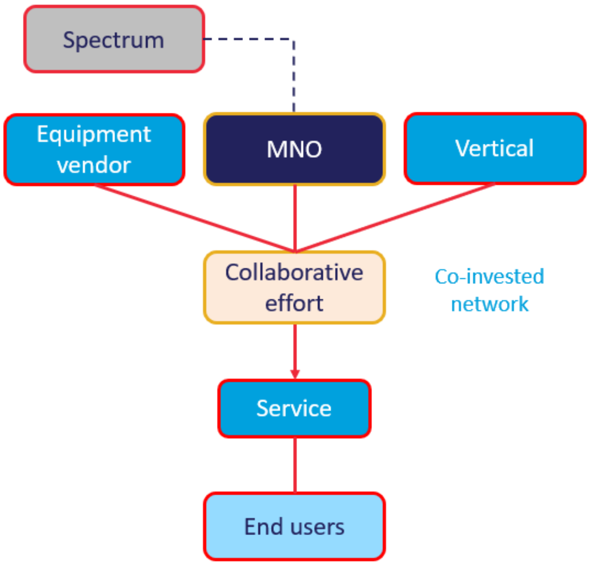

Figure 9: Connectivity provisioning - Collaborative model

Lastly, one can imagine in the future the new role of a **Broker** who negotiates with a number of both fixed and mobile network operators and infrastructure owners (Figure 10). Spectrum acquisition obligation remains with the MNOs which, in turn, negotiate alongside their fixed counterparts with a single broker who then introduces a service with preferential terms for all parties against a fee. In the European digital single market, negotiations and services can be expanded to a pan-European marketplace.

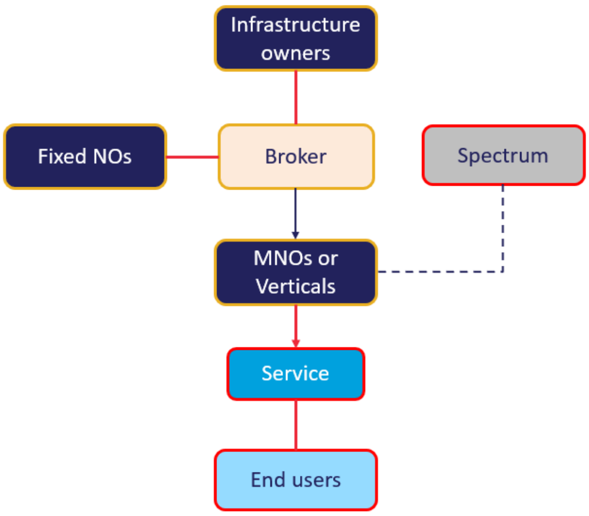

Figure 10: Connectivity provisioning - Broker model

2.2.2. Network deployment models

To achieve the technical specifications that 5G networks promise, 5G uses high frequency bands that have never been used in the past by terrestrial telecom operators in the access network. Higher frequencies offer higher bandwidth, leading to enhanced connectivity properties, but those come at the expense of short propagation reach. This short reach leads to larger needs in terms of sites needed to cover a specific area with 5G versus previous technologies, causing practical difficulties in terms of power and backhauling. In addition, there will be cases where installation of additional antennas, such as small cells, will be required within buildings or places of strong commercial interest like stadiums, concert halls and shopping malls.

To date, MNOs deploy their own proprietary networks, to which they have exclusive access, and then provide services to end users and wholesale access to MVNOs (Figure 11, (a)). This is the simplest network deployment model that exists in the market. Recent trends and needs have triggered the demand for more sophisticated network deployment models. Single deployment or sharing models, as these are outlined in the following sections, are the latest and greatest example.

2.2.2.1. Single deployment models

In single deployment models, as the name suggests, one player (usually an MNO) invests in deploying a network, which it can then use for its own benefit, or re-sell part of the capacity to one or multiple other ecosystem players. However, apart from MNOs, other parties might be willing to play the role of the wholesale operator by acquiring spectrum and access to sites and deploying the necessary infrastructure (Figure 11, (b)). This model will likely be employed in areas where further network densification is needed to meet capacity requirements, such as shopping malls and stadiums.

The second variant is commonly known as the “**neutral host**" model which combines two important concepts – "hosting" and "neutrality". In this deployment model, an independent player, the neutral host, deploys and operates the network (through self-operation or outsourcing) and then provides wholesale access to those interested in providing their services (Figure 11, (c)). The hosting aspect refers to an entity that provides a certain set of resources that are made available to clients, such as MNOs, allowing them to provide uninterrupted services at the expense of reduced flexibility and complex billing relationships. The "neutrality" aspect refers to the host acting as a shared platform to multiple hosted clients. Neutrality in this context does not imply strict equality between hosted clients, as the resources offered to each client are subject to the commercial agreement between the neutral host and the client, and policy-based management may be applied. From a hosted client’s point of view, the system behaviour and services using the resources of a neutral host should be available without user intervention and, ideally, they should be seamless and identical to those provided by their hosted clients’ dedicated resources.

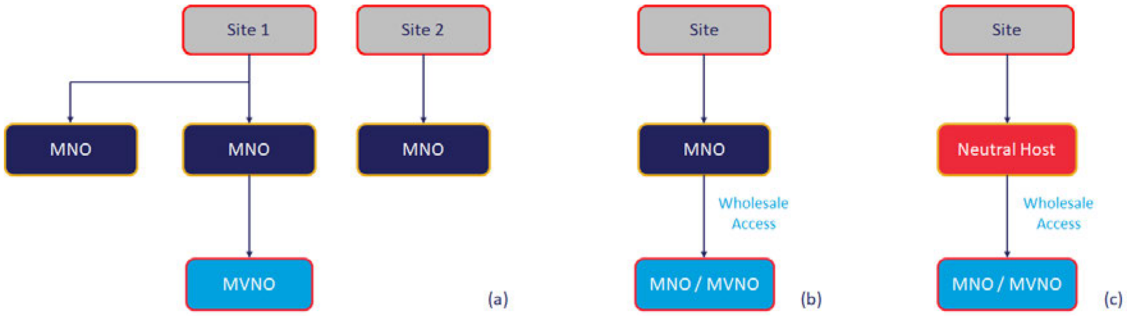

Figure 11: Single deployment models

From a more technical viewpoint, the neutral host model allows building network slices, which encompass a variety of resources, such as network storage and computing. These slices are leased to service/content providers and/or network operators, which, in turn, are able to operate the virtual resources they have been assigned in order to offer their services.

This concept of a neutral host has been around for some time, but it is likely that it will realise its full potential with 5G due to:

1. the need for enhanced and ubiquitous connectivity in urban context coupled with increasing radio coverage and bandwidth requirements
2. the smart cities as 'entities' play a pivotal role within the 5G framework and a city municipality could even itself take the role of 5G neutral host
3. the neutral host model is well suited to fully satisfy the 5G requirements for the different use-cases within the same neutral network.

It should also be noted that the neutral host network deployment model is not only a technical framework, but also a business framework around the creation of new Service Level Agreement (SLA) categories that will dictate the interactions between host and hosted clients.

2.2.2.2. Infrastructure sharing models

Infrastructure sharing is the process of creating partnerships and sharing network costs to provide mobile connectivity to end users. Infrastructure sharing can be passive or active depending on the elements that are being shared. In some cases, it is the telecom regulator that promotes infrastructure sharing while in others, the operators themselves get into commercial sharing agreements without any regulatory intervention. Opportunities that infrastructure sharing models present include CAPEX/OPEX reduction, faster network coverage expansion (especially in rural area) and reduced carbon footprint amongst others, while some of the main obstacles have to do with the limited flexibility and capacity that the partnering operators have when sharing a network (Table 2).

Opportunities
CAPEX/OPEX reduction
Improved cost efficiency
Improved coverage and capacity faster
Reduced time to market for new services
Connectivity provision for underserved areas
Reduced carbon emissions and electricity power
Better spectral efficiency
Obstacles
Limited network control
Limited flexibility in network investment decisions
Complex SLA that defines the relationship between the operators - possible litigation between operators
Limited service differentiation potential
Risk of breach of confidentiality
Decreased investment in quality infrastructure
Risk of abusing dominant position

Table 2: Opportunities and obstacles of infrastructure sharing

In passive sharing, passive network elements such as masts and cabinets are shared between operators. In active sharing, active network elements, such as antennas and controllers are shared between the operators. Examples of active sharing arrangements with joint deployment in the EU are shown in Table 3.

Country	MNOs involved	Spectrum Sharing	Geographic Scope	Time Frame
Bulgaria	two MNOs	No	national	Permanent
Cyprus	MTN and Primetel	No	national	
Czech Republic	T-Mobile CZ; CETIN	No	Country divided into two parts, excl. two biggest cities Prague and Brno	2013- 2033
Denmark	Telenor and Telia	Yes	national	2012-
Finland	DNA Ltd and Telia FI Ltd	Yes	regional, i.e. north and eastern part of Finland (50% of area, 15% of population)	2015-
France	SFR and Bouygues Telecom	Yes	excluding dense areas (more than 200k inhabitants) and rural white areas: ~85% of territory and 57% of population	N/A
Greece	Vodafone GR and WIND Hellas	No		2012-
Hungary	Magyar Telekom and Telenor		National except Budapest	
Poland	Orange & T-Mobile	Yes	National	2011
Romania	Orange and Telekom Romania	No	National except 11 municipalities	Obligation for three years. After that, commercially driven.
Spain	Orange and Vodafone	No	In rural areas with less than 25.000 inhabitants	2006-
Sweden	Tele2 & Telenor	Yes	national	2009-
Sweden	Telenor & Hi3G	Yes	rural	2001-
Sweden	Telia & Tele2	Yes	national	2001-
UK	Three and EE	No	national	
UK	Telefonica (O2) and Vodafone	No	national	

Table 3: Active sharing arrangements with Joint Deployment, (BEREC)

In active sharing, there is also the possibility a partner of an agreement to steer traffic to the network of another partner without investing in active infrastructure. Usually, this type of sharing, known as national roaming - without joint deployment, does not normally extend nationwide but is used to increase network coverage (Table 4).

Country	MNOs involved	Time Frame	Technology	Commercially driven / regulatory intervention
Austria	T-Mobile; Hutchison	2012-	2G vs 3G	Commercially
Croatia	Tele 2 d.o.o.; Hrvatski Telekom d.d.			Commercially
Denmark	Hi3G; Telia	N. a.	2G, 3G	Commercially
France	Orange; Free Mobile	2012 - 2020	2G, 3G	2G regulation; 3G commercially
Norway	Telia; ICE	2015-2021	2G, 3G, 4G	Merger remedy
Spain	Yoigo/ Telefónica	-2019	2G, 3G, (4G)	Commercially
Spain	Yoigo/ Orange	2017-	2G, 3G, (4G)	Commercially

Table 4: National roaming (without joint deployment), (BEREC)

It is worth highlighting that the vast majority of network sharing agreements are made between exactly two operators, not more. This is likely due to the increased technical complexity that network sharing agreements between more than two players have and potential disagreements between the players in the venture's governance model. An exception to this trend is South Korea, where all four major operators have agreed to jointly roll out a 5G network in March 2019 including base stations, although specific details have not yet been released.

In Luxembourg there are no general sharing agreements in place between operators, however there are pragmatic sharing arrangements for determined sites. VOX and JOIN have signed commercial network sharing agreements with POST in the past. VOX started offering its services as an MVNO in 2004, following a commercial agreement with Post in 2003. The agreement was terminated in 2009 after Orange acquired and rebranded VOX. JOIN still offers its services leveraging its agreement with Post. Hence, prior network sharing experiences in Luxembourg could provide valuable lessons for future discussions related to network sharing in the 5G era.

2.3. 5G business models in Luxembourg

Based on preliminary exchanges with the relevant stakeholders in Luxembourg, operators will likely use the network deployment model they used in previous generation mobile networks for the most part of their 5G network. In this model, each operator deploys its own infrastructure to provide services to its clients ('parallel networks'). However, during the test pilots or in cases where deployment of parallel networks will be impossible or uneconomic, other network deployment models could be investigated, such as the neutral host model or that of shared infrastructure. Should a network sharing agreement go through, various parties expressed the view that active infrastructure sharing will likely be limited to Radio Access Network (RAN) sharing. Sharing of the core network will likely be avoided to reduce the complexity required to interconnect all systems between the partnering operators. In the case of deployment of a new network, like for 5G, sharing may result in more significant cost savings versus sharing in existing networks. Moreover, network sharing and neutral host models can be a cost-efficient way to deploy telecom networks, especially in areas where the business case of deploying parallel networks is uneconomic. The Government is committed in working alongside ILR to identify and address any barriers to 5G infrastructure deployment and sharing, while maintaining a balance between incentivising infrastructure investments, promoting competition and realising socioeconomic benefits.

3. Luxembourg 5G pilots

The 5G ecosystem in Luxembourg is starting to formulate as there are companies already involved in 5G research activities. A proposal for a R&D project (5GCroCO) examining autonomous driving use cases has been submitted for funding from the EU Horizon 2020 program involving stakeholders from Luxembourg and other countries. The project's aim is to define a successful path towards cooperative, connected and autonomous mobility services in cross-border scenarios and to reduce the uncertainties of a real 5G cross-border deployment. The 5GCroCo project aims to trial 5G technologies in the Metz-Merzig-Luxembourg cross-border corridor, traversing the borders between France, Germany and Luxembourg. The project brings together partners from the automotive and mobile communications industries and has the support from the national governments.

This section discusses five potential pilots that were identified during the discussions with several stakeholders as the most promising ones to investigate further any operational and regulatory challenges that have to be tackled for mass deployment of 5G to become a reality.

It should be highlighted that not all potential stakeholders related to the identified pilots were interviewed during the formulation of this report and they will be contacted at a later stage if needed.

3.1. How the potential pilots were identified

The five potential pilots include a mixture of both generic pilots covering applications and services in a range of sectors and pilots focused on a specific sector. The pilots are supposed to be established in different geographical areas with different topologies to extract as much varied insights as possible. Areas with existing fixed and mobile infrastructure, such as fiber and LTE networks, will be preferred as they qualify as more suitable to setup a 5G pilot than less well-connected areas. The selection of the five potential areas was made based on the criterion of socioeconomic benefit maximization for the country should a 5G network be installed. Figure 12 shows the different candidate areas for 5G pilot installation as they arose from the conversations with the 5G ecosystem stakeholders (see Appendix II for the full stakeholder list).

In each pilot, it is assumed that at least one telecom operator and one equipment vendor will be involved to deploy the required infrastructure for the pilot. Satellite communication could potentially participate in future pilot deployments. In all examined pilot candidates, satellite communications could play a threefold role:

- Push content to the edge of the network to ensure the perceived low latency
- Backhauling of sites
- Act as an umbrella (network of networks) to connect the selected pilot cases

In the following sections of the chapter, other stakeholders are presented which could be involved in each pilot along with possible use cases and a SWOT analysis for each potential pilot. The list of stakeholders and use cases are not exhaustive but rather indicative, giving a general direction on areas that could be used for each of the pilots.

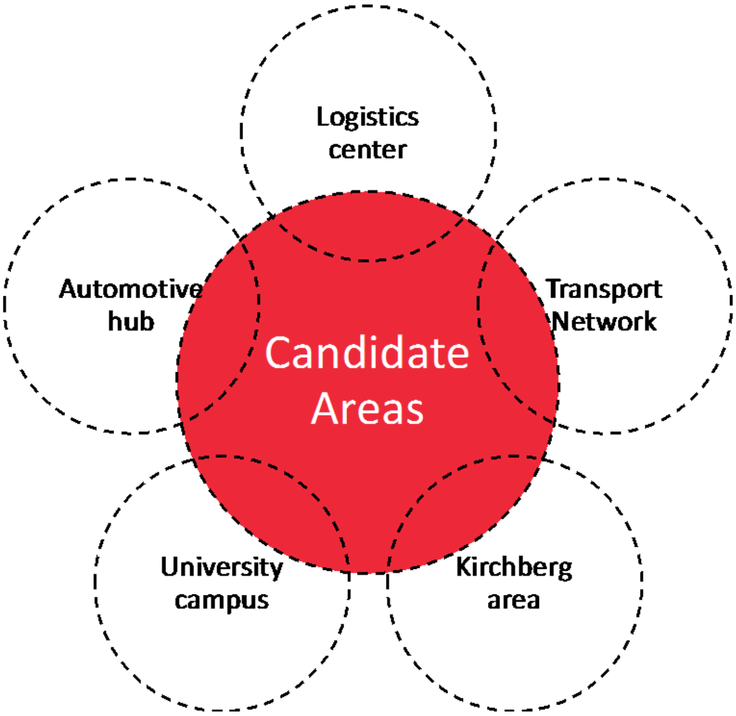

Figure 12: Candidate areas for 5G pilot deployment

3.2. Management and funding of pilots

The Government is committed to working with all relevant public and private stakeholders to create the conditions necessary to drive innovation and investments in 5G.

The Government is considering to co-fund the development of pilots so to stimulate private investment in 5G and reap the benefits of this technology as early as possible. Specifically, government funding for the development of 5G pilots is expected to be supplemented by investment from other parties participating in the pilots, such as academia, network operators and equipment vendors. In this context, the Government plans to earmark a budget that will be allocated to the agreed pilots. The amount of the budget and the way it will be allocated across the three years and between the different pilots will be defined at a later stage More details on funding schemes that could exist for the pilots are provided in chapter 6.

3.3. Pilot description

3.3.1. Pilot 1 - Kirchberg Area

Kirchberg is a district expanding to an area of around 3.5 square kilometres and is heavily occupied by business offices. Kirchberg is also home to the Chamber of Commerce and several EU institutions like the European Parliament, European Commission, European Investment Bank and the European Court of Justice. The Interdisciplinary Centre for Security, Reliability and Trust (SnT) is part of the University of Luxembourg (uni.lu) which is also partially in the area. Luxembourg Philharmonie, the Luxembourg Museum of Modern Art and the National Sports and Culture Centre 'd'Coque' are also located in Kirchberg, as the Luxembourg Convention Center. At the northwest part there is a shopping mall, the headquarters of RTL, the Luxexpo exhibition center and a major movie theatre complex. Lastly, the newly constructed tram line crosses through the Kennedy Avenue the area of Kirchberg (Figure 13).

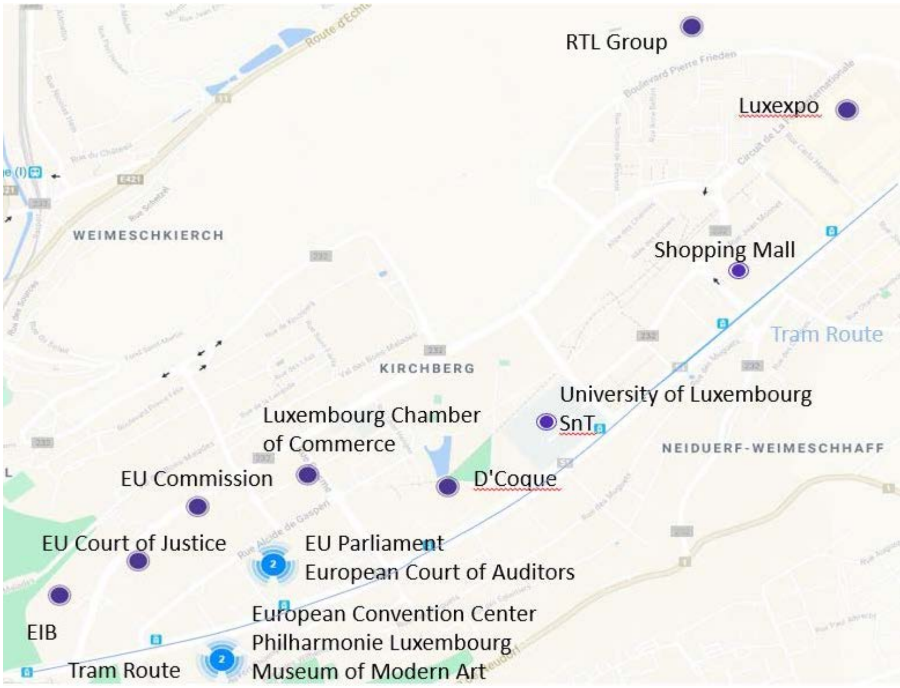

Figure 13: High level map of Kirchberg

The daily stream of people and the differentiation in the activities that take place in the area of Kirchberg makes it a very promising candidate for a 5G pilot. Both indoor and outdoor deployment scenarios can be examined, with a large variety of potential stakeholders that could be interested such as the UoL, Luxtram, Luxexpo, EU institutions and the shopping mall.

The pilot can be used for uni.lu research purposes in several areas around 5G (security, artificial intelligence, machine learning, etc.). Possible use cases can include media and content delivery to tram passengers, high bandwidth connection to the office workers, IoT applications or applications focused on building management and surveillance. Use cases associated to high population concentration for a limited period, like the shopping mall, events at Luxexpo or concerts at the Philharmonie could also be investigated (Table 5).

Stakeholders	Indicative Use cases
Research (UoL)	SDN, NFV, IoT, security, drones
Commercial (Shopping Mall)	AR, VR
Cultural (Philharmonie)	Augmented Reality, Virtual Reality, UHD video delivery, immersive video services
Transportation (Luxtram)	eMBB with increased mobility
Office area (EU buildings, EIB)	eMBB, security, building management
Exhibition center (Luxexpo)	eMBB, AR, VR, immersive video services

Table 5: Potential stakeholders and use cases - Kirchberg area pilot

One of the possible drawbacks of a pilot at Kirchberg is that the area is quite large for a small size pilot. A way to get around this issue would be to deploy individual 5G network islets in the area and use existing infrastructure, like satellite links, to connect them. The large number of different building owners is also an issue that must be considered, due to problems that may arise related to licensing permits for antenna deployments. However, Fonds du Kirchberg, which sets the guidelines for development and construction in the area, and Ville de Luxembourg, are supportive of investments in telecom networks infrastructure. Another issue that must be addressed is the potential interference between the different indoor and outdoor networks (terrestrial or satellite) that may be in operation in the area (Figure 14).

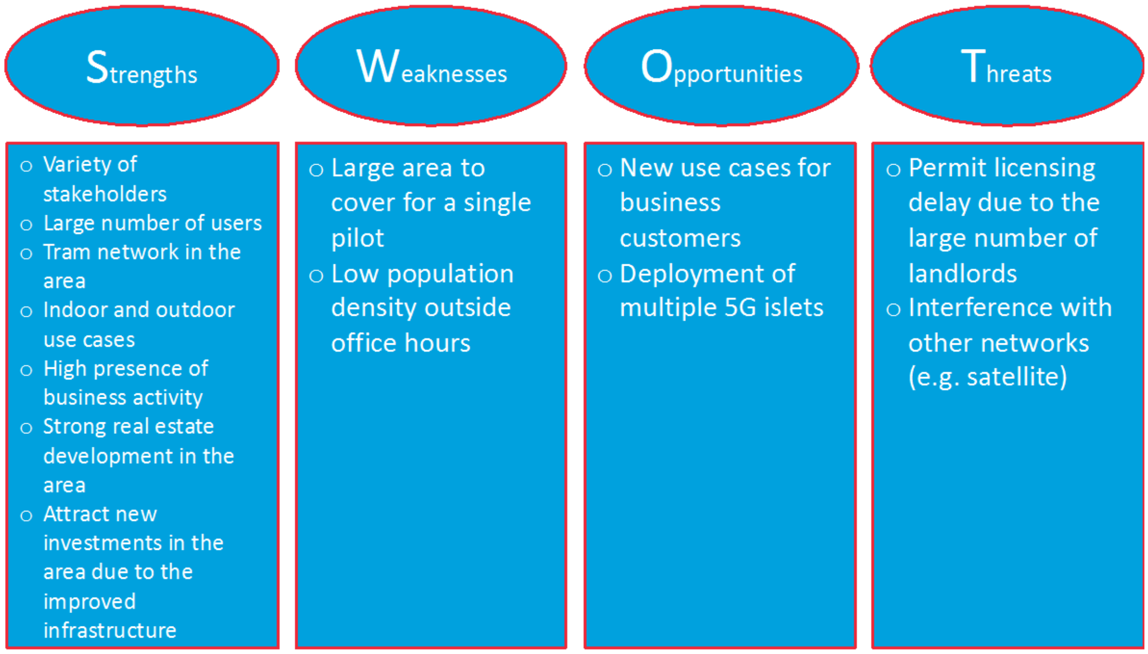

Figure 14: SWOT analysis - Kirchberg area pilot

3.3.2. Pilot 2 - University campus in Belval

The University campus in Belval is a candidate for future pilots because of the unique characteristics it presents. The campus is near a large area of strong commercial activity and has the potential to become a research and cultural hub, where a large number of users, stakeholders and researchers will be experimenting with 5G should a pilot gets deployed in the area. This mixture of research and commercial opportunities that exist in the wider area around the campus, make it a very attractive location for a 5G pilot due to the different use cases that could be investigated.

Belval is a development site with parts belonging to the districts of Esch-sur-Alzette (Luxembourg's second biggest city) and of Sanem and is undergoing a redevelopment plan that will turn it into a scientific and cultural hub. Most parts of the University of Luxembourg have already moved to the area, while the plan is to move all University Faculties (except of the Faculty of Law, Economics and Finance) to Belval until the end of 2019. The campus will soon become a major research center for Luxembourg (hosting already other research entities like Luxembourg Institute of Science and Technology (LIST), Luxembourg Institute of Socio-Economic Research (LISER)), an ideal hub for researchers to perform R&D activities in the area of 5G but also in other research areas that can benefit from 5G, such as IoT, Artificial Intelligence, Automotive, Smart Grid, Health, Media etc.. Belval also hosts Luxinnovation and the Technoport start-up incubator hub (Figure 15). A 5G pilot in the area could also give start-ups the opportunity to become part of the new 5G ecosystem, understand the benefits it can offer, develop their own products and services and test them before commercialisation.

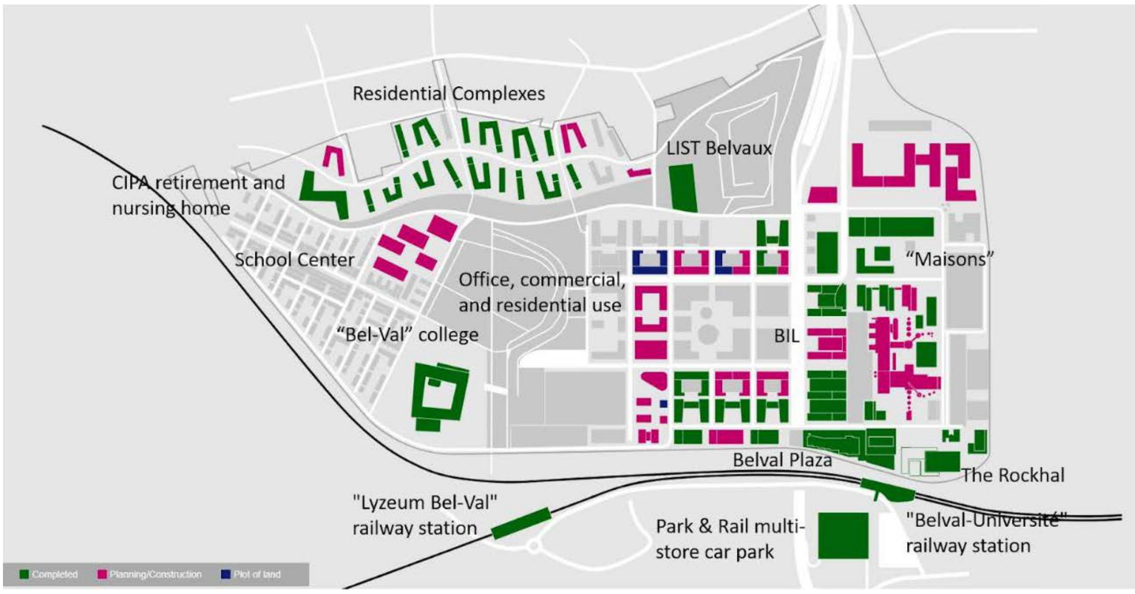

Figure 15: High level map of Belval

Besides the scientific hub, Belval is also home to a shopping mall and the largest concert venue in Luxembourg where a number of events take place every year, making it a great candidate for Augmented Reality, Ultra High Definition broadcast and immersive video 5G use cases (Table 6).

Stakeholders	Indicative Use cases
Research (UoL, LIST)	SDN, NFV, IoT, security
Commercial (Shopping Mall, BIL)	AR, VR, Fintech (secure transactions)
Cultural (Rockhal)	AR, VR, UHD video
Transportation (Bus, Train)	eMBB with increased mobility
Residential area	eMBB, Smart Home

Table 6: Potential stakeholders and use cases - University campus pilot

Possible obstacles for a 5G pilot deployment include the possibility that the deployments have to be made in areas that were recently renovated resulting in a reluctance to install new equipment. In addition, there are frequency planning issues as the area is adjacent to the borders of France (Figure 16).

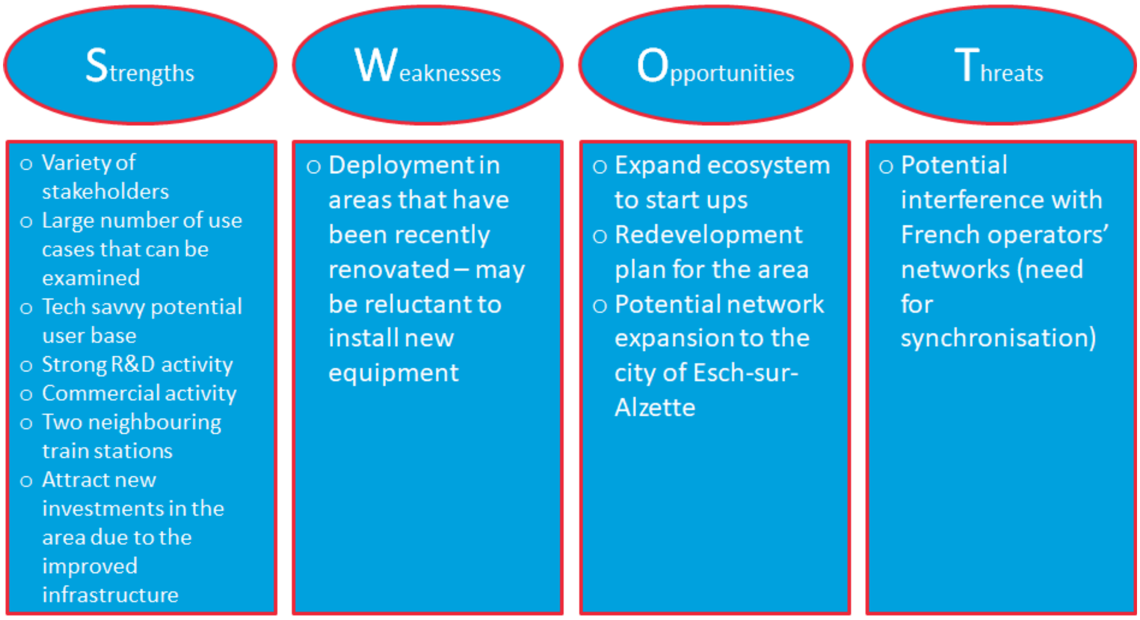

Figure 16: SWOT analysis - University Campus pilot

3.3.3. Pilot 3 - Automotive Hub in Bissen

Luxembourg automotive sector covers a wide range of expertise in materials, components, sensors, equipment, automation, connectivity, infotainment and applications. A pilot targeted to use cases related to the automotive sector can be implemented at Roost, close to Bissen. The wider area comprises the "Circuit Goodyear" racing track, national driving test centre and the Luxembourg Automotive Campus (Figure 17). The Automotive Campus is currently growing and the plan is to house the R&D departments of several companies in the automotive sector. Circuit Goodyear is a 3km-long privately-owned track (by Goodyear) in Colmar-Berg used for a series of car and moto racing events as well as for driver training courses. The Goodyear innovation center that is working on R&D projects is in the area while a new tire plant is planned to start operating in 2019.

Figure 17: High-level map of Automotive campus and Goodyear circuit

A trial in this area has the niche that it can be used to examine use cases related to autonomous driving using the expertise and prototypes of the researchers of the automotive hub in a controlled and safe environment without causing any traffic interference.

Potential use cases for this pilot include aspects of the automotive market, such as autonomous driving, road safety and traffic management, digitalisation of transport, logistics, intelligent navigation, infotainment systems, etc. Use cases related to 5G in the manufacturing sector such as increased efficiency, employee safety, remote control and maintenance, assets monitoring and communication within the factory area could also be examined. Furthermore, use cases of video delivery (immersive video services) to the increased density of users during the races and other sport racing activities could also be examined (Table 7).

Stakeholders	Indicative Use cases
Automotive Industry (Luxembourg Automotive sector)	Autonomous driving, Logistics, infotainment, intelligent navigation, traffic efficiency
Racing Track (Goodyear)	Autonomous vehicle
Factory (Goodyear)	Logistics, Factory 4.0
Sport Events Organisation	eMBB, AR, VR, immersive video services

Table 7: Potential stakeholders and use cases - Automotive hub pilot

A pilot in the automotive hub has the advantage that it would interest many stakeholders from the automotive industry to test and develop different use cases, a task that would be very difficult to implement on a real road. Furthermore, the pilot can act as an added value asset that would bring more stakeholders in the area and attract new investments to Luxembourg. The weaknesses of this pilot are that the track is private and that is also used for other activities (Figure 18).

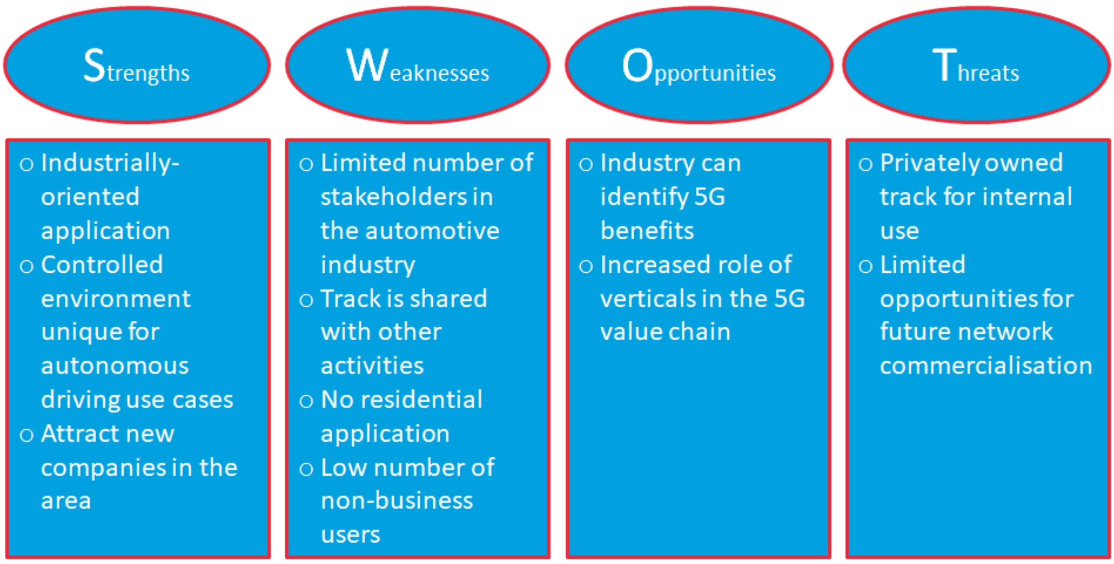

Figure 18: SWOT analysis - Automotive hub pilot

3.3.4. Pilot 4 - CFL multimodal in Dudelange

CFL multimodal is a multimodal logistics service provider, covering the entire logistics chain. The company offers a broad and personalized service portfolio: combined and conventional rail freight, wagon maintenance and repairs, customs clearance, as well as forwarding and logistics services.

The CFL multimodal Group is operating the Luxembourg Intermodal Terminal. Located on the Rail Freight Corridor 2 (North Sea-Mediterranean) and at the crossroads of the North-South and East-West transport routes, the terminal is ideally positioned as an international hub for the consolidation of multimodal transport flows across Europe.

On a 33 ha total surface, the terminal is equipped with four rail tracks of 700 m each and two gantry cranes, as well as with two 700 m rail motorway platforms, with a total yearly capacity of 600.000 units. It is located at the Luxembourg Eurohub South logistics park, which provides infrastructures and services such as logistics service providers, customs office and bonded warehousing.

Combined train shuttles connect the Luxembourg Intermodal Terminal to the main industrial regions and the ports of the North Sea as well as the Baltic Sea and Southern Europe.

By offering various logistics services CFL multimodal in Dudelange becomes a strong candidate for a 5G pilot. The warehouse owned by CFL, providing 30,000 square meter of storage space, is located in the Eurohub South site in Dudelange and could be convenient for a 5G pilot.

This warehouse is in close proximity to the international highway network (A3 and A13), the intermodal terminal and the rail network (Figure 19). This proximity can link to interactions with Pilot 5.

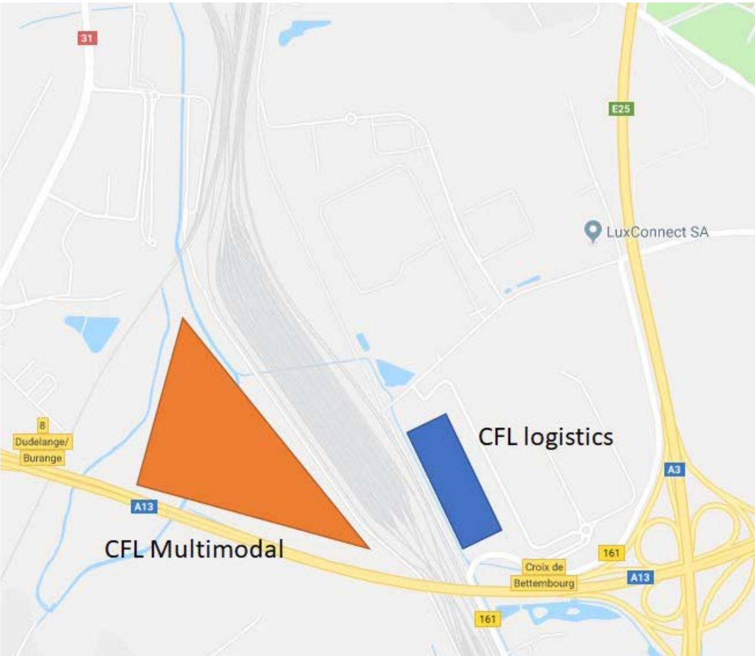

Figure 19: High level map of Eurohub South

The pilot will be used to investigate use cases related to the digitalisation of logistics operations. By connecting all devices, sensors, cameras and other equipment of the logistics centre to a 5G network, the aim is to have a warehouse in which devices, machines and humans can share real time information using 5G. The network can also be used for parcel tracking in a more accurate, effective and secure way and using real-time analytics on top can improve the decision-making process for the logistics hub operator. 5G can improve the logistics supply chain by introducing automatic recognition, automatic storage and movement, tracking, protection and self-inspection for the managed goods (Table 8).

Stakeholders	Indicative Use cases
Logistics (CFL logistics)	tracking, real time warehouse management, analytics
Train network (CFL)	Logistics

Table 8: Potential stakeholders and use cases - CFL logistics centre pilot

This pilot provides a very good environment for examining use cases related to 5G and IoT in the sector of logistics. It can be used as an example for highlighting the benefits that 5G can bring to the logistics sector. The weaknesses include the limited number of involved stakeholders and that the warehouse is used in everyday operation and deploying a 5G network and examining various use cases might be difficult without interrupting the operation of the warehouse (Figure 20). Moreover, the low number of non-business users in the area limits the commercialisation opportunities of the pilot network.

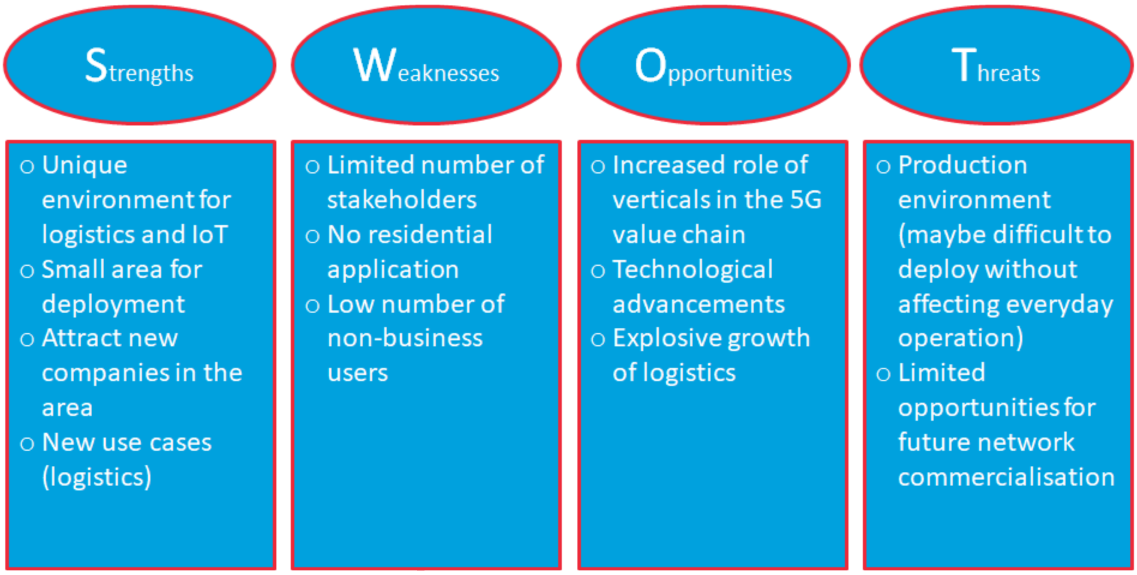

Figure 20: SWOT analysis - Logistics centre pilot

3.3.5. Pilot 5 - Transport Networks

The Trans-European Transport Network (TEN-T) is a Europe-wide network consisting of roads, railway lines, inland waterways, maritime shipping routes, ports, airports and rail-road terminals. The network crossing Luxembourg is part of the North Sea-Mediterranean Corridor. The road network that goes through Luxembourg includes the following highways A1 (Luxembourg City - Wasserbillig), A6 (Luxembourg City - Kleinbettingen) and A3 (Luxembourg City - Dudelange) (Figure 21). These highways essentially connect Luxembourg city with Germany, France and Belgium. Regarding the train network, currently it goes through the Luxembourg intermodal-hub in Bettembourg and connects Luxembourg with several European cities while many other cities are planned to be connected in the following years (Figure 22). A pilot in parts of the TEN-T network is aligned with the objectives of the 5G Action Plan which states that all major terrestrial paths must have uninterrupted 5G coverage by 2025.

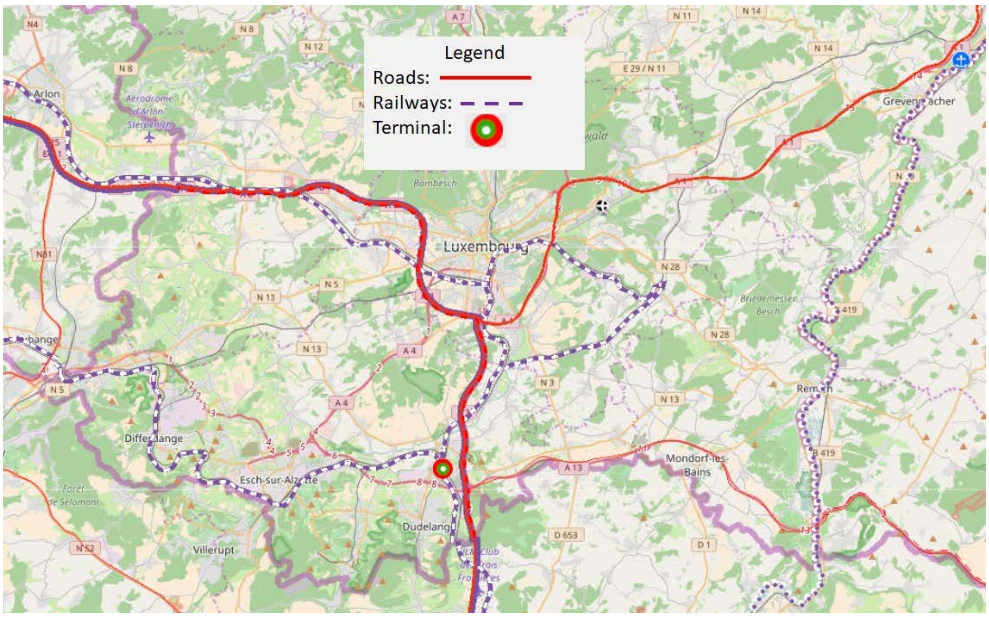

Figure 21: Map of TEN-T networks in Luxembourg, (European Commission)

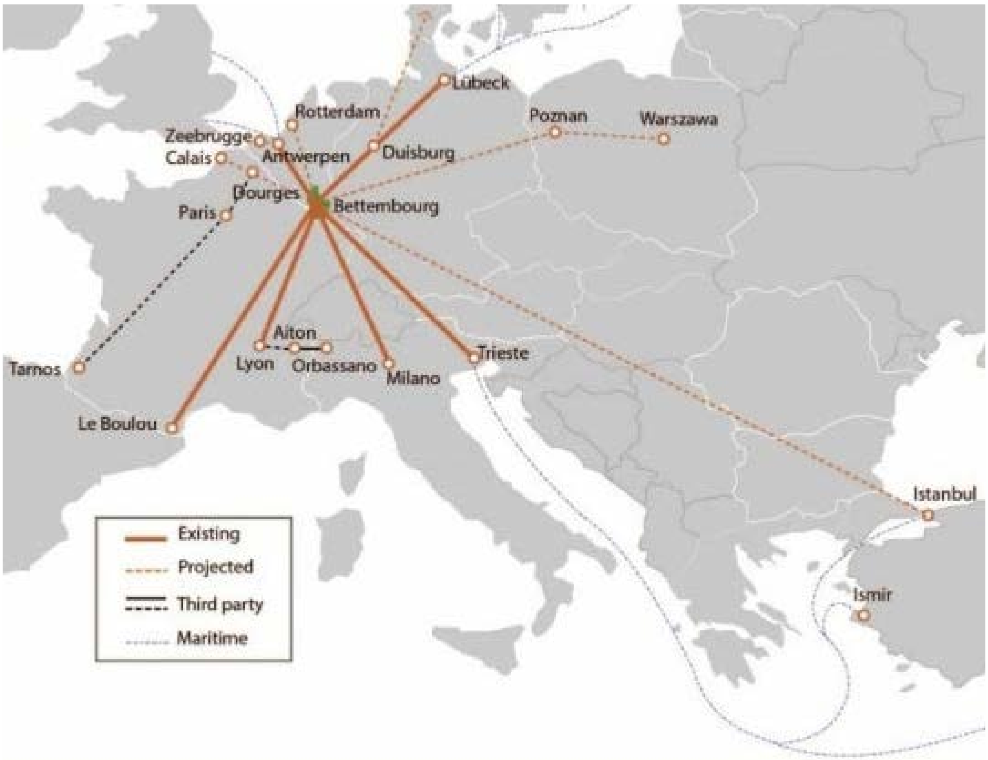

Figure 22: Intermodal-hub connections with other countries, (CFL)

A pilot in the road network can be used for validating use cases related to the autonomous driving, traffic management, intelligent navigation and logistics, while at the same time providing infotainment services to the users. Regarding the railroad network, use cases associated to the delivery of infotainment to passengers, logistic management services and rail network operation can be examined. The inclusion of the intermodal hub in the pilot can bring additional stakeholders in the area of logistics (Table 9).

Stakeholders	Indicative Use cases
Highways (operators cars, trucks)	Autonomous driving, traffic management, infotainment, intelligent navigation, logistics
Logistic companies	tracking, real time warehouse management, analytics
Train network (CFL)	Infotainment in trains, Logistics, predictive maintenance

Table 9: Potential stakeholders and use cases - Transport networks pilot

The pilot in the transport networks is in line with the 5G Action plan objectives, bringing together several stakeholders and could potentially be used by a large number of users. The main potential drawbacks of this pilot are that the area is too large to be covered by a single pilot and that there might be interference in parts of the network (from wireless networks) due to its proximity to the borders (Figure 23). The lack of a regulatory framework addressing issues on Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communications as well as the safety issues that can arise in real time testing are critical factors for the success of the pilot.

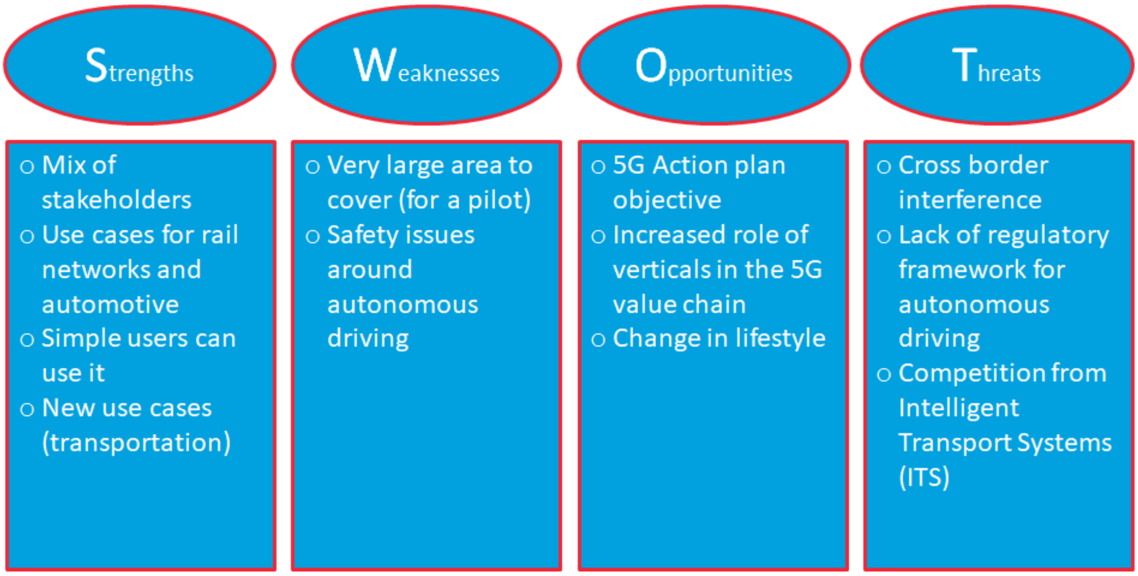

Figure 23: SWOT analysis - Transport networks pilot

4. 5G Forecasting

In this section, the methodology, assumptions and a 5-year forecast for the 5G mobile subscriptions in Luxembourg are presented. Such a forecast is an essential input when estimating the viability of 5G-related investments as it estimates the potential demand of future 5G networks. The forecast is the work of inCITES Consulting and is not necessarily endorsed by the Government.

4.1. Subscription forecast methodology

The chosen mobile connectivity forecast methodology includes the data collection, forecast scoping, statistical modelling and forecast calibration steps and it is based on several inputs as shown in Figure 24, such as:

- Population income distribution
- Socioeconomic data
- Mobile broadband penetration targets
- Mobile network coverage
- Network planning and management
- Market data from the regulator/operators
- 5G-enabled devices availability
- Spectrum holdings and 5G spectrum auction plans

Using the aforementioned inputs and considering the unique characteristics of the Luxembourgish market, several assumptions have been made to calibrate the 5G subscription forecast.

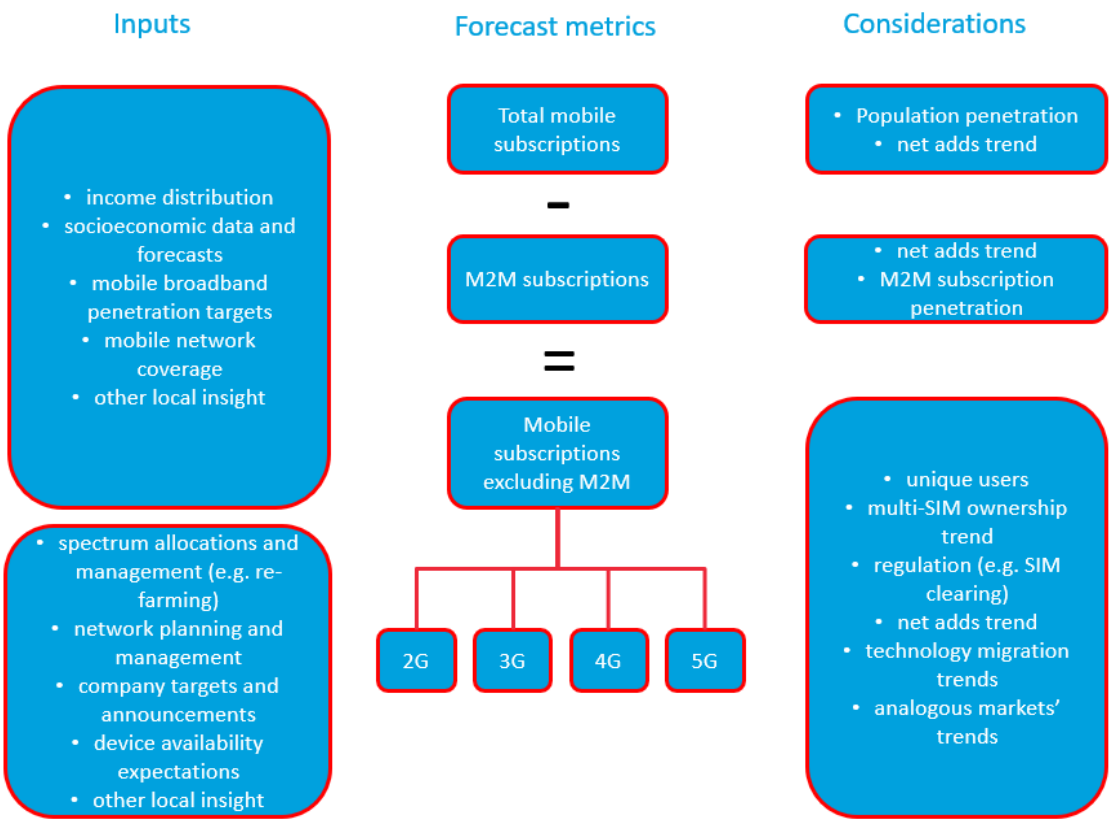

Figure 24: 5G subscription forecast components, (inCITES Consulting)

4.2. Subscription forecast assumptions

The factors that were considered during the forecast scoping phase of the 5G mobile subscription forecast are shown in Table 10. The formulation of the assumptions listed below is based on discussions with Luxembourg telecom ecosystem stakeholders.

Factors	Forecast Assumptions
5G network launch year	Based on conversations with network operators and according to the Digital Agenda Europe connectivity targets, a commercial 5G network in Luxembourg is expected to be deployed in 2020.
5G network coverage	5G network coverage is expected to be very limited in 2020, as network operators are planning to deploy '5G islets' based on 5G non stand-alone new radio standards in 2020 and then increase coverage and move to 5G stand-alone new radio-compliant networks in the following years.
5G-enabled devices availability	The first commercial 5G-enabled devices, such as smartphones, tablets and laptops are expected to be available in 2019. However, some large device manufacturers are expected to launch their flagship 5G-enabled devices in 2020, or even 2021, which might delay the wide adoption of such devices. In any case, 5G-enabled devices are expected to be available in the market before the launch of the first 5G network in Luxembourg.
5G-enabled devices pricing	The initial 5G-enabled devices are expected to come in the high-end of the price spectrum as was the case when 3G and 4G devices were introduced. Although this will pose a headwind to the initial adoption of 5G, Luxembourg has one of the highest GDP per capita ratios and mobile ARPUs (average revenue per user) in the EU. Hence, the high price point of the initial 5G-enabled devices is not expected to prevent the early adopters from getting their hands on those devices. It is also expected that 5G-enabled devices' average selling price (ASP) is expected to erode faster than any previous technology family. This is a trend that was also observed when 4G was launched due to the commoditization of the hardware components and the increasingly fiercer competition amongst the hardware manufacturers that will drive prices of 5G-enabled devices lower faster than in previous technology generations.
5G mobile user base	A low number of 5G-enabled devices at a high price point is expected to create a relatively small user base during the launch year. However, as more device manufacturers launch 5G-enabled devices and the ASP of those devices erodes, the 5G mobile user base is expected to grow exponentially as was the case with previous technology families. 5G mobile user base growth will also depend on the 5G networks coverage.
5G service pricing	Mobile plans for 5G-enabled devices are expected to not have a price premium versus 4G plans. This is expected to provide a tailwind for the adoption of 5G networks. The reasoning behind this assumption is that subscribers will likely not be willing to pay a premium just for higher mobile broadband speeds initially, as seen when the industry migrated from 3G to 4G. However, when more differentiated services on 5G networks get introduced, then the operators might see their ARPU rising.

5G service differentiation	The provided services in the early years after launch of 5G networks are not expected to be very differentiated versus 4G and 4.5G networks. NSA 5G NR networks are expected to be able to provide enhanced user experience in eMBB and infotainment applications. However, as operators start launching SA 5G NR networks, the supported use cases and service differentiation will continue to flourish. Hence, the expected limited service differentiation in the early years of 5G networks will pose headwinds in the adoption of 5G networks.
CAPEX for network investments	4G networks were introduced in Luxembourg in 2012 and ever since the operators have been continuously investing in improving their 4G coverage and enhancing their networks. Therefore, some Luxembourgish operators have indicated some hesitation to invest a large sum of money in 5G networks in the early years, since they might not have recouped their 4G network investments yet. Hence, it is sensible to expect small-scale 5G network deployments in 2020, which will grow gradually with time.
Profitable business cases	Unless a profitable business case arises for Luxembourgish operators, they are expected to procrastinate their 5G network investments.
Spectrum availability	Three pioneering bands, 700 MHz, 3.6 GHz and 26 GHz have been identified for Europe. However, spectrum re-allocation will be necessary in Luxembourg and in neighbouring countries, meaning that the spectrum is not available immediately. The 700 MHz band and the 3.6 GHz bands should be available by July 2020, while the 26 GHz band is expected to follow later.

Table 10: Primary 5G forecast assumptions

4.3. Global 5G forecasts

One of the key trends observed in the technology industry is that the adoption cycle of new innovations becomes faster while the replacement cycles of the adopted technologies shortens. The greatest example of that is that it took more than a hundred years for the first telephone to reach one billion uses. It took the TV forty-nine years to cross the same mark, twenty-two years for the mobile phone, fourteen years for the Internet and only eight years for Facebook. Currently, telecom market analysts are trying to estimate the success of the next mobile technology and forecast its future market adoption based on a range of inputs and techniques. Specifically, Ericsson expects 1 billion 5G subscriptions, or 12% of total mobile subscriptions by 2023, while GSMA forecasts 1.1 billion 5G connections by 2025, representing 12% of total mobile subscriptions (Table 11). Despite the different opinions regarding the pace of the adoption of 5G, there is clear consensus that it will be faster than any previous mobile technology.

Source	5G Forecast
Ericsson Mobility Report	1 billion mobile 5G subscriptions, 12% of total mobile subscriptions, by 2023
GSMA	1.1 billion connections, or 12% of total mobile connections, by 2025
CCS Insights	1 billion 5G subscriptions by 2023, 2.6 billion by 2025
Ovum	400 million 5G subscriptions in 2022
Strategy Analytics	577 million 5G subscriptions by 2023
inCITES Consulting	1.1 billion 5G subscriptions in 2024

Table 11: Global 5G subscription forecasts

The main factors that will drive faster adoption for 5G vs. 4G are expected to be the following:

- 5G impact/benefits

Governments and institutions around the world have endeavoured to size the economic and societal benefits that 5G will unlock. In the EU, a European Commission report[9] suggests that benefits of €62.5 billion will arise from first order benefits in Automotive, Healthcare, Transport and Utilities verticals in 2025. A report[10] from the American Consumer Institute Center for Citizen Research revealed that deploying and investing in a 5G network in the USA will generate $533 billion in GDP and $1.2 trillion in long-run consumer benefits. A Deloitte analysis[11] in Australia identified that 5G network deployment and investments could generate approximately $AUD 73.4 billion. On a global level, an IHS study[12] has shown that 5G networks will fuel sustainable long term growth to global GDP and that in 2035 5G will enable $12.3 trillion of global economic output, the global 5G value chain will generate $3.5 trillion and 5G will support 22 million jobs through improvements in productivity, economic growth and income. The large number of benefits that 5G networks promise has convinced governments in several regions to invest large sums of money in the technology to make the most of it as early as possible. USA, the EU, China, South Korea and Japan are some of the countries that drive global 5G research forward. Hence, it is apparent that the trust shown in the new mobile technology is immense and stronger than when 4G networks were introduced, evident by the investment amounts committed to it globally.

- Mobile user base

The global mobile user base reached 5 billion in 2017 and is expected to reach 5.9 billion by 2025, growing at a Compound Annual Growth Rate (CAGR) of 2.1%, according to GSMA[13]. When 4G was introduced in 2009, the global mobile user base stood at just under 2.6 billion, approximately 50% below the 2017 figure. Hence, it is expected that the ever-growing mobile user base that will exist in the following years will be a tailwind to the adoption of 5G. Better consumer tech savviness and technology awareness versus when 4G was launched will also play a positive role in the swift adoption of 5G.

- Hardware manufacturers competition

Due to the commoditization of hardware components, many new hardware manufacturers have entered the market taking share away from traditional players. In addition, several Asian manufacturers have also expressed their intentions to expand internationally, triggering significant price competition against existing industry behemoths. In fact, at least 21 smartphone manufacturers are currently working together with chipset vendors so to launch commercial 5G-enabled smartphones as early as possible. The picture differs significantly from 2009, when 4G was introduced and only a handful of devices were available in the first years after the network launch. Hence, we believe that the fierce competition amongst hardware manufacturers will accelerate the adoption of 5G.

- Demand for IoT/M2M applications

[9] https://connectcentre.ie/wp-content/uploads/2016/10/EC-Study_5G-in-Europe.pdf
[10] http://thelosteconomy.com/wp-content/uploads/2017/07/ACI-5G-Report-Final.pdf
[11] https://www2.deloitte.com/content/dam/Deloitte/au/Documents/Economics/deloitte-au-economics-5g-mobile-171017.pdf
[12] https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf
[13] https://www.gsma.com/mobileeconomy/wp-content/uploads/2018/02/The-Mobile-Economy-Global-2018.pdf

One of the use case families of 5G networks is massive machine-type communications (mMTC), which encompasses various IoT/M2M applications, such as smart cities and smart homes. Ericsson in its Mobility Report[14] forecasts that cellular IoT connections will reach 3.5 billion by 2023, up from 0.7 billion in 2017, growing at a CAGR of 30% between 2017-23. Although 4G and 4.5G networks can initially serve many IoT/M2M connections, operators will eventually need to upgrade their networks to accommodate more sophisticated IoT/M2M applications, which may not have been identified yet. Therefore, the need to accommodate a larger number of more sophisticated IoT/M2M applications will be a tailwind in 5G adoption in the latter years of the forecast horizon - 2023 and beyond*.

* The inCITES Consulting 5G subscription forecast does not include IoT/M2M connections.

4.4. Luxembourg 5G subscription forecast

Technology penetration is measured with two metrics, namely, population penetration and the share of the total addressable market that the technology captures. Figures 25 and 26 show the population penetration of 5G subscriptions excluding M2M and 5G subscriptions as a percentage of total mobile subscriptions excluding M2M for Luxembourg until 2025. The three scenarios identified are the optimistic, base and pessimistic and vary in the severity of the input assumptions as those were outlined in *section 4.2.*

4.4.1. Optimistic scenario

The optimistic scenario is based on the following assumptions: 5G will have to be commercially launched in 2020 as per the Digital Agenda for Europe targets and its coverage will have to be growing at a similar manner with 4G when that technology was launched. A variety of 5G-enabled devices will have to be available from 2020 and their ASP will have to erode faster than how 4G-enabled devices' ASP eroded. 5G plans will have to have zero price premium over 4G plans and operators will have to identify profitable business that will motivate them to commit to investing in the technology as early as possible (Table 12, 13).

4.4.2. Base scenario

The forecast assumptions that formulated the base scenario were less strict versus the optimistic scenario. 5G will have to launch commercially in late-2020 and its coverage will have to grow at a slower pace vs. 4G. Only a handful of 5G-enabled devices will have to be available in the early stages after its commercial launch and their ASP will have to erode at a slower pace vs. 4G-enabled devices at a similar time frame. 5G plans will have to be priced at a premium vs. 4G plans and the operators will not be able to identify various profitable use cases that will make them invest in 5G from an early stage (Table 12, 13).

4.4.3. Pessimistic scenario

In the pessimistic scenario, the adoption of 5G will be quite slower than 4G and technology commitment from the operators will be minimal. In this scenario, 5G will be launched commercially in late-2020 or later and its coverage will grow at a much slower pace vs. when 4G was introduced. A limited number of 5G-enabled devices will be launched initially, and their

[14] https://www.ericsson.com/en/mobility-report/reports/june-2018/iot-connections-outlook

ASP will erode at a much slower pace vs. 4G-enabled devices at a similar time frame with when 4G was introduced. 5G plans will carry a premium over 4G plans and commitment to the new technology from the mobile operators will be minimal due to the late or non-existent identification of strong and profitable use cases (Table 12, 13).

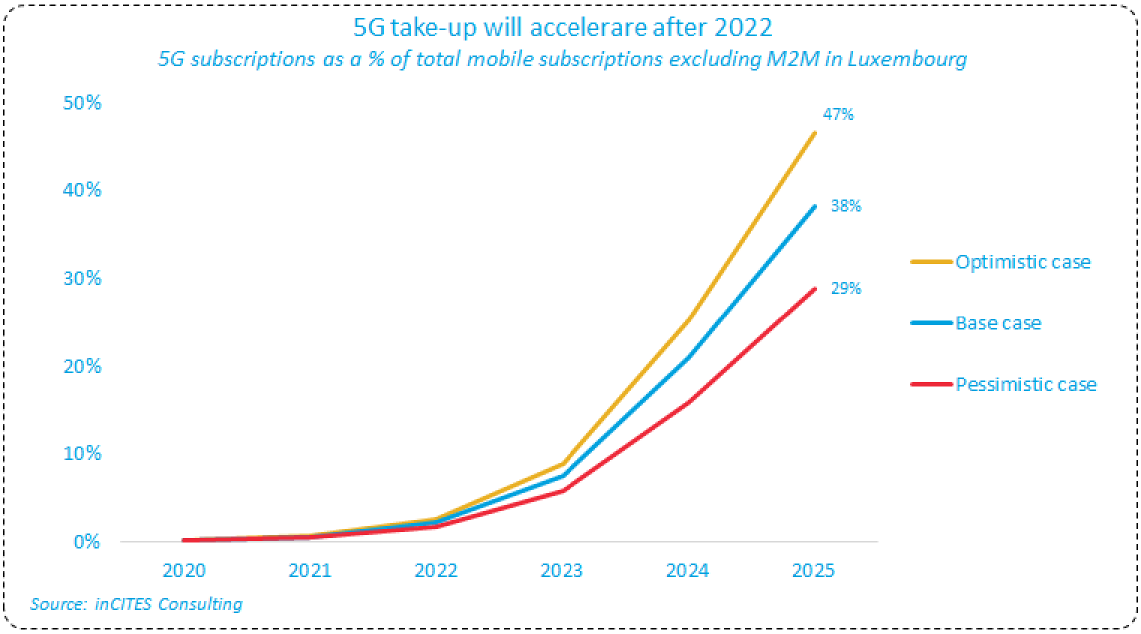

Figure 25: 5G share forecast of total mobile subscriptions excluding M2M

Luxembourg 5G forecast	2020	2021	2022	2023	2024	2025
Optimistic Scenario	0.2%	0.7%	2.5%	8.9%	25.2%	46.6%
Base Case Scenario	0.1%	0.6%	2.2%	7.6%	20.9%	38.2%
Pessimistic Scenario	0.1%	0.5%	1.7%	5.8%	15.9%	28.8%

Table 12: 5G subscriptions as a percentage of total mobile subscriptions excluding M2M

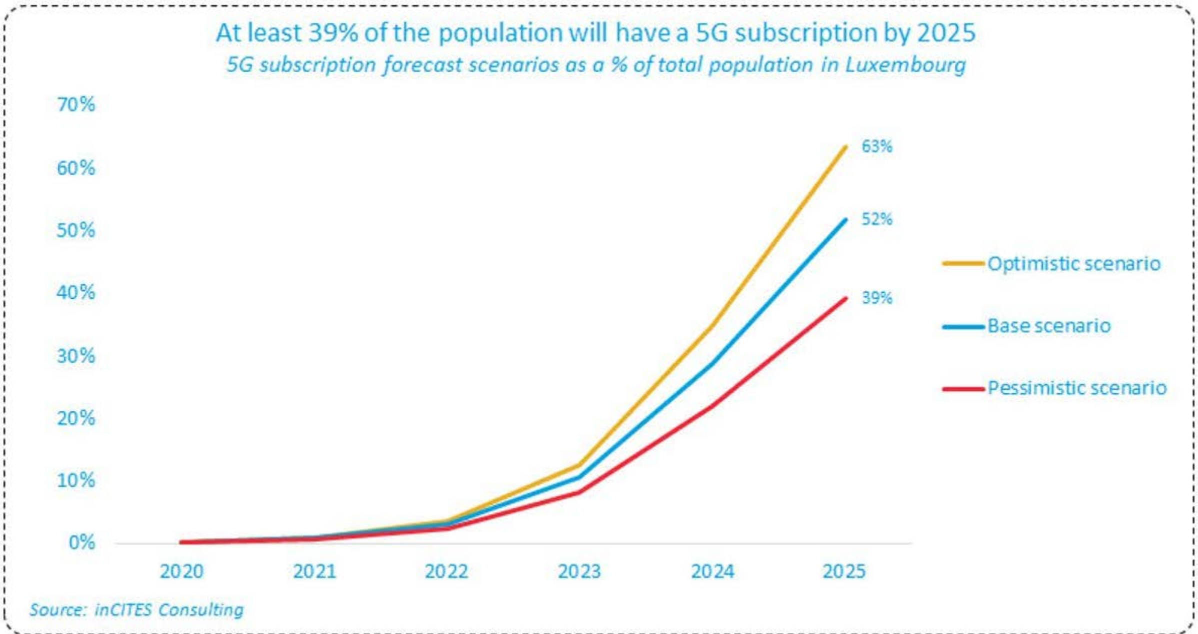

Figure 26: 5G population penetration scenarios

Luxembourg 5G forecast	2020	2021	2022	2023	2024	2025
Optimistic Scenario	0.2%	0.9%	3.5%	12.4%	34.7%	63.3%
Base Case Scenario	0.2%	0.8%	3.1%	10.6%	28.8%	51.8%
Pessimistic Scenario	0.2%	0.7%	2.4%	8.1%	21.9%	39.2%

Table 13: 5G subscriptions as a percentage of total population in Luxembourg

4.5. Opportunities with business customers

5G is an all-encompassing technology aiming to cater new, differentiated services to both consumers and businesses. However, industry analysts, operators and equipment vendors are highlighting the additional benefits that 5G will bring to the vertical markets as one of the main brand new revenue streams that 5G networks will unlock and which has a huge potential. 5G has the potential to bring significant changes to a number of industries, such as Manufacturing, Energy and utilities, Automotive, Financial services, Retail, Agriculture, Transportation, Media and entertainment and Healthcare. Benefits from the digitalization of those industries can lead to the emergence of a plethora of new use cases with significant socioeconomic benefits.

One promising use case which has received significant coverage is the so-called 'Industry 4.0', which refers to the anticipated fourth industrial revolution that will be enabled with 5G. This revolution will be a combination of advanced production techniques with smart technologies that will not only be connected and autonomous but they will also be able to communicate, analyse and use data to further optimise the production process. Digitalisation of the production process is expected to drive additional revenues for network operators and significant cost savings for the manufacturers.

Ericsson forecasts that the potential additional revenue gain for the operators, depending on their role in the value chain, from the 5G-enabled industry digitalisation market is between 12-36%. Globally, this corresponds to $204-619 billion by 2026. To harness this opportunity, the operators need to identify which use cases are relevant for their market, what role they want to play in the new value chain and how to cost-effectively deploy networks for the most relevant use cases for them.

4.6. Making 5G in Luxembourg a reality

Taking into account the industry expectations for 5G, coupled with Luxembourg's strong digital assets and anticipated 5G take-up, an investment in 5G from an early stage by the digital ecosystem would permit Luxembourg to fulfil its vision to be one of the pioneers in the new digital era. 5G is also an essential enabler of the Government's Rifkin strategy. The Government needs to provide the necessary regulatory, policy and financing framework in support of the economic actors to achieve this goal.

5. Regulatory Considerations

5.1. The need for a flexible regulatory framework to facilitate 5G deployment

Traditionally, mobile networks are designed as a set of macrocells that provide radio coverage to a large area. In the last years, however, mobile data traffic is experiencing an explosive growth stemming from the use of bandwidth-starving applications driving the evolution of mobile networks and vice versa. To address the increasing demand for capacity and to meet the users' need for higher data rates, coverage and quality of service, operators resort to network densification by installing more base stations. The need for densification will increase further with 5G which is expected to bring a remarkable increase in data traffic. 5G mobile networks are expected to be heterogeneous networks (hetnets) consisting of a mix of macrocell sites, denser than those for 4G, to provide wide area coverage and small cells to improve localised coverage and to increase capacity (Figure 27).

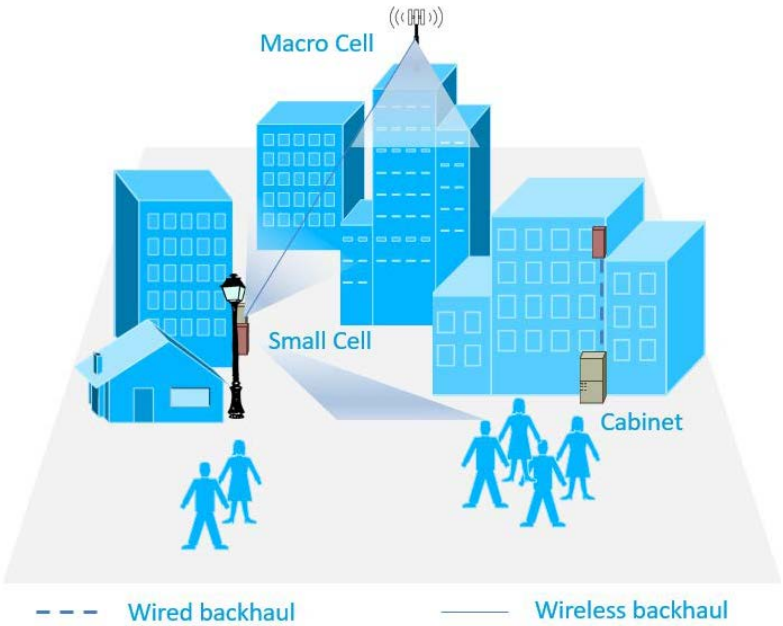

Figure 27: Heterogeneous 5G mobile networks

With 5G, the use of higher frequencies, namely 3.6 GHz and 26 GHz, will be essential to achieve higher data rates at the expense of having to deploy a larger number of smaller cells due to the shorter transmission range that higher frequencies can achieve. This problem is further exacerbated when indoor 5G coverage is considered, due to the energy-efficient materials that are used in the newer buildings that cause significant signal attenuation. Although the use of lower frequencies for 5G transmission could be a remedy, this would lead to a significant reduction of the provided capacity, thereby losing some of the advantages offered by 5G. Thus, the deployment of indoor small cells seems to be the only viable solution.

With 5G it is expected that the deployment of a large number of macro and small cell antennas will be required to accommodate the increasing demand for capacity. Past regulatory practice was generally based on the requirements of physically larger high-power macrocells. This approach might not be appropriate in the case of networks with smaller cells.

Regulations to consider are of different types such as:

- Approvals for site usage and deployment, such as building permits and rights of way
- Infrastructure and spectrum sharing rules
- Access to public infrastructure or urban furniture
- Health and safety rules

Apart from operators, vendors and regulators, several stakeholders, such as municipalities, landlords and real estate developers, will see their role changing in the 5G era, as issuers of permits, issuers of rights of way or infrastructure owners. Thus, deploying 5G networks will involve not only installing more antennas, but also accommodating for the new role of existing ecosystem players, while ensuring a fine balance between competition and investments. To satisfy the above conditions and achieve a smooth transition to 5G, a flexible and evolutionary regulatory framework which promotes simplified processes and accelerates network deployments could be necessary, a requirement which is also aligned with Action 4 of the 5G for Europe Action Plan[15] that recommends to:

"...identify immediately actionable best practice to increase the consistency of administrative conditions and time frames to facilitate denser cell deployment, in line with the relevant provisions of the proposed European Electronic Communications Code."

5.2. Considerations along the network deployment phases

Network deployments consist of several phases from equipment certification and permissions to design, planning, installation and network optimisation. Each of these phases contains a degree of complexity that can cause delays and / or increase the deployment cost. Figure 28 shows a simplified deployment process along with the complexities in each deployment phase. Generally, the greatest bottlenecks exist in the site identification and building and planning permissions phase. Equipment certification and approval and network installation phases are a bit less cumbersome. Finally, the operators find the network design and planning and network optimisation phases the less complex.

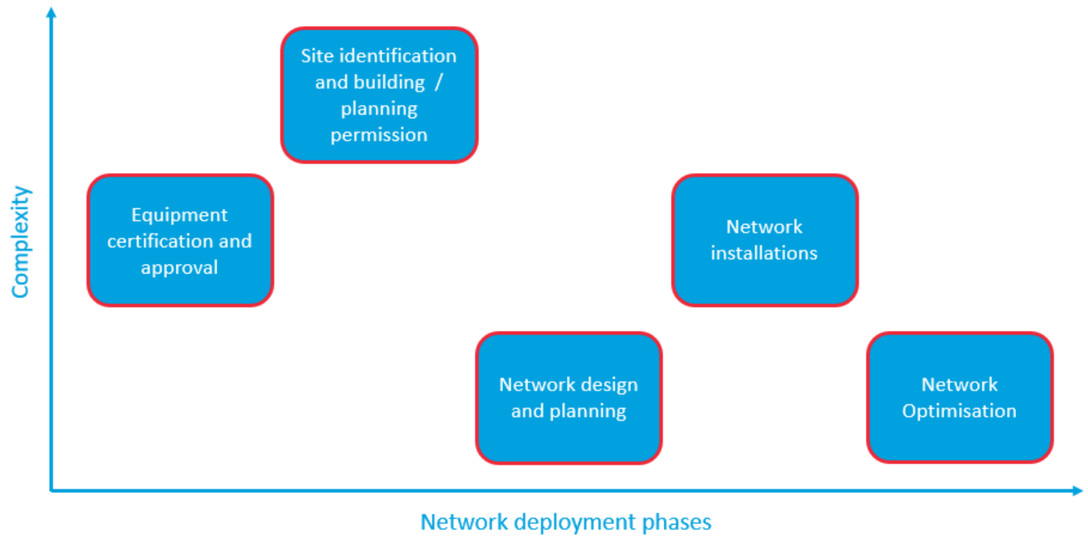

Figure 28: Bottlenecks across the different deployment phases

[15] http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=17131

The increased complexity that 5G network architecture will introduce will likely cause additional complexity for the operators. Hence, a review exercise that will tackle those issues should be considered to facilitate a smooth transition to 5G.

5.2.1. Certification and Permits

A first step towards deployment facilitation could come through a simplification of the procedures related to the required permission for the network equipment installation. To ease the deployment of a large number of 5G cells, it could be considered to favour an easily repeatable and replicable process. For instance, the height of the installed antenna and/or the Effective Isotropic Radiation Power (EIRP) metric are already used in many countries as criteria for exemption or simplification of the procedures.

Indicative examples of metrics used as thresholds for the need for declaration or installation permission are:

- Antenna height: Canada (15m), Germany (10m), the Netherlands (5m), France (12m), United Kingdom (4m/15m)
- Power level: Chile (low power), France (up to 5W simple declaration is needed), Japan (low power type approved, 20mW), Malaysia (EIRP of 2W), Germany (10W)
- A combination of height and power: United States
- Regional-based simplified procedures: Spain

In particular it could be examined if the installation of small cells can be facilitated, taking into account their relatively small size and visual impact. In the US, according to FCC rules, small cells can be exempt from environmental assessment in case they meet certain size and visibility criteria. In addition, the FCC has set time limits for the authorities to decide on permit applications in case of collocation (90 days) and new installations (150 days). In a radical move, the UK has removed all restrictions for placing small cell antennas on commercial buildings/structures to support mobile rollout. This has simplified network investment considerations for the MNOs which now can expand their 4G mobile networks for 4G and better prepare for 5G.

The relevant public authorities should work together closely with a view to simplify administrative procedures, reduce delays and lower the cost for operators while protecting the general public interests involved.

5.2.2. Electricity

One of the biggest difficulties that the industry will face with 5G installations is the need for electrical power on each cell site. To tackle this problem, the authorities could facilitate the deployment of small cells near sites with electrical power like bus shelters, lights or buildings. To address this potential problem, operators are investigating off-grid network deployments including power over Ethernet, the construction of power generators or the use of renewable energy sources suitable for isolated installations in remote areas.

On top of the above-mentioned problems, stakeholders in Luxembourg highlighted that the necessity to deploy an electricity meter for each small cell installation would increase both the complexity and deployment costs considering the number of small cells that will need to be installed.

5.2.3. Environmental issues

Organisations like WHO have issued recommendations and suggested limits for the allowed radio frequency exposure that are also endorsed by the EU Council Recommendation No 1999/519.

In Luxembourg, the current regulation states that at any place where people could be present in normal circumstances, the operator shall not produce a field strength above 3V/m. This limit applies to one “radiating element”, i.e. per antenna. However, the interviewed stakeholders have raised doubts whether the existing radiation limit will still be relevant when 5G networks are introduced. The larger number of sites along with the use of intelligent antennas (MIMO and beamforming techniques) may result in higher power levels when and where it is needed and lower levels once the use is reduced. The new technology could trigger an adaptation of the regulatory framework, while still taking the principle of precaution into account.

5.2.4. Access to public infrastructures

The need to deploy more antennas and new network equipment will be accompanied by issues associated with gaining access to sites and infrastructure as well as with backhauling. These issues should be addressed during the network planning stage to avoid impeding 5G network deployments.

As per the conversations with the 5G stakeholders in Luxembourg, locating new available installation sites and agreeing on the contract terms with landlords is a very lengthy and cumbersome process. Thus, access to public buildings, furniture and lamp posts can significantly accelerate the deployment of 5G networks and especially small cells networks. Access to passive infrastructure, however, such as ducts and masts will also be required. Although access rights were explicitly defined in “Loi du 27 février 2011”, there is still space for improvement especially in the regulation referring to street lamp posts and furniture.

Addressing the need for backhauling for the selected sites will also be important. Although an alternative solution with microwaves has been suggested, this technology depends on weather conditions, as it can be impacted by heavy rainfall. Thus, access to fiber, depending on availability, will be necessary to address the need for backhauling. The high density of the existing fiber network in Luxembourg constitutes an advantage that should be used for 5G deployment.

5.2.5. Spectrum

Timely availability and price of spectrum will be critical factors for the deployment of 5G. Hence, it is essential to set up a roadmap for the grant of spectrum and to investigate solutions beneficial for both the regulator and investors. A ‘spectrum fee holiday’, that is to provide free access to spectrum for a predefined period provided that spectrum owners invest in 5G could be among the potential regulatory considerations.

5.3. Current regulatory initiatives

The Government has already introduced some reforms in Luxembourg facilitating the investments in next generation networks, including:

- Legislation for cost reduction, motivating operators to cooperate on civil works (obligations of transparency, register of civil works, etc - “Loi du 22 mars 2017; arts 3 – 7”). Although this legislation was passed to facilitate fiber deployment, the framework of the legislation is wide-enough to make it applicable to mobile deployments.

- Legislation for access rights (“Loi du 27 février 2011”). This legislation defines the access rights to both the State’s and telecom operators’ passive infrastructure as well as to public buildings, roads etc.

The above-mentioned legislations coupled with the existing Government strategy for high-speed internet, have resulted to a far-reaching fiber network in Luxembourg which will facilitate the smooth transition to 5G.

Despite Luxembourg’s progress in the recent years, several obstacles, such as those mentioned above, must be tackled for Luxembourg to be amongst the leaders in the 5G era. Space for improvement exists in the network planning and regulatory frameworks. The implementation of 5G pilots will also allow to further assess those issues and to develop appropriate remedies in cooperation with all the stakeholders.

6. 5G Funding Schemes

Investments in the development of mobile networks, that are usually driven by the private sector, might need to be complemented by public investments when they contribute to the achievement of the EU 5G connectivity targets. In most cases, there is no necessity to finance the full network, but rather focus on strategic and/or re-usable pilot deployments assuring the overall “5G readiness” and motivating further private investments. Having identified the potential benefits of 5G, the Government considers the option to co-fund the development of relevant pilot testbeds across the country.

To this end, the Government intends to earmark an amount from the National Budgets 2019-21 that will be allocated to the development of 5G networks based upon the outcome of further analysis. A possible scenario would be that the Government would hold a tender through Public-Private Partnership (PPP) for all interested parties to submit their applications for the development of pilots (as those are outlined in Chapter 3, or any other proposal for a pilot testbed) with strong potential socioeconomic benefits for Luxembourg. The 5G early deployment pilot selection process would evaluate the social, economic, financial and technical soundness of the submitted applications. The earmarked budget allocation decisions across the selected pilots will be made at a later stage. The agreed pilot funding scheme will be designed under EU rules and State aid Commission guidelines, where applicable.

6.1. Public-Private Partnership (PPP) model for pilot deployment in Luxembourg

The model which is to be followed is a PPP whereby the Luxembourg Government and the private partners would co-invest - possibly with other interested parties - on the deployment of the selected pilots. The PPP model on the deployment of broadband networks is used either in cases where deploying a network is uneconomic for the network operators or when the state wants to boost future investments on innovative technologies, like 5G. Many forms of PPP exist, depending on the nature and unique project characteristics, but their main defining feature is the degree of control and involvement of the private party. Figure 29 illustrates some indicative types of PPP models.

In a PPP model, a new company is usually created in the form of a Special Purpose Vehicle (SPV) and is responsible for the deployment and management of the pilot. The SPV must sign an agreement with the public body, describing specific terms and processes that the deployment and operation of the pilot will have to be compliant with. The proposed agreement reflects the extent to which both parties share the investment risk.

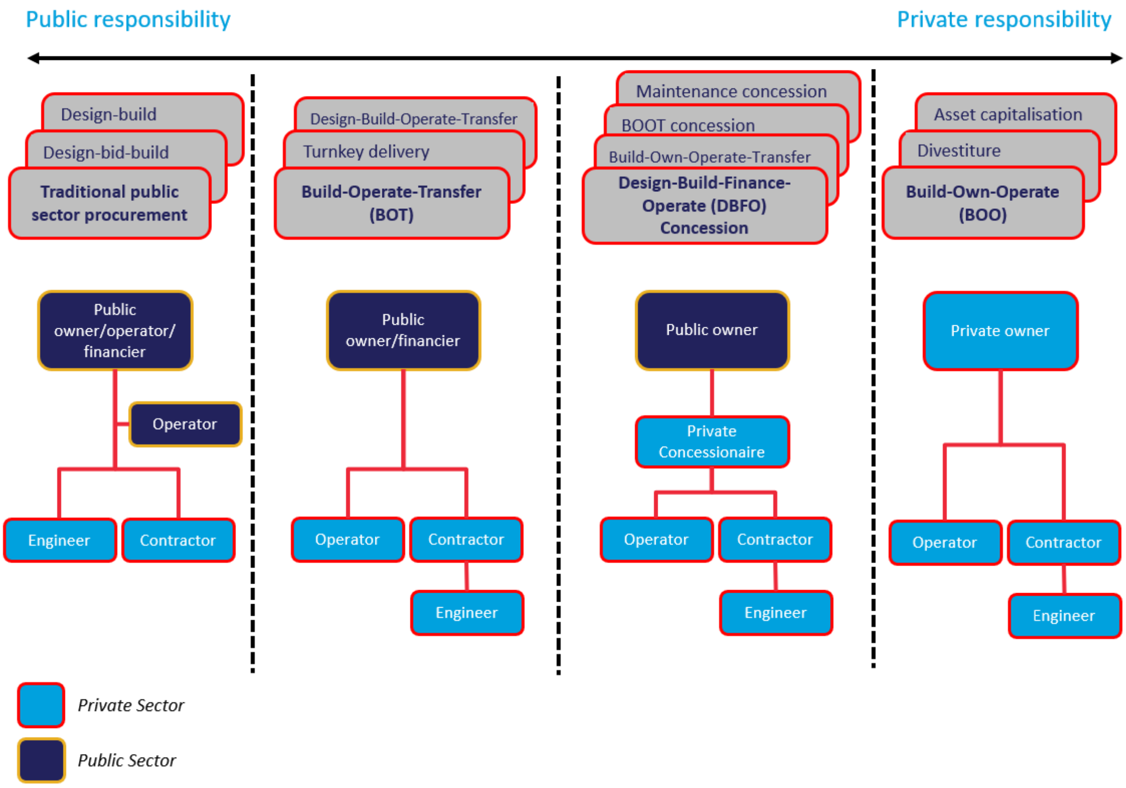

Figure 29: Project procurement options, (European Commission)

The process for the PPP model should be well defined and followed precisely to avoid delays. The process is broken down into several stages, in which the PPP is iteratively developed and appraised throughout the process, while government approval at every key stage is needed. Figure 30 summarises the end-to-end PPP process.

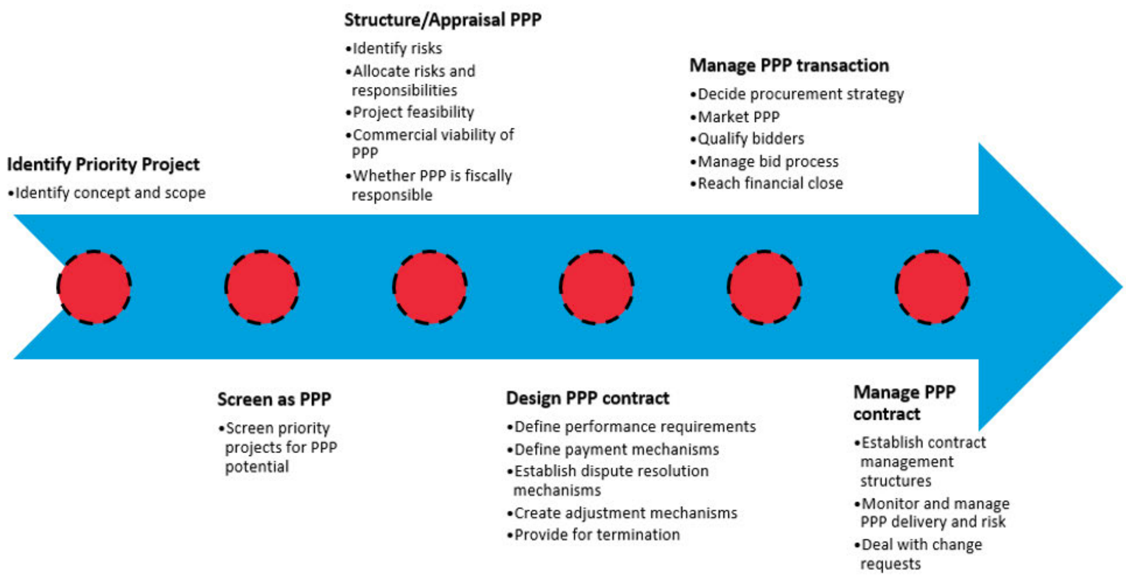

Figure 30: PPP process stages, (inCITES Consulting)

The deployment of 5G pilot testbeds in Luxembourg belongs to the above categories as the network will initially be used purely for testing and not for commercial purposes, thus, not generating any revenue. After the testing period, the first years of the commercialisation period, the take-up of 5G is forecasted to remain at low levels, as shown in Figure 25, likely leading to a non-profitable commercial network operation. These anticipated uneconomic conditions should be justified before the initial negotiations between the public and private parties begin, using appropriate tools, such as socioeconomic, techno-economic and/or cost-benefit analyses.

The Government's eventual aims is for the funded 5G pilots to become part of the future nationwide network, while driving private investments in 5G. Hence, the most appropriate PPP model is the Build-Own-Operate (BOO), which leverages the operators' expertise without the need to transfer the pilot network to the Government at the end of the PPP contract. In a BOO model, the ownership of the end solution remains with the private party.

6.2. Funding sources

Although the Government is seeking to fund the pilot deployment, alternative funding sources, such as EU funds should also be investigated. Should the Government receive funding from EU funds, the project will have to be supported by the JASPERS team, a partnership between the European Commission (Directorate General for Regional Policy), EIB, European Bank for Reconstruction and Development (EBRD) and Kreditanstalt für Wiederaufbau (KfW). In case the private party is interested in funding its part with a loan, the Government may endorse the loan application to either a commercial bank or any other European institution.

The European Fund for Strategic Investments (EFSI) regulation[16] facilitates the establishment of investment platforms under EFSI as a tool to pool investment projects with a thematic or geographic focus. The establishment of these investment platforms responds to the growing demand for financing of smaller-scale, higher-risk broadband projects across Europe, which currently do not have access to EU finances.

In December 2016, the EIB and European Commission announced the development of the Connecting Europe Broadband Fund, dedicated to the development of broadband infrastructure across the EU. The Fund is the first investment platform to support broadband infrastructure under the EFSI, which is the central pillar of the Investment Plan for Europe. The investment platform is also open to the participation of private investors.

EIB funding is also a supportive financial tool for the operators that can be combined with any other public funding source or the PPP process. In fact, in the last decade the EIB has approved several loans for the development of telecommunication networks for 5G and other broadband technologies.

[16] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2015.169.01.0001.01.ENG

7. Summary and Recommendations

This expert report underpins the Government's overarching aim to become a frontrunner with regards to 5G deployment. It is believed that 5G will be highly beneficial both directly for the citizens who will get access to new and more advanced services and the overall economy of Luxembourg.
Leveraging the technology capabilities it promises to deliver, 5G will bring several enhancements in medical support, assisted living, social mobility, transport management and environmental considerations amongst others. 5G will also drive digitalisation of the vertical industries, creating a more inclusive and connected economy, paving the way for new growth opportunities and concrete quality of living improvements for the citizens. The Government considers 5G to be key in enabling increased productivity and business innovation, drive the creation of new jobs and attract new investments in the country.

To be in line with the European roadmap, several potential early 5G deployment pilots were identified through a series of discussions with 5G ecosystem stakeholders, taking into account the criterion of socioeconomic benefit maximisation for the country. The final selection of the pilots that will be deployed and the amount of public funds that will be allocated to them will be defined at a later stage. The 5G early deployment pilots should trigger the interest of several stakeholders that will investigate further any operational and regulatory challenges that must be tackled for the mass deployment of 5G. These challenges will be constantly re-evaluated during the pilots as our understanding for these issues improves.

However, several issues that should be addressed prior to the deployment of 5G networks have already been identified from the discussions with the 5G stakeholders, leading to the following list of recommendations for those they may concern:

- **Recommendation 1: Facilitate the timely availability of spectrum**
  - Tackle interference issues with existing spectrum users
  - Make spectrum available in the 5G bands according to the pan-European roadmap
  - Address synchronisation issues with other networks, including those with neighbouring countries

- **Recommendation 2: Provide incentives for investments in 5G**
  - Provide co-financing of initial pilots for early 5G deployment in strategic areas
  - Consider a spectrum fee model that encourages investments in new networks

- **Recommendation 3: Process simplification that reduces administrative complexity**
  - Streamline and digitise paperwork to minimize the approval processes and reduce their total duration
  - Consider procedures under which certain groups of network equipment can be exempt or subject to fast track approval
  - Allow for per group (vs. site-by-site) installation permissions and agreements

- **Recommendation 4: Facilitate the reduction of incurred costs**
  - Reduce the application complexity to avoid additional overhead costs
  - Reconsider the need for certain post-installation measurements with a view to replace it with a simple declaration of compliance coupled with occasional controls to ensure ongoing compliance
  - Encourage the use of fibre for backhauling
  - Consider a proportionate fees regime for site rental to ease the deployment of a larger number of antennas

- **Recommendation 5: Alleviate public concerns**
    - Pursue efforts regarding transparency by making the authorisations and measurement results publicly available
    - Increase public awareness of the benefits of 5G

- **Recommendation 6: Address any environmental considerations**
    - Promote network densification with small cells to ensure low radiation levels
    - Re-evaluate the accuracy of the limit of 3V/m, considering the new technological developments along with the potentially large number of intelligent antennas using MIMO and beamforming techniques

- **Recommendation 7: Increase the availability of sites with power and backhaul**
    - Facilitate access to lamp posts, street furniture and public buildings
    - Facilitate additional deployment and access to fibre

Appendix I: International activities

A number of countries are striving to be leaders in 5G network deployment to have a head start in the race to the future. South Korea, Japan, Australia and China are at the forefront of 5G research in Asia, US leads the way in the Americas, Qatar and Saudi Arabia in Middle east while Finland, Sweden, Norway, Switzerland, UK and France have prepared themselves well for the next generation of mobile technologies. Outside the funding provided for 5G research on a national level, regional level funding and inter-country level cooperation consortia have also been formed.

I.1. Asia

Asian countries have a tradition in being pioneers in developing and embracing new technologies. 5G will be no exception. South Korea, Japan, China and Australia amongst other Asian countries have been at the forefront of 5G research and development with major operators within those countries planning to launch 5G networks as early as 2019. Additionally, 5G research cooperation between some of those countries has been very strong, with the ICT ministers of South Korea, Japan and China agreeing to collaborate on the standardization and commercialisation of 5G, reducing roaming fees between the three countries and facilitating the deployment of 5G and other advanced technologies for the 2020 Summer Olympics in Tokyo and the 2022 Winter Olympics in Beijing.

I.2. Europe

The European Commission (EC) has made a significant effort to facilitate the uniform and swift transition to 5G for all member-states . They have aligned their roadmaps leading up to the launch of 5G networks, which has been made possible through the European Commission's 5G Action Plan for Europe, which has been supported by all major network operators in Europe who signed a '5G Manifesto[17]' in July 2016. In terms of timelines, the EU has set the following targets:

- Launch pre-commercial 5G trials in 2018 followed by the launch of early 5G networks in the same year
- Encouraging member states to develop national 5G deployment roadmaps
- At least one major city in each member-state must have a commercial 5G network by end-2020
- All urban areas, major roads and railways to have uninterrupted 5G coverage by 2025

These targets are supported through a variety of policy, regulatory and financing measures and all member states have gradually adopted National Broadband Plans in order to develop an effective broadband policy and properly plan public interventions in the telecommunications sector.

The European Commission has founded the 5G Infrastructure Public Private Partnership (5G-PPP) together with industry manufacturers, telecommunications operators, service providers,

[17] http://telecoms.com/wp-content/blogs.dir/1/files/2016/07/5GManifestofortimelydeploymentof5GinEurope.pdf

SME and researchers whose purpose is to deliver 5G solutions, architectures, technologies and standards. 5G-PPP projects will be implemented in three phases:

- Phase 1 was completed in mid-2018 and it was focused on research and specifications
- Phase 2 aims to contribute to the development, testing and optimisation of 5G technologies for industry verticals. Projects of this phase started at June 2017
- Phase 3 will deliver large-scale pan-European trials as per 5G-PPP's '5G Pan-European Trials Roadmap[18]', which comprises four main categories, namely, 5G Private Trials, 5G Vertical Pilots, 5G Platforms and 5G Trials Cities, leading to the flagship pan-EU flagship event, Euro 2020. Phase 3 breaks into three parts: Part 1: Infrastructure projects, that have started on July 2018, Part 2: Automotive Projects where the results will be announced on August 2018 and Part 3: Advanced 5G validation trials across multiple vertical industries in which projects are expected to begin on summer 2019.

Regarding non-EU countries, Switzerland and Russia have made the most significant progress in terms of 5G development. In Switzerland, a major network operator is planning to launch a 5G network in late-2018, though it is still unclear if device manufacturers will have launched 5G-enabled devices before 2019, in which case the operator will not be able to start recouping its investment immediately. In Russia, there are several research centers dedicated to research and development of 5G networks, with the most major one being the National Research and Development Institute of Technology and Communications (NIITS). Several major Russian operators are aiming to launch 5G networks by 2020.

Outside the aforementioned initiatives, the Nordic countries, namely, Sweden, Iceland, Denmark, Finland and Norway, together with Lithuania have signed a Letter of Intent[19] to cooperate in 5G research and development, committing in making their region 'the first and best interconnected 5G region in the world'.

I.3. Americas

In the Americas, operators in the US have been amongst the first operators globally to outline their plans for commercial 5G deployment, with all four operators, namely, Verizon, T-Mobile, AT&T and Sprint being very aggressive in their 5G research and development efforts. In addition to the operators' willingness to invest in 5G, the regulator (Federal Communications Commission - FCC) sees 5G as an opportunity to drive growth not only for the telecoms industry but for the economy as a whole. As a result, FCC has created an investment-conducive framework for operators with three main pillars, namely, spectrum, infrastructure and backhaul network, paving the way for operators to deploy 5G networks with the minimal possible effort. Canada aims to launch 5G not earlier than 2020, while other countries in the region, like Brazil and Mexico are also preparing for commercial 5G launches in late-2019 / early-2020.

Research collaboration amongst the different players in the region is also very strong through the 5G Americas organisation. 5G Americas is an industry trade organisation comprising all major telecom operators, service providers and device manufacturers operating in the region. Its mission is to foster the advancement of LTE networks and their evolution to 5G, throughout the ecosystem's networks, services, applications and connected devices.

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[18] https://5g-ppp.eu/wp-content/uploads/2017/05/5GInfraPPP_TrialsWG_Roadmap_Version2.0.pdf

[19] https://ec.europa.eu/digital-single-market/en/news/nordic-countries-sign-letter-intent-be-forefront-5g-development

I.4. Middle East and Africa

In Middle East and Africa, 5G development is primarily driven by the Gulf states. Specifically, Qatar, Saudi Arabia and UAE have been at the forefront of 5G development, with Ooredoo Qatar claiming to be the first company in the world to launch a commercial 5G network on the 3.5GHz spectrum band in May 2018, concurrently with Etisalat in UAE and Saudi Telecoms Company in Saudi Arabia. Other countries in Middle East and Africa are also trialling 5G, such as Bahrain, Kuwait, Ghana and South Africa though they are not as aggressive as Qatar, Saudi Arabia and UAE in terms of launch timelines.

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Appendix IV - Abbreviations

3GPP - 3rd Generation Partnership Project

5G PPP - 5G Infrastructure Public Private Partnership

AR - Augmented Reality

ARPU - Average Revenue Per User

ASP - average selling price

B2B - Business-to-Business

BOO - Build-Own-Operate

BOT - Build-Operate-Transfer

CAGR - Compound Annual Growth Rate

CAPEX - Capital Expenditure

DAE - Digital Agenda Europe

DBO - Develop-Build-Operate

EBRD - European Bank for Reconstruction and Development

EC - European Commission

EFSI - European Fund for Strategic Investments

EIRP - Effective Isotropic Radiation Power

eMBB - enhanced mobile broadband

FCC - Federal Communications Commission

ICNIRP - International Commission for Non-Ionizing Radiation Protection

IoT - Internet of Things

ITM - Inspection du Travail et des Mines

ITU - International Telecommunications Union

KfW - Kreditanstalt für Wiederaufbau

LED - Light Emitting Diode

LIST - Luxembourg Institute of Science and Technology

LISER - Luxembourg Institute of Socio-Economic Research

M2M - machine-to-machine

MBB - Mobile Broadband

MEC - Mobile Edge Computing

MIMO - Multiple Input Multiple Output

mMTC - massive machine type communications

MNO - Mobile Network Operator

MVNO - Mobile Virtual Network Operator

NFV - Network Function Virtualisation

NIITS - Russian National R&D Institute of Technology and Communications

NPBIs - National Promotional Banks and Institutions

NSA - Non-Standalone

OPEX - Operational Expenditure

PPDR - Public Protection and Disaster Relief

PPP - Public-Private Partnership

RAN - Radio Access Network

RSPG - Radio Spectrum Policy Group

SA - Standalone

SDN - Software Defined Network

SLA - Service Level Agreement

SnT - Interdisciplinary Centre for Security, Reliability and Trust

SPV - Special Purpose Vehicle

TEN-T - Trans-European Transport Network

UoL - University of Luxembourg

UR-LLC - ultra-reliable and low-latency communications

V2I - Vehicle to Infrastructure

V2V - Vehicle to Vehicle

VLC - Visible Light Communications

VR - Virtual Reality

WHO - World Health Organisation

Appendix V: List of strategy report participants

List of stakeholders who agreed to share their views on 5G in Luxembourg:

- Broadcasting Center Europe
- Cegecom
- Chemins de Fer Luxembourgeois
- Dense Air Ltd
- Eltrona Interdiffusion S.A.
- Ericsson
- Huawei
- Institut Luxembourgeois de Régulation
- Luxconnect
- Luxinnovation
- Malo Capitals and Consulting S.A.
- Ministry of Economy
- Ministry of Environment
- Ministry of Health
- MTX Connect
- Orange Luxembourg
- Post
- Société Européenne des Satellites
- Tango
- Université du Luxembourg - Centre Interdisciplinaire pour la Sécurité, la Fiabilité et la Confiance (SnT)
- Ville de Luxembourg
- Zero1

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