Perspectives on Vertical Industries and Implications for 5G

by NGMN Alliance

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Abstract

The NGMN 5G White Paper, published in February 2015, outlines, among other things, a wide range of use cases, and discusses the requirements or the required considerations and studies in enabling them. In order to fully realize a sustainable ecosystem, both technical and economic realities need to be carefully assessed. This includes a prominent focus on "Verticals" requirements of 5G, in growing interaction with, engagement of, and input from the Verticals industries. This paper highlights the technical requirements for a number of selected use cases across the vertical industry and the external factors that need to be addressed to make these use cases economically viable. In particular, use cases from the automotive, transport and logistics, health and wellness, smart cities and utilities and agriculture industries are described together with an assessment of roadmaps/ maturity, relevant telco roles, external dependencies, necessary capabilities and outlook. Common themes emerge in terms of the required capabilities to support the use cases, the relevant roles that telco operators could play and also external dependencies that must be taken into account.

Some use cases are already implemented to some extent based on existing technologies and are supported by an evolving ecosystem and a growing understanding of viable business models. Other use cases are not mature yet and require some time to develop the business models and ecosystems. At the same time, existing technologies are evolving to improve or enable some of the required capabilities (e.g., support for massive number of low-cost low power devices). Thus, the required capabilities that must be supported by a new technology as well as the timing of those capabilities must also take into account the evolution of existing technologies as well as the anticipated maturity of the use cases that will depend on those capabilities. NGMN anticipates that the insights presented in this paper will help facilitate a healthy debate on the scope and timing of key 5G capabilities and to create the necessary ecosystems to address the relevant opportunities.

Contents

LIST OF ACRONYMS

AAA	Authentication, Authorization, and Accounting
AR	Augmented Reality
bCall	Breakdown Call
CAGR	Compound Annual Growth Rate
CAM	Cooperative Awareness Message
CAMP	Crash Avoidance Metrics Partnerships
C2C-CC	Car to Car Communication Consortium
D2D	Device-to-Device
DENM	Decentralized Environmental Notification Message
DoT	Department of Transportation
DSRC	Dedicated Short Range Communication
eCall	Emergency Call
eHealth	Electronic Health
eMBB	Enhanced Mobile Broadband
ETC	Electronic Toll Collection
FTTH	Fiber to the Home
GDP	Gross Domestic Product
HARQ	Hybrid Automatic Repeat Request
HD	High Definition
HEW	High Efficiency WLAN
HEVC	High Efficiency Video Coding
ICT	Information and Communications Technologies
IIC	Industrial Internet Consortium
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technology
ITS	Intelligent Transportation System
LAN	Local Area Network
LPWA	Low Power Wide Area
MBB	Mobile Broadband
MEC	Mobile Edge Computing
mHealth	Mobile Health
MTC	Machine Type Communications
mMTC	Massive MTC
MNO	Mobile Network Operator
OTT	Over-The-Top
PAN	Personal Area Network
PHY	Physical Layer
PKI	Public Key Infrastructure
QoS	Quality of Service
RF	Radio Frequency
RFID	Radio Frequency Identification
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
UNECE	United Nations Economic Commission for Europe
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle

V2X	Vehicle to Anything
VR	Virtual Reality
uMTC	Ultra-reliable Machine Type Communication
WAVE	Wireless Access in Vehicular Environment
WLAN	Wireless Local Area Network
xMBB	Extreme Mobile Broadband

1 INTRODUCTION

The NGMN 5G White Paper, published in February 2015 [1], outlines, among other things, a wide range of use cases, and discusses the requirements or the required considerations and studies in enabling them. In order to fully realize a sustainable ecosystem, both technical and economic realities need to be carefully assessed. This includes a prominent focus on "Verticals" requirements of 5G, in growing interaction with, engagement of, and input from the Verticals industries. This paper highlights the technical requirements for a number of selected use cases across the vertical industry and the external factors that need to be addressed to make these use cases economically viable. In particular, use cases from the automotive, transport and logistics, health and wellness, smart cities and utilities and agriculture industries are described together with an assessment of roadmaps/ maturity, relevant telco roles, external dependencies, necessary capabilities and outlook. NGMN anticipates that the insights presented in this paper will help facilitate a healthy debate on the scope and timing of key 5G capabilities and create the necessary ecosystems to address the relevant opportunities.

2 AUTOMOTIVE INDUSTRY

With the advent of electric vehicles and a steady progress towards highly automated driving, the industry is undergoing a transformation that could redefine the roles of existing players and create opportunities for new entrants.

2.1 Key drivers of industry change

Four key themes, namely, safety, comfort, efficiency and changing demographics, are driving the transformation in the automotive industry.

- **Safety** – There is a strong interest from governments and the automotive sector to reduce traffic accidents, protect vulnerable road users (e.g., children, cyclists) and facilitate timely reaction in case of accidents (e.g., eCall).
- **Comfort** – The driver is most of the time doing routine tasks, preventing him/ her from attention to other activities, such as work related tasks, or simply relaxing. Comfort services support the driver in complex and tiring traffic situations and make driving more enjoyable.
- **Efficiency** – Efficient flow of traffic has the potential to improve road utilization, reduce fuel usage/ energy consumption, improve car utilization and reduce commuting time, thereby benefitting the environment and productivity.
- **Demographics** – Factors such as total cost of ownership, opportunity cost of driving time and ageing populations are negatively impacting traditional car ownership and usage models leading to the emergence of new mobility paradigms and business models.

2.2 Market prospects and roadmap

Over 1.1.15B cars were counted worldwide in 2013, and over 88M cars were sold in 2014 (China 22.49M, US 16.84M, Japan 5.56M), over 67M of which were sold by the top ten manufacturers (Toyota Group 10.23M, VW Group 10.14M, GM 9.92M). This implies average life cycle of a car could be around 13 years, and a feature newly mandated by regulations (e.g., eCall, V2X) could penetrate roughly 30% in 3 years in the total car market.

Trials for safety applications as well as highly automated driving are being conducted by various parties, e.g., automotive companies and OTTs, sometimes in collaboration with the government (e.g., US DoT) and telecom operators. It is anticipated that automated driving in the early stages will completely depend on car sensor information, without any cooperation among road users based on message exchange. Wireless communication (V2X) is expected to enhance traffic safety, road efficiency and driving comfort, by enabling collective perception and coordinated manoeuvre.

Some governments (e.g., US DoT, Strategic Innovation Promotion Program (SIP) in Japan) and industry consortia such as SAE, C2C-CC, CAMP, and Amsterdam Group, have defined roadmaps suggesting, among other things, that highly automated driving will hit the road around 2020, and mature towards 2025-2030. To realise such roadmap, uncertainties around the business ecosystem, infrastructure financing, and legal issues (liability) need to be clarified. To this end, UNECE approved new regulations in March 2016 to explicitly allow automated driving technologies that transfer driving tasks to the vehicle for use in traffic. It is expected that specific technical provisions for self-steering systems will be adopted by the World Forum for harmonization of vehicle regulations by 2017. Legislatives in several world regions have also recently started to revise and to amend the current legal situation. Further developments are anticipated to prepare the ecosystem aligned with the roadmap.

In addition, road side infrastructures already exist today for various purposes, e.g., tolling, traffic monitoring, license plate number detection, red light violation, and speed control. Various applications also exist today that could be categorized as “info-mediation” business, with examples being fleet management, vehicle maintenance, and geo-fenced ads. Those solutions are largely regionally dependent and proprietary, and are anticipated to grow in terms of diversity and adoption.

2.3 Ecosystem and key players

The automotive ecosystem could be described as shown in Table 1. Various players from different industry sectors, as well as regulators and governments, need to work closely together to bring all the benefits and enable sustainable businesses. Government policy can influence the market incentives for different types of vehicles. In addition, features that have impact on safety or the environment are heavily regulated, and regulators can mandate certain features in all vehicles. Car manufacturers may shift from traditional consumer sales models to mobility service provider business models. Platforms to manage and analyse dynamic data will become essential, supported by underlying telecom infrastructure.

Table 1: Automotive ecosystem

Domain	Function		Examples	Key players
Backend	Infotainment		Proximity information, audio/video streaming, navigation	OTT, car manufacturers, content providers
	Vehicle management (location, activity, diagnostics, etc.)		Fleet management, transport/ logistics optimization, border control, tolling, info-mediation/ financial services (after service, leasing, insurance)	Car manufacturers, rental car providers, fleet management companies
	Digital map, traffic management		Digital map provisioning/ distribution, traffic/ signal control	Governments, digital map providers, car manufacturers, OTT
	Security		PKI platform, AAA, firewall, DSRC Security Credential Management System (SCMS)	IT providers, telco operators
Communication infrastructure	Recognition	V2N	Infotainment, eCall, bCall, diagnostics, software update, digital map update, traffic information, road side information, PKI update	Telco operators, ITS providers, cities/ municipalities/ townships
		V2I	Reading ahead, cooperative control including merging and lane change could include infrastructure assistance, ETC	Governments, road operators, ITS operators, telco operators, auto manufacturers and their Tier 1 suppliers
		V2P	Reading ahead, cooperative control	Car manufacturers, telco operators, ITS providers, OTT
Vehicle		V2V	Reading ahead, cooperative adaptive cruise control and platooning, automated cooperative driving	Car manufacturers, suppliers, telco operators

		On-board sensors	Road, object recognition	Car manufacturers, suppliers
	Decision		Trajectory, control decision	
	Manipulation		Acceleration, braking, steering	
Road infrastructure	Roads		Highways, roads, parking, sign posts, traffic signals, tollgates	Road infrastructure operator (private/ public), general constructors

2.4 Relevant use cases

A large number of automotive use cases have been identified. These could be categorized mainly into the following six use cases.

1. **Assisted driving** – is to empower the driver with useful information (e.g., real-time maps for navigation, speed warnings, road hazards, vulnerable road users, video see-through systems, sensor sharing etc.) to manoeuvre the vehicle to achieve efficient traffic flow and/ or to prevent or minimize the impact of accidents. At least two components of telco relevance could be considered, i.e., V2N communications for mid/ long-term environment modelling (acquiring the latest digital map, including information on traffic signs, locations of traffic signals, road construction, and congestion) and V2X communications for short-term environment modelling (recognizing surrounding objects). For the mid/ long-term modelling, on board sensor data (e.g., video streams) can be uploaded to digital map servers, so that they can be analysed to detect pot holes, congestion, road conditions, free parking space, etc. Statistically reliable number of samples could be used to maintain the map data in the server, and combined with information from other sources (e.g., road authorities), the latest map can be downloaded to the vehicle to assist navigation. This will create intense real-time traffic on the V2N uplink. The downlink may not be intense due to the delta nature of dynamic map data, if the vehicle already has a relatively recent version of the map for its current location. For the short-term modelling, on board sensors play a major role, but V2X could expand the range of detection at difficult conditions, e.g., sight blockage at corners, by trucks, rain, or fog. Such V2X needs low latency and high reliability capabilities and a mechanism to dynamically associate devices with other devices in the vicinity, irrespective of the connectivity provider. Other components such as positioning, voice recognition, and augmented reality could facilitate these applications. An important factor that will shape the market potential of this use case is the legal framework for the types of information that can be displayed or announced toward the driver, and the liable entity if an accident is caused by providing wrong information.

2. **Autonomous/ cooperative driving** – enables driving functions to be taken over by the vehicle. Different levels of automation, with varying degrees of driver involvement can be envisaged culminating in full automation where recognition, decision-making and manoeuvring are performed solely by the vehicle. Fully autonomous vehicles can cooperate to different degrees ranging from information exchange about intentions (e.g., for overtaking) to fully synchronized driving where intentions are constantly exchanged and cooperative decisions are made and constantly updated (e.g., platooning). Similar to the assisted driving use case above, telcos could have relevant roles in V2N communications for mid/ long-term environment modelling and V2X communications for short-term environment modelling. In addition, a role in V2X communications for cooperative driving could be foreseen. Here, much more stringent requirements on security, latency, reliability and interworking (among different car makes, pedestrians, operators, etc.) need to be met. The extent to which current solutions on the verge of commercialization (e.g., WAVE/ DSRC, ITS-G5) could fulfil such requirements is still unclear. Also, realizing the full extent of benefits from cooperative driving depends on the availability of a critical mass of capable and compatible vehicles on the road (e.g., 40% penetration could achieve almost 90% of cooperative awareness gains according to recent studies). Regulatory mandate could be used to speed up the time to gain critical mass (e.g., 30% penetration in 3 years). But that also means that the mandated solution will be the de-facto standard due to network effects, making it difficult for late entrants to enter the market. Even with a regulatory mandate, autonomous vehicles will need to coexist with legacy vehicles. In this case some graceful degradation of autonomous driving capabilities (e.g., speed reduction) may be necessary to avoid accidents. Perhaps dedicated lanes (e.g., on motorways) or even road infrastructure for autonomous

vehicles may be needed. In addition, the legal framework for certification (e.g., ISO 26262) and liability in case of accidents could have big implications on the viability of telco involvement.

3. **Tele-operated driving** – enables operation of a vehicle by a remote driver. This covers both full remote driving as well as limited impasse arbitration cases for autonomous vehicles. Areas where full remote driving could find applications include disaster scenes, unknown/ unexpected terrains and environments where lives could otherwise be put in danger by manual driving (e.g., mining, construction, nuclear plants, etc.)[1, 2]. At least two components of telco relevance could be considered. First, V2N communications for reporting information obtained from the vehicle and its environment to the remote driver. This includes video and sound feeds from all directions, car diagnostics, motion vectors, etc. Second, V2N communications to reliably deliver control commands from the remote driver to the vehicle to manoeuvre the vehicle in real-time. Stringent requirements on latency, reliability, bandwidth (to stream multiple video feeds) and security need to be met to support this use case. The latency and reliability that are realistically achievable limit the maximum speed for safe operation. Thus, local and/or private environments where vehicle speed is reduced and there is limited or no interaction expected with passengers, pedestrians and standard vehicles are potential candidates for full tele-operated driving. For cases where tele-operated driving is limited to impasse arbitration, e.g., when an autonomous vehicle stops the car safely and waits for remote direction to get going again, the requirements on latency and reliability could be relaxed as the autonomous driving system ensures a certain level of safety. However, wide-area coverage will be required. Beside the technical requirements, the legal framework for certification (e.g., remote booths, drivers) and liability in case of accidents, will also impact the economic viability of this use case. For instance, ISO 26262 could imply a long time to market and some legal liability for telcos. For further study might be whether the legal issues are less complex when tele-operated driving happens within the confines of an enterprise (e.g., mining, construction, etc.).

4. **Info-mediation** – spans several domains that rely on processing information acquired from or reported by vehicles to provide services such as security (e.g., stolen vehicle tracking, border control), safety (e.g., eCall, bCall) and other value-adds like fleet management (car sharing, real-time tracking for logistics, scheduling and dispatching, etc.), toll charging, insurance, geo-fenced advertisement, and vehicle maintenance (e.g., over-the-air update of vehicle systems). Depending on the service, components for this use case could include positioning, diagnostics reporting, big data analysis, remote management/ control, interconnection with partners in the ecosystem (e.g., police, emergency services, insurance companies, etc.) and billing platform. Of these, V2N connectivity for reporting different kinds of information (e.g., vehicle diagnostics, load information, driver monitoring, etc.) and for remote management/ control could be relevant for telcos. The requirements would vary, depending on the service. Most services are currently offered using existing cellular systems. However, enhanced coverage (e.g., underground/ multi-storey parking) is required to enable info-mediation services even in challenging environments for mobile communication.

5. **Infotainment** – is about broadband connectivity to occupants of the vehicle for entertainment (e.g., video streaming, virtual reality, augmented reality) and productivity (e.g., video conferencing, in-vehicle office). With the advent of ultra-high resolution screens (4K, 8K) with adaptable form factors, the demands placed on bandwidth will be extremely high. This demand is expected to grow as assisted and autonomous driving enters the mainstream. Tethering to a smartphone is commonly used to provide broadband connectivity to a vehicle but penetration losses due to metallic glass affects the quality of the signal. The demand for higher data rates and a consistent user experience are likely to make tethering less attractive

[1] NGMN does not foresee tele-operated driving on public roads. Also, operation involving carrying passengers is not foreseen. The strict requirements on latency and reliability that would be required for safe operation would be too challenging to meet in such environments and for the foreseen vehicular speeds which cannot be tolerated for operation with passengers and/or on public roads. Just to give an example, if a control cycle needs to be achieved for 10 cm granularity, an end-to-end round trip latency of 7.2 ms needs to be achieved at 50 km/h. However, use of 60 fps HD video already consumes 16.7 ms and control messages at 100 Hz already consume 10 ms. As such, vehicle operation needs to be limited to very low speeds.

[2] In predictable and fully managed (private) environments, e.g., warehouses and harbours, autonomous driving could be more suitable and cost efficient.

in the future. There is also a trend to equip high-end vehicles with on-board connectivity modules (e.g., in-car Wi-Fi and LTE backhaul) and this could be expected in standard vehicles within the next five years. Solutions such as Wi-Fi based routers also exist to retrofit vehicles with such modules. A telco could provide the large bandwidth mobile backhaul to the vehicle. Different solutions, including Wi-Fi, could be used to provide the in-vehicle network that relies on this backhaul. Global coverage will be an important requirement in this use case. Complementary solutions such as on-board caching of library-type content could help but the efficiency of such solutions would depend on how the legal framework for content rights management evolves.

6. **Nomadic nodes** – equips vehicles with on-board small cells that can be integrated in the telco network to provide additional capacity and/ or coverage. V2N connectivity is required to provide the backhaul to the nomadic node. The last mile could then be served with cellular or Wi-Fi from the nomadic node. The actual capacity/ coverage gain of using nomadic nodes compared to traditional deployment models requires further study. Furthermore, the spectrum license that would apply in this case, i.e., whether to treat the nomadic node as a terminal or as a base station, needs to be clarified as it has implications on the practicality and costs of deployment.

From these analyses, at least the following four opportunities for 5G could be foreseen:

- V2N for mid/ long-term environment modelling (dynamic high-definition digital map update)
- V2X for short-term environment modelling (sensor sharing)
- V2X for cooperation (coordinated control)
- V2N for remote vehicle operation[3]
- Mobile wireless backhaul (addressed as part of eMBB)

2.5 Required capabilities

Table 2 lists the required capabilities to support the potential opportunities for 5G identified in the automotive industry.

Table 2: Capabilities required for relevant automotive use cases

Use case attribute	V2N for mid/ long-term environment modelling (dynamic high-definition digital map update)	V2X for short term environment modelling (sensor sharing)	V2X for cooperation (coordinated control)
Description	- Uploading of sensed data to servers for dynamic digital map update - Downloading of the latest digital map information	Expand detectable range beyond on board sensor capability by sharing views (e.g., raw sensor data) or detected objects (e.g., abstract object information) among traffic participants by V2X	- Coordinate trajectories among vehicles by negotiating over V2X (distributed control via V2V or centralized control via V2N/ V2I), e.g., for collision avoidance, overtaking, platooning, merging - For example, at intersections, it may be the traffic signal that collects information, makes coordinated decision, and commands control - Another example is to share detailed planned trajectory via V2X for collaborative driving - Another example is to share coarse driving intention (e.g., changing lanes or moving/ stopping/ parking in T sec at [x,y,z]) for changing lanes, merging at highway and roundabout, crossing at 4-way stop and have consensus among all involved vehicles via V2X
Need for 5G	5G	5G	5G

[3] The requirements for this are still under discussion in NGMN and will appear in the subsequent deliverable

Experienced data rate	- 10-45 Mb/s uplink - Uplink intensive if analysis/ abstraction is done by the server side based on raw data (e.g., video), not if analysis/ abstraction is done by the vehicle side - H.265/ HEVC HD stream: ~10 Mb/s LIDAR: ~35 Mb/s (6 vertical angles, 64 elements, 10 Hz horizontal rotation) - Data volumes to be downloaded can be huge, e.g., when downloading 3D map data for autonomous driving at country border, but as downloading can start well in advance, there is no concrete requirement on the DL rate	- 0.5-50 Mb/s per link, depending on the abstraction level of shared information, which may evolve over time - Detected object: ~0.5 Mb/s (60 byte/object, 100 objects, 10 Hz) - CAM/ DENM: few 100 byte/msg, 20 Hz (according to current standards) - H.265/ HEVC HD stream: ~10 Mb/s - LIDAR: ~35 Mb/s (6 vertical angles, 64 elements, 10 Hz horizontal rotation)	- 5 Mb/s per link - CAM/ DENM: few 100 byte/msg, 20 Hz (according to current standards - could increase for higher level of automation) - Planned trajectory: ~2.5 Mb/s (32 byte/coordinate, 10 ms resolution, 10 s trajectory, 10 Hz) - Coarse driving intention: ~0.05 Mb/s (few 100 bytes (e.g., 500 byte) /msg, 10 Hz)
Latency	Not critical (100 ms end-to-end seems to be tolerable) - Downloading may be for maps to be used 5 min later, and hence not time-critical	<20 ms end-to-end	- <3 ms end-to-end for platooning[4], [5] - <10 ms end-to-end for cooperative manoeuvres[6]. - <100 ms end-to-end for coarse driving intention - These requirements apply regardless of whether the messages are exchanged directly between vehicles (PC5 – sidelink) or via the infrastructure (Uu – uplink, core network and downlink). The exact latency budget for interfaces at different protocol layers will depend on the technical design.
Reliability (IP packet delivery within the latency bound)	Not critical	99% – 99.999% - Reliability requirements depend on the abstraction level of shared information. Low-level data (e.g., raw pixels from camera sensors) is more tolerant to errors, whereas high-level abstract data (e.g., objects recognized on the road) should be transmitted with very high reliability.	Critical (99.999%)

#Devices	- A sufficient number of cars needs to be supported for simultaneous downloading of map updates.
	- For uploading,
	  - No need for all cars to report. Sufficient to have statistically reliable amount of samples
	  - Amount of uplink reporting may be controlled by the server to protect from overload
		~10 (~100) in vicinity (few 100 m ~ 1 km), depending on traffic conditions (e.g., rush hour, motorway, etc.)	~10 (~100) in vicinity (few 100 m ~ 1 km), depending on traffic conditions (e.g., rush hour, motorway, etc.)

Battery	Not critical (cars have large batteries)	Not critical (cars have large batteries)	Not critical (cars have large batteries)
Coverage	Important	Important/ critical	Critical (for areas/ roads where

[4] It is important to consider the latency requirement, together with the reliability, data rate, and mobility requirements. This could be different per scenario and representative scenarios need to be elaborated in further studies.

[5] The latency requirement for platooning is more stringent, since the distance between the vehicles in the platoon is considered to be very small (in the order of few meters), but the relative speed may be considerably lower than other cases. Hence, the coverage (range) and mobility requirements may be relaxed, assuming direct exchange of messages among the platoon participants.

[6] The latency requirement for cooperative manoeuvres strongly depends on details such as the scenario and the driving situation. A latency requirement of 10 ms end-to-end (as an order of magnitude rather than an exact value) has been proposed by the automotive industry based on profound knowledge. This may translate into different air interface latency requirements, depending on whether the messages are exchanged directly between vehicles or via the infrastructure. In the latter, this could translate to a one-way radio PHY latency (excluding HARQ) in the order of 1 ms.

		- Up to 100 m – 1 km, depending on the vehicle speed, vehicle density and information exchanged	service is provisioned) - Up to 300 m range
Mobility	Up to 250 km/h ground speed on highway for V2N	Up to 500 km/h relative speed between vehicles on highway for V2V	- Up to 500 km/h relative speed between vehicles on highway for V2V - Up to 250 km/h ground speed on highway for V2N (V2I)
Interwork/ roaming	- Interwork and roaming needed for downloading of latest map - No need to support interwork/ roaming for uploading sensed data, as sufficient data can be collected from local participants	- Interwork needed so that devices in vicinity can communicate regardless of connectivity provider - Roaming needed as cars travel abroad	- Interwork needed so that devices in vicinity can communicate regardless of connectivity provider - Roaming needed as cars travel abroad
Security	Need data integrity and at least non-mutual authentication	Need data integrity, mutual authentication, confidentiality, user privacy	Need data integrity, mutual authentication, confidentiality, user privacy
Positioning accuracy	- <30 cm relative to other map objects; feasibility to be studied - Indoor positioning also needed, e.g., tunnels, parking	<30 cm (can be <10 cm in certain cases, e.g., parking, pedestrian); feasibility to be studied	- <30 cm (can be <10 cm in certain cases, e.g., parking, pedestrian); feasibility to be studied - <1 m for sharing coarse driving intention
Other capabilities		- Dynamic association of devices with other devices in proximity - D2D and multicasting/ broadcasting may be beneficial to optimize spectrum usage - Ensure earlier vehicles with only IEEE 802.11p based DSRC capability (760 MHz in Japan, 5.9 GHz in US, Europe) can communicate - Resiliency	- Dynamic association of devices in proximity - D2D or MEC may be needed to achieve low latency - D2D and multicasting/ broadcasting may be beneficial to optimize spectrum usage - Ensure earlier vehicles with only IEEE802.11p based DSRC capability (760 MHz in Japan, 5.9 GHz in US, Europe) can communicate - Resiliency
External dependencies		- Legal framework (liability) may take years to be established, e.g., applicability of ISO 26262 on telco networks - Regulatory mandate (influences IEEE 802.11p penetration and network effect)	- Legal framework (liability) may take years to be established, e.g., applicability of ISO 26262 on telco networks - Framework (e.g., separate road systems) for coexistence with legacy incompatible vehicles - Regulatory mandate (influences IEEE 802.11p penetration and network effect) - Device capability prospects, e.g., sensing/ control periodicity, processing latency (>14 ms predicted at 2025)
Other considerations	Some aspects of this use case are already happening today over 3/ 4G	3GPP has ongoing Work Item on LTE V2X and Study Item on 5G V2X	3GPP has ongoing Work Item on LTE V2X and Study Item on 5G V2X

2.6 Outlook

Telco operators have a strong competitive advantage to provide mobile backhaul services to sustain infotainment and productivity on the move. Telco operators could also support various info-mediation services, like vehicle diagnostics, fleet management, and geo-fenced ads, leveraging V2N. In addition, telcos could provide V2X services to support various communication needs (e.g., digital map download/ update, object recognition, information sharing) for assisted, autonomous and highly coordinated driving. As the automotive industry already started adopting DSRC (760 MHz ITS in Japan and 5.9 GHz DSRC in the US and Europe) for V2X, it is essential that vehicles with 5G V2X capability are also interoperable with "legacy" vehicles with only the current DSRC capability. Viable implementation models need to be studied further, also taking into account the long product lifecycle in the automotive market (i.e., 10 – 14 years), to enable higher levels of automation with 5G, while protecting the ongoing DSRC investments. Perhaps knowledge and experience of telcos in system migration could help in this regard.

The above cases require not only big technological strides in the next generation access technology but also clarity on several important issues. First, continuous coverage is necessary for the entire roads where these services are envisioned. But providing such wide coverage might come at a significant cost, which may not be justified by the potential revenues. Although other models could be considered, e.g., commercial network sharing, etc., the spectrum requirements for these models will need deliberate discussions among stakeholders, including also the government. Whether this will result in some viable and sustainable business models or remain solely as a public service is still unclear.

Second, uncertainties exist in the legal framework regarding liability for different entities in the autonomous driving value chain. The time to market, costs and risks for telcos will change significantly if telcos need to undergo certification (e.g., ISO 26262) and take on some legal liability in case of accidents (e.g., as a result of network unavailability or poor quality of service). In addition, cities need to be prepared for such a paradigm change. For example, cities need to provide sufficient parking spaces for shared autonomously driving cars, and establish road systems with clear sign posts where those services are provided. These issues could shape the realistic role of the operator in the automotive industry and needs to be carefully studied and understood.

3 TRANSPORT AND LOGISTICS

Several opportunities within the general paradigms of end-to-end flow optimization and just-in-time delivery are being unlocked in the transport and logistics sector by the availability of cheap computing and ICT resources, modern control systems and the proliferation of sensors with increasingly sophisticated capabilities. In particular, big data analytics coupled with reliable connectivity and appropriate interfaces between relevant players in the ecosystem can enable significant efficiency gains which can translate into a reduction in operating costs, better customer experience and new revenue opportunities.

3.1 Key drivers of industry change

The transformation in the transport and logistics sector is driven by three key themes:

- **Efficiency** –Efficient transport of people and goods has the potential to improve the capacity and utilization of transport infrastructure, reduce fuel usage, increase predictability, reduce losses and reduce commuting time, all of which will benefit productivity and the environment. The drive towards a complete transport and logistics chain which acts just in time aims to improve such efficiency gains and realize the subsequent benefits.
- **Safety** – There is a strong interest from governments and the transport and logistics sector to reduce transport-related accidents (including the protection of pedestrians, warehouse workers, etc.) and facilitate timely reaction in case of accidents.
- **Demographics** – Changing population (e.g., increasing population in urban areas, ageing population spread out in urban and suburban areas, etc.) creates opportunities for new and sustainable mobility paradigms for both people and goods. The overarching drive to facilitate and sustain economic growth also motivates both government and the industry to explore new models to cost-efficiently design, fund, build/ expand, integrate, operate and maintain the transportation infrastructure.

3.2 Market prospects and roadmap

Industry consortia such as Industrial Internet Consortium (IIC) are identifying best practices for using ICTs, sensors and big data analytics to improve efficiencies in different industries, including transportation and logistics. Tracking of goods and containers with the help of GPS modules is already considered mainstream. Big wholesalers and retailers also have proprietary solutions to improve inventory management. Standardization could further reduce the costs and increase adoption. The use of sensors and big data analytics to monitor the state of equipment (or goods) and provide insights into the life cycle (e.g., ageing) and optimum time for repair and replacement is seen as promising, and is already finding applications in the rail industry. It is expected that such technologies will also be adopted in many other industries due to the huge cost saving potential.

Within the framework of Intelligent Transportation Systems (ITS), several governments are also studying and/ or implementing legislation and policies to improve the efficiency of the transportation infrastructure. For example, the European Commission has already laid out a vision for a comprehensive and intelligent Trans-European Transport Network (TEN-T) covering infrastructure as well as communication systems between infrastructure and vehicles. The main corridors of TEN-T are anticipated to be operational by 2030 funded by a public-private partnership model. The cooperative ITS corridor spanning Austria, Germany and the Netherlands is serving as a pilot to harmonize the technical standards for such smart infrastructure.

3.3 Ecosystem and key players

In addition to the key commercial players, governments also play a crucial role in the provisioning of transport infrastructure through right of way and zoning laws, funding and other policies (e.g., environment). Through government policies and regulations, different transport modes (e.g., road, rail, air, sea) could exhibit specific advantages. Also, transport could span several national territories which require some degree of harmonization of rules and technologies to realize full benefits.

3.4 Relevant use cases

Some representative use cases with relevance for telcos in the transport and logistics industry are described below.

1. **Inventory and supply chain management** – focuses on the use of low-cost, low-maintenance sensors to track components in stock (e.g., in a warehouse) as well as to track the flow of goods throughout the supply chain (e.g., from raw material to delivery of final product) to enable efficiency gains possible with just-in-time awareness and delivery. For inventory tracking in a warehouse, for instance, devices with embedded sensors could upload information to a central cloud (e.g., ID, location, etc.) that allows determination of the stocking levels of various components in near real-time. Upon reaching a critical stocking level an order could be automatically placed with the supplier to replenish the stock just in time. In the supply chain, embedded devices could be used to track the raw materials through various stages of processing until the finished product and also throughout the delivery (e.g., shipping, delivery to warehouse, etc.) to the intended recipient. Big data analytics can help to eliminate areas of inefficiencies in the supply chain and increase predictability – a key component for just-in-time delivery. Components for this use case includes connectivity, a platform to collect and process the data as well as interconnections to other players (e.g., raw material suppliers, manufacturers, transport companies, etc.) in the ecosystem. Telcos could provide the connectivity as well as the platforms to collect and process big data. For the connectivity, uplink would be the most relevant but the data rate requirements of individual devices are not critical. Rather, connectivity support for a massive number of such devices is the key challenge. Another challenge is the tracking of goods without the need of an expensive GPS receiver in the device. This implies that the network should provide localization capabilities in combination with good coverage. Such devices may also be energy-constrained (e.g., due to very small sizes), necessitating the need for low-power network protocols to sustain them throughout their intended lifecycle. Currently, RFID technology is used for such inventory and supply chain management. Cellular-based technologies would need to facilitate easy migration and/ or coexistence to ensure proper end-to-end operation.

2. **Smart travel** – optimises the flow of commuters and improves the commuting experience by individualized information availability. For instance, commuters could be provided with connections opportunities at the next stop, the directions to the platforms/ stations/ gates for these connections and

integrated ticketing/ billing. Comfort and leisure resources (e.g., shops, bathrooms, etc.) together with proximity, status and directions could also be communicated in real-time. By aggregating and processing information from various sources (e.g., sensor/ smartphone data from many commuters) proper estimates of travel time, congestion at different facilities, etc. that take into account historical and prevailing real-time conditions could be obtained. Such optimization can also be used by airports and other transport hubs to better plan and optimize aspects such as layout and siting of facilities (e.g., shops, bathrooms). Components for this use case include positioning, big data collection and processing, connectivity and interfaces with other players within the ecosystem (e.g., payment processing, facilities management, traffic authorities, businesses, etc.). Telcos could play a role in connectivity provisioning and in providing/ processing data (e.g., estimates of number of people and trajectories) to facilitate the optimizations. However, the type of data that could be collected and processed as well as the intelligence that could be shared by a telco from the processed data may be limited by the prevailing regulations in the jurisdiction as well as local attitudes towards privacy. The requirements on data rates and latency would vary depending on the nature of the information transmitted as well as where data processing is performed. Using cloud services to process and transfer immersive AR to commuters would require higher data rates, especially if this is provided to many commuters at a hub. Coverage is also very important.

3. **Smart airport** – utilizes numerous sensors, big data analytics and communication technologies to automate different aspects of the operation of a modern airport to improve efficiency while delivering improved customer experience at lower cost. For instance, passenger handling operations such as ticketing, check-in, baggage drop-off, transfer, etc. could all be automated. Embedded sensors would enable real-time localization and tracking of baggage, parcels as well as (mobile) airport assets. Additionally, performance optimization and predictive maintenance of airport assets (e.g., ground support vehicles and equipment) and airline assets (e.g., airplanes) can be facilitated by means of embedded sensors and big data analytics. Exchange of information between the aircraft and the ground-based operational and maintenance teams could allow for maintenance issues to be handled as soon as the aircraft lands. Repair and maintenance could also be streamlined and accelerated by use of virtual/ remote assistance complemented with AR/VR applications. Though framed in the context of an airport, this use case is also applicable to any transport hub such as a train station, a bus terminal or a port. The components include positioning, platform for big data collection and processing, connectivity and interfaces to relevant stakeholders in the ecosystem. A telco could play a role in the connectivity provisioning as well as in providing the platform for big data collection and processing. Requirements on data rate and latency would vary depending on the application (e.g., more stringent if it involves AR/VR rendered in the cloud). Coverage, especially in deep indoor, is critical. Ability to support massive deployment of sensors in a scalable manner would also be important for some applications. Due to the closed nature of an airport, non-cellular based technologies could be viable candidates for applications such as asset tracking and predictive maintenance. Nevertheless, a holistic offering by a telco which addresses all relevant applications would be compelling due to benefits such as the ability for all devices to inter-operate and the potential ease of management.

4. **Drone/ robot delivery service** – automates delivery of goods and services by the use of robots and unmanned aerial vehicles (e.g., drones). One could imagine a situation where a fleet of autonomous vehicles drive autonomously in a platoon from one warehouse to another to deliver goods/ packages. At the warehouse, robots would scan the packages and load them onto drones for delivery to the end customer in such a manner that the entire chain operates according to the just-in-time paradigm. Here, the drones could be operated from a central control point or they could operate autonomously based on a predefined working mode and framework. Interfaces between the end-customer, the retailer and the transport operator (this could also be the retailer) is necessary to ensure real-time planning and adherence to the just-in-time paradigm. An operator’s role could be in providing V2N communications for mid- to long-term environmental modelling and dynamic control as well as in the provisioning of V2X communications for short-term environment modelling and cooperative driving/ flying. The stringent requirements on data rates, latency and reliability discussed in Section 2.4 for tele-operated and autonomous driving are relevant for this use case as well. In addition, the flying altitudes for the drones may impose additional spatial coverage requirements. Nevertheless, the full potential of this use case and the viability of telco involvement will also depend on the legal framework for the safe operation of drones and autonomous vehicles (including legal intercept and control of rogue ones), which is still under discussion in many jurisdictions.

From the above use cases, at least the following opportunities could be foreseen:

- Massive connectivity for non-time-critical sensing (for predictive maintenance, asset tracking, monitoring, etc.)
- Massive connectivity for time-critical sensing and feedback (for context-aware services, e.g., recommendation, geo-fencing)
- V2N for remote drone operation

3.5 Required capabilities

Table 3 lists the required capabilities to support the potential opportunities for 5G identified in the transport and logistics industry.

Table 3: Capabilities required for relevant transport and logistics use cases

Use case attribute	Massive connectivity for non-time-critical sensing	Massive connectivity for time-critical sensing and feedback	V2N for remote drone operation
Description	Non-time-critical sensing and reporting. For example - Predictive maintenance, asset tracking, monitoring	Time-critical sensing, reporting and feedback/ control. For example - Context-aware services Recommendation at shopping mall, airport	Real-time remote operation of drones
Need for 5G	Wi-Fi, LPWA, 4G, 5G?	4G, 5G	5G

Experienced data rate	In the order of 1 Mb/s or less	- Uplink: small data rate per sensor, but multitude of sensors results in bandwidth demand in backhaul;
		- Downlink: depending on user device up to 30~40 Mb/s in case of 4K video delivery (2160/60/P)
			- 10-50 Mb/ s for video feeds from drones to the remote operator
			  - H.265/ HEVC HD stream: ~10 Mb/s
			  - LIDAR: ~35 Mb/s (6 vertical angles, 64 elements, 10 Hz horizontal rotation)
			- Up to 1 Mb/s for control commands

Latency	Not critical	<30 ms end–to-end.	10-30 ms end-to-end
Reliability (IP packet delivery within latency bound)	Not critical	Not critical	Critical
#Devices	10^4/ km^2	10^4/ km^2	For further study
Battery	15 years for wireless sensors	15 years for wireless sensors	Critical
Coverage	Important	Important	Critical - Coverage in air space to be investigated
Mobility	Depends on use case	Depends on use case	Up to 250 km/ h
Interwork/ roaming	Roaming needed as vehicles and aircraft travel abroad	Interworking and roaming needed	Interworking and roaming needed - Since coverage and reliability are critical, there may be a need to rely on multiple networks
Security	Critical (data integrity, privacy)	Critical (data integrity) Privacy for revealed preferences	Critical (authentication, data integrity)
Positioning	30 cm – 1 m sufficient for many applications - <30 cm for applications that require exact localization (e.g., tracking specific objects in a warehouse) - Indoor positioning also needed, e.g., warehouse, airport, train station - localization without the need for a costly GPS receiver in the end-device	30 cm – 1 m sufficient for many applications - <30 cm for applications that require exact localization (e.g., tracking specific objects in a warehouse) - Indoor positioning also needed, e.g., warehouse, airport, train station - localization without the need for a costly GPS receiver in the end-device	For further study
Other capabilities		Context recognition: Either by local means (e.g. tags, barcodes) and/ or intelligent combination of available data.	Resiliency

External dependencies	Legal framework on data protection and privacy	Data Privacy aspect. Tracking of users and combination with their revealed plans as precondition to provide tailored information, could conflict with personal aim to be not such transparent to external parties	Legal framework currently evolving and not consistent across jurisdictions; role of mobile networks in commercial drone business still to be elaborated
Other considerations	Specific requirements on handheld equipment need to be addressed for the E2E ecosystem to work (e.g., blast protection class for workers who handle airplane fuel)	Specific requirements on handheld equipment need to be addressed for the E2E ecosystem to work (e.g. blast protection class for workers who handle airplane fuel)	Effect of (multiple) drones sending with line-of sight-conditions to all surrounding cells to be investigated

3.6 Outlook

Telcos strength in connectivity provisioning will continue to be useful in the ongoing transformation in the transport and logistics sector. 5G could provide new capabilities which would enable a telco to support emerging requirements on enhanced data rates, reliability and massive connectivity of low powered sensor devices. But a key to unlocking the full potential of this transformation is big data analytics. In this regard, the platform to collect data from different sources as well as the algorithms to process the data to obtain useful and actionable insights is important.

Additionally, close cooperation with relevant stakeholders is essential. Portable data formats coupled with standardized interfaces could enable collection and aggregation of data from many different sources. These will also make it possible to easily share important insights obtained from data analytics to a broader range of players in the ecosystem to create additional value. The extent to which such harmonization and interface standardization can be achieved will have implications on the potential values that can be created in this space and the viability of new players entering into the market.

Different (and proprietary) solutions are currently used in different sectors for functions such as inventory management, asset tracking, supply chain management and maintenance. An important issue that needs careful consideration is how these legacy systems would be migrated and possibly integrated into a new end-to-end system, also taking into account the long life-cycle of some assets. In addition, the legal and regulatory framework for the kinds of (personal) data that can be collected and how it can be used is evolving and the possibility for regional-specific frameworks and mandates cannot be excluded. This could reduce potential economies of scale. All these issues need to be carefully assessed in order to fully understand the potential opportunities for telcos in this space and the extent to which they can be successfully exploited.

4 HEALTH AND WELLNESS

Electronic health (eHealth), where electronic processes and communication technology support healthcare practice, and mobile health (mHealth) in particular, where mobile communication devices are used for such support, are leading a transformation in healthcare delivery with potential implications on the value chain.

4.1 Key drivers of industry change

The ongoing transformation in the healthcare industry is driven by two key themes, namely:

- **Demographics and growing costs** – Ageing populations in developed countries, especially in Europe and parts of Asia, together with increased prevalence of chronic and lifestyle-driven diseases (e.g., diabetes, obesity, asthma) contribute to unsustainably high annual growth in healthcare expenditure. At the same time, increasing populations in developing countries calls for sustainable expansion of healthcare coverage, at least to ensure availability of basic health services despite remote or dense population environment. In both worlds the society must seek new models (e.g., remote health services) to sustain health and wellness, given general lack of conventional resources (e.g., hospitals, doctors, clinicians).

- **Efficient personalized care** – The growing demand for flexible treatment and care options need to be met in an efficient manner. The industry sees the value to utilize the power of ICT (e.g., data analytics, ubiquitous network coverage, wearable devices) to develop new healthcare paradigms, toward more preventive (e.g., lifestyle and wellness), decentralized (e.g., treatment and care outside hospitals) and personalized (e.g., individualized remote diagnosis, therapy and medicine dosage) healthcare delivery.

4.2 Market prospects and roadmap

According to the World Bank, many developed countries spend around 10% (17% for the US) of GDP annually on direct healthcare costs. eHealth and mHealth currently constitute a tiny fraction of this expenditure. The global mHealth market is estimated to be worth around 59 billion dollars by 2020, representing a nine-fold increase compared to 2012. This encompasses different categories such as diagnostic services, healthcare systems strengthening, monitoring services as well as prevention and wellness. Health monitoring services are the most promising in terms of forecasted market and timeframe. In particular, in the US, these services are projected to account for over 70% of the overall demand in 2020 (over 60% in 2013).

Many governments have made eHealth a primary pillar in the drive towards sustainable healthcare delivery and the necessary legislative frameworks are under discussion or already established (e.g., eHealth legislation in Germany) to facilitate adoption. Private stakeholders (e.g., insurance companies, pharmaceutical companies) also see potential opportunities with adoption of data-driven individualized healthcare. Nevertheless, the adoption of eHealth has been slow due to legal (e.g., data protection restraints, liability of services) and technical challenges (e.g., lack of standardized and interoperable processes, interfaces and data formats, regionally and globally) and it could take a while before these issues are fully resolved.

4.3 Ecosystem and key players

Actors from diverse sectors must work together to deliver values. In some regions of the world, several domains in the ecosystem that directly affect individuals and their health (e.g., data protection, pharmaceuticals, allowed practitioners, etc.) are heavily regulated, whereas in some others the regulations are more relaxed or even absent. In addition, government policy heavily impacts the regulations for healthcare funding and can affect penetration of innovations in the healthcare sector. Adoption of ICT in the health sector opens up opportunities for new players and with it, potentially new regulations to safeguard both individual privacy and public health which could impact the viable roles of the different players.

4.4 Relevant use cases

Some relevant use cases in the health and wellness industry where an operator could play a role are discussed below.

1. **Health and wellness monitoring** – involves the use of various types of sensors and wearable devices to track health-relevant indicators. Currently, such devices use short range communication technologies such as e.g., PAN (e.g., Bluetooth) and LAN (e.g., Wi-Fi) to connect to a hub (e.g., smartphone, gateway towards the fixed line). The data is used by apps (e.g., on a smartphone) to help the individual to monitor and manage wellness and/or diseases (e.g., blood glucose level management). Typically, these apps are not standardised. With the ability to upload the data to a third-party (e.g., medical doctor, insurer, data broker) periodically or in real-time, several beneficial interventions that rely on big data analytics and expert knowledge could be envisaged. Public health services could also make use of such data (with the

consent of the individuals), together with other data sources (e.g., social media content), to monitor and detect the onset of epidemics. Nevertheless, the realization of these benefits relies on relaxation of data protection rules in several jurisdictions to permit the use of personal data in such a manner. At the same time, there is a desire from individuals for stronger security guarantees to protect sensitive personal data, which limits the possibilities for such data collection and use. Even with relaxed data protection rules and increased possibilities for data collection and analytics, standardized interfaces and data formats will be needed to realize full benefits of big data analytics. Also, healthcare systems would need to evolve their policies to support the use of such data analytics and the relevant applications (e.g., currently there are only very few healthcare systems in Europe that reimburse the use of apps for healthcare professionals). These upper layer aspects may be outside an operator's traditional competence. But an operator could play a role in enabling connectivity between the monitoring devices/ sensors and a third-party for data collection and analytics. Here, the bandwidth and latency requirements may not be critical and could be addressed with existing cellular technologies. The challenge would be to enable a massive increase in the number of connections per square meter while also guaranteeing some level of quality of service (QoS).

2. **Remote healthcare** – enables individualized consultations, treatment and patient monitoring outside traditional healthcare institutions (hospitals and clinics). Patients and practitioners could use video conferencing and telepresence facilities for remote consultation and visits. This could be complemented by remote transfer of health-related data from sensors and devices (e.g., in real-time or pre-uploaded to the cloud). Treatment could also be offered through the use of smart pharmaceutical devices which allow dosage of a drug, which will have to be given routinely, to be controlled and administered correctly. Practitioners could remotely monitor progress of treatment in real-time with the help of data from health sensors as well as voice and video feeds and adjust treatment as necessary. This could involve, e.g., remotely adjusting the dose of the prescribed medication. This type of treatment could be relevant to patients who otherwise would have to travel a large distance to see the practitioner. Here, telco operators could play a relevant role in providing the connectivity and platforms needed to facilitate transfer of data from sensors, video and voice feeds and remote commands to administer medication, possibly as a partner with other players (e.g., pharmaceutical companies). Requirements on bandwidth would depend on the nature of video feeds and health-related data. Remote treatment may require delivery of real-time commands and controls which introduces low latency requirements. QoS guarantees will be essential for some mission-critical services and could have legal liability implications for an operator.

3. **Assisted surgery** – uses telepresence and data feeds to allow a specialist surgeon to remotely assist another surgeon or medical practitioner to perform a surgery. For instance, a specialist remote surgeon could watch a live 3D video feed and provide real-time guidance (e.g., through his/her voice guidance complemented by augmented reality for the local expert) so that a surgeon on location (e.g., emergency scene, small town, etc.) can successfully perform a surgery on a patient. A telco operator could provide the connectivity required for telepresence and the transfer of necessary health images. For this, reliability of the connection would be critical. Also, high demands will be placed on the bandwidth for the delivery of high resolution 3D video and other images in real-time. Compared to the case of 'Remote Surgery' (described below), latency is not critical even if not negligible. However, QoS guarantees will need to be provided and met. Beside these technical constraints, the legal framework on liability could have important implications. A need to undergo certification could, for instance, imply telcos taking on some liability in the event a network-related issue (e.g., downtime, congestion, etc.) causes an unsuccessful surgery.

4. **Remote surgery** – allows a surgeon to remotely operate a surgical robot to perform surgery on a patient. A telco's role involves the provisioning of the communication link to allow video and audio feeds as well as data to be reliably transferred in real-time between the surgeon and the remote surgical robot. Here, extremely high reliability and very low latency are necessary. In addition, transfer of high resolution images and video to the surgeon requires large bandwidth on the uplink. To enable this use case in any kind of emergency, high availability of the necessary robots and surgeons certified for their use will also be required. Nevertheless, QoS guarantees on extremely low latency and reliability requirements might imply

that only local services could be supported in an economical manner. Alternative deployment models could also be explored (e.g., commercial network sharing, etc.) but these models will need deliberate discussions among stakeholders, including also the government. Also, the legal framework on certification and liability for the communication link (e.g., in the event of a failure) could change the value proposition for a telco operator.

5. **Info-mediation** – spans several domains that rely on processing information to provide value-added services. For instance, hospital assets could be managed and tracked in real-time using embedded sensors. Patient check-in and check-out can be automated with the aid of sensors (e.g., wearable devices) and real-time billing could be facilitated through interconnection with the relevant intermediaries (e.g., insurance companies, banks, etc.). Positioning, big data analysis, remote management/ control, interconnection with partners in the ecosystem (e.g., insurance companies, banks) and billing platform are all necessary components for info-mediation, depending on the specific value-added service. The connectivity required to report different kinds of information could be provided by telcos and the requirements would vary depending on the service. Given the closed nature of the hospital/ clinic environment, alternative connectivity solutions by system integrators using technologies operating in unlicensed spectrum could also be viable for some services (e.g., asset tracking in the hospital).

From the above use cases, at least the following opportunities could be foreseen:

- Real-time video/ telepresence/ augmented reality (for remote healthcare, assisted surgery)
- Massive sensor connectivity (for health and wellness monitoring)
- Real-time command and control (for remote medication, remote surgery)

4.5 Required capabilities

The required capabilities to support the identified 5G opportunities in the eHealth and mHealth sectors are identified in Table 4.

Table 4: Capabilities required for relevant health & wellness use cases

Use case attribute	Real-time video/ telepresence/ augmented reality for remote healthcare and assisted surgery	Massive sensor connectivity for health and wellness monitoring	Real-time command and control for remote medication and surgery
Description	Live video feed (4K, 8K, 3D) in both uplink and downlink for remote healthcare (consultation, diagnosis, treatment, monitoring) and assisted surgery	Connectivity for sensors, wearable devices and other medical devices for health monitoring and info-mediation	Real-time commands to control medical devices for treatment (.e.g., medication, surgery)
Need for 5G	5G	4G, LPWA, 5G?	5G?
Experienced data rate	- 4K (2160/60/P): 30~40 Mb/s - 8K (4320/60/P): 80~100 Mb/s - HD H.265/HEVC: ~10 Mb/s	Up to 1 Mb/s or less	Up to 1 Mb/s for control commands
Latency	100 ms end-to-end	In the order of seconds to minutes	10-100 ms end-to-end
Reliability (IP packet delivery within latency bound)	Critical	Not critical	Critical
#Devices	10^3 / km^2 - Activity factor=50% Not critical for assisted surgery	10^4 / km^2	Up to 100 / km^2 for remote medication
Battery	Not critical	15 years for wireless sensors (e.g., body parameter sensors)	Critical for remote medication
Coverage	Important - Including underground, air (up to 3 km above ground), at sea (up to 50 km offshore)	Important - Including underground, air (up to 3 km above ground), at sea (up to 50 km offshore)	Important - Including underground, air (up to 3 km above ground), at sea (up to 50 km offshore)
Interwork/ roaming	Interworking and roaming needed for life critical services	Interworking and roaming needed for life critical services	Interworking and roaming needed for life critical services

Security	Critical (identity, authentication, data integrity, privacy)	Critical (identity, authentication, data integrity, privacy)	Critical (identity, authentication, data integrity, privacy)
Positioning	Not critical, 1-10 m - Indoor positioning also needed, e.g., house, medical centre	Not critical, 1 -10 m - Indoor positioning also needed, e.g., house, medical centre	Not critical - For remote surgery, a robotic device will take care of local accuracy
Other capabilities	Resiliency for life-critical services		Resiliency for life-critical services
External dependencies	Uncertain regulatory and legal environments in different jurisdictions	Uncertain regulatory and legal environments in different jurisdictions	Uncertain regulatory and legal environments in different jurisdictions

4.6 Outlook

Telepresence and augmented reality could play a big role in remote healthcare (consultation, diagnosis, treatment and monitoring). New technologies could enable telcos to deliver the high data rates required for live streaming of high resolution video and augmented reality. However, alternative technologies (e.g., FTTH, HEW) could also be used in indoor environments. Outdoor environments could provide an opportunity for telcos. For use cases such as assisted surgery, the reliability requirements would be critical. Remote surgery imposes very stringent requirements on latency and reliability. Providing and meeting QoS guarantees for such services would pose a significant challenge. In addition, the legal environment regarding liability could significantly impact the prospects for telcos to play in this space.

Other opportunities exist in the layers above connectivity. For instance, providing platforms for big data collection, brokerage and analysis could facilitate the provisioning of individualized medicine and value added services (e.g., billing, guaranteeing legal compliance of market participants). Nevertheless, the opportunities in this space are currently limited by technical (e.g., lack of standardized interfaces, data formats, security), regulatory (e.g., constraints on what can be done with personal data in many jurisdictions, RF constraints on medical devices) and legal liability issues.

5 SMART CITIES AND UTILITIES

Smart cities leverage the power of ICTs to deploy, manage, use and maintain a city's assets to meet the needs of the citizens, the society and the environment efficiently and sustainably. Smart city initiatives could span areas such as infrastructure (e.g., street lighting, transportation systems), utilities (e.g., power plants, energy distribution networks, water supply networks and waste management), public safety (e.g., law enforcement, disaster warning and management) and other public services (e.g., healthcare, education, civic engagement and participation). Thus, developments in several vertical industries have a direct relevance for smart cities as well.

5.1 Key drivers of industry change

Several drivers already mentioned for the previous vertical industries are also relevant for smart cities. In addition, some specific drivers are elaborated below.

- **Efficiency** – Improvements in several areas such as energy distribution and use (e.g., mismatch between supply and demand, context-unaware lighting), public transport (e.g., long transfer/ waiting and commuting times) and education can help to reduce costs while meeting the needs of citizens and improving their quality of life.
- **Sustainability** –Meeting the demands of urban living in an environmentally-friendly manner is increasingly an important objective among the citizenry, corporations and the government. Initiatives that help to reduce carbon footprint (e.g., smart mobility, energy efficient buildings) or reduce resource use (e.g., recycling, sharing) are particularly high on the agenda of many municipalities.

- **Demographics** – Changing urban populations, with changing needs and expectations drive the need for cities to explore new ways to engage with the citizenry, ensure participation and improve the quality of life. E-government initiatives make local governments more accessible and also improve the transparency of their activities to the citizens.

5.2 Market prospects and roadmap

There is current expectation that smart city programs will generate more efficient management of different municipal functions. At the same time, city governments are constrained by budgets, lack of resources and lack of expertise in the implementation of smart cities systems. The Black & Veatch's 2016 Strategic Directions: Smart City/ Smart Utility report finds that almost 60% of respondents believe the adoption of smart city systems will take between 6 to 15 years. That report also finds that improved efficiency, reduced costs and resource sustainability were the top drivers of smart city initiatives. Moreover, almost half of respondents viewed high-speed data networks as the most important investment to begin a smart city program and two thirds of respondents consider asset management as the top business area to improve from greater use of data analytics.

The growth of living labs plays an important role in smart cities development. It allows for cities to test different solutions, and identify gaps, before rolling out complete solutions. Government grants are currently being allocated to selected cities, and cities are working with the industry to propose solutions to the many different areas of interest. The lighthouse projects, GrowSmarter, Remourban and Triangulum, under the European Horizon 2020 funding provide some good examples. The majority of initiatives in smart cities today is supported by such grants.

5.3 Relevant use cases

Some relevant use cases in smart city initiatives where an operator could play a role are discussed below.

1. **Connected lighting** – LED-based lighting is replacing incandescent, fluorescent, mercury, and sodium lamps in almost all indoor (e.g., home, factories, etc.) and outdoor (e.g., street lighting) applications due to their efficiency, durability, versatility and longevity. LEDs cost three to four times more up front than traditional streetlamps, but they last three to four times longer and produce two to three times more light per watt, delivering up to 70% in annual electricity savings. Additional applications on-top of basic lighting can be enabled by creating a lighting network. For instance, (several) lights could be remotely or locally turned on in a formation based on demand or on motion and estimated trajectory. Maintenance and diagnostics could also be facilitated by regular diagnostic reports (e.g., a few times a day) from light fixtures to a central server. For the case of street lighting, the energy and maintenance savings may not be enough to pay for the connected lighting infrastructure at today's cost, necessitating the need to bundle additional services. Service bundling is particularly appealing to lighting suppliers since the expected longevity of LEDs impacts potential revenues from regular light replacement. Hence, the connected light infrastructure could also find applications in monitoring (e.g., crime, power outages, pollution, noise levels, etc.), reporting (e.g., traffic information), coordination (e.g., disaster relief), as sites for small cells or as roadside units for V2X services.

   Telcos could provide the connectivity and some value-added information (e.g., estimated trajectory of a pedestrian) required for such services. Nevertheless, proper functioning of these services requires good interworking between all partners (e.g., light supplier, lighting provider, telco, vendors, OTT application providers), which could be a challenge in the absence of standardized interfaces and data formats. The benefits of utilizing cellular technology include the ability for all devices to inter-operate and the potential ease of management of the lights. Since such infrastructure usually have very long lifetimes, issues surrounding migration are non-trivial and need careful study.

2. **Public safety** – Advances in sensors, commoditization of computing and the availability of high-bandwidth and reliable communication networks opens up new opportunities for security services/ law enforcement

to detect and fight crime and improve public safety. Real-time multi-modal analysis of information acquired through multiple sources (e.g., surveillance cameras, drones, sensors, social network) could significantly reduce event detection time and improve identification accuracy. Such detection and identification could be performed locally at the source or in real-time at a central cloud. Communication interfaces between data processing points and security/ law enforcement would be crucial to enable swift response to any identified public safety issues. Different public safety networks may need to interconnect with one another for information sharing as well as with commercial networks (e.g., use of an automobile for relay service in D2D communication). Telcos could provide secure, reliable, resilient and high bandwidth connectivity necessary to facilitate communication between all the different nodes (information collection, processing, and response points). Depending on the particular needs of the local public safety services, additional requirements on prioritized access, security (e.g., network isolation) and resilience (e.g., fall back to basic services, e.g., voice, should always be possible) may need to be satisfied. Currently, a mix of different legacy solutions are used by security services and law enforcement agencies for their communication needs. Migration of these systems to support such new capabilities would be a non-trivial exercise, which deserves further consideration. Telcos are expected to support communication across public safety devices and systems with high reliability, security and bandwidth.

3. **Emergency service management** – The scope of emergency services includes natural disasters (e.g., earthquakes, floods, tsunamis, epidemics, etc.) as well as man-made emergencies (e.g., terrorism, fires, accidents, etc.). Today, Early Warning Systems (EWS) are used to monitor and estimate the probability of some natural disasters (e.g., tsunamis) or detect their occurrence (e.g., earthquakes, fires) and initiate communication to warn appropriate entities. Monitoring, estimation and detection can all be improved by advances in sensors and big data analytics. Yet, without appropriate means to warn the affected citizenry and communicate/ initiate appropriate response actions, the effectiveness of EWS in minimizing casualties from such events could be limited. Hence, a means to target communication to the right group of people with sufficient lead time, once an event is estimated/ detected, is crucial. This could involve sending text, voice or video messages to all those affected. Additionally, disaster response equipment and mechanisms (e.g., shutting down elevators in case of fire, prioritizing traffic lights for emergency vehicles, etc.) could all be automatically activated via such communication. Search and rescue as well as other recovery efforts could also be facilitated by communication with sensors (e.g., wearables could send beacons to help identify trapped survivors and victims, embedded sensors on equipment could send information about their actual status, etc.) and with the help of autonomous or remotely-controlled robots and aerial vehicles. Support for all these capabilities requires telcos to deploy highly resilient networks which can support prioritized access as well as basic operation with very low energy consumption over a very wide area even in case of disasters (which most often comes along with power outages). These networks should also have the capability to send geo-fenced notifications and interface with appropriate entities to facilitate all aspects of emergency detection, warning/communication and response. Current cellular systems have some built-in capabilities to send geo-fenced EWS warnings, e.g., using SMS messages, and this capability could be reused. Additionally, technologies such as virtualization allow networks to recover quickly after downtimes caused by natural disasters and can be employed even in existing cellular systems to improve resilience.

4. **Smart grid** – enables enhanced monitoring, management, protection and control of energy generation and distribution networks leading to increased availability and resilience. The electricity industry is undergoing a massive transformation both from a supply side as well as from a demand side perspective. On the supply side, there is a trend towards decentralized, smaller power generation sources with a far less stable power delivery. In addition, there is a growing adoption of storage solutions. On the demand side, there is proliferation of end devices with diverse usage and energy consumption patterns (e.g., electric vehicles, IoT, etc.). This transformation poses new requirements on the capabilities and architecture of the involved communication networks. In the backhaul/ backbone domain, networks providing appropriate protection, control and monitoring functionality will be needed. The communication platform will need to fulfil stringent requirements in terms of latency (e.g., for automated fault detection,

localization and service restoration), security, resilience and reliability. At the same time it should also provide a high degree of flexibility in terms of potential services, temporary deployments and the geographic spread. The access communication platform should allow efficient connection of a massive amount of smart meters with a potential life-cycle of more than 15 years – requirements on latency, reliability and bandwidth are less stringent than in the backhaul/ backbone domain. But coverage, especially in deep indoors, is quite important. The reliability and security of network systems are essential for mission critical applications. This includes the requirements for user/ device authentication, and the protection of the data and the identity of the end devices. Telcos could provide the communication platform for the access network and possibly for the backhaul. Currently, different solutions exist for the access domain, which could make harmonization and/ or migration to new technologies challenging.

From the above use cases, at least the following opportunities could be foreseen for smart cities:

- Real-time video for monitoring and guidance
- Massive connectivity for non-time-critical sensing (weather, pollution levels, etc.)
- Massive connectivity for time-critical sensing and feedback (detection of natural disasters, smart grid control, context-aware lighting)
- V2N for remote vehicle/drone operation[7] (see Table 3 for the capabilities required for remote drone operation)

5.4 Required capabilities

Table 5 identifies the required capabilities to support the identified opportunities in the smart cities space.

Table 5: Capabilities required for relevant smart cities and utilities use cases

Use case attribute	Real-time video for monitoring and guidance	Massive connectivity for non-time-critical sensing	Massive connectivity for time-critical sensing and feedback
Description	Live video feed (HD, 4K, 8K, 3D) in both uplink (remote monitoring, surveillance) and downlink (guidance for citizens and law enforcement officers)	Non-time-critical sensing and reporting. For example, weather, pollution	Time-critical sensing, reporting and feedback/ control. For example Detection of natural disasters, smart grid control and context aware lighting
Need for 5G	5G	Wi-Fi, LPWA, 4G, 5G?	4G, 5G
Experienced data rate	- 4K (2160/60/P): 30~40 Mb/s - 8K (4320/60/P): 80~100 Mb/s - HD H.265/HEVC: ~10 Mb/s	In the order of 1 Mb/s or less	- Uplink: small data rate per sensor, but multitude of sensors results in bandwidth demand in backhaul; - Smart grid: - Up to 5 Mb/s in downlink and uplink

Latency	100 ms end-to-end	In the order of seconds to minutes	- 30 ms end-to-end
			- Smart grid:
			  - <5 ms end-to-end for transmission/ grid backbone,
			  - <50 ms end-to-end for distribution/ grid backhaul,
			  - <1 s end-to-end for access

Reliability (IP packet delivery within latency bound)	Critical	Not critical	Critical for smart grid - 99.9% – 99.999% for the different domains/applications
#Devices	10^3 / km^2 - Activity factor=50%	10^4/ km^2	10^4/ km^2
Battery		15 years for wireless sensors	15 years for wireless sensors
Coverage	Important - Including underground, air (up to	Important	Important

[7] Requirements for V2N for vehicle operation are still under discussion in NGMN and will appear in the subsequent deliverable.

	3 km above ground), at sea (up to 50 km offshore)		
Interwork/ roaming	Interworking and roaming needed for life critical services	Roaming needed as vehicles and aircraft travel abroad	Interworking and roaming needed
Security	Critical (identity, authentication, data integrity, privacy)	Critical (authentication, data integrity, privacy)	Critical (authentication, data integrity, privacy)
Positioning	Not critical, 1-10 m	Not critical for applications where device location would be known (e.g., fixed devices)	Not critical for applications where device location would be known (e.g., fixed devices)
Other capabilities	Priority control for authorities and emergencies		Ultra-reliability for Smart Grid Backbone (Transmission), high reliability for distribution and access
External dependencies	Uncertain regulatory and legal environments in different jurisdictions regarding privacy		

5.5 Outlook

The smart cities market is an attractive opportunity for network operators. However, it must be understood that these markets are very complex and involve many players and stakeholders. With unique/ creative business cases, network operators would be well positioned for the growth of IoT, which forms the basis for many smart city services. But partnerships may be necessary to enable the solutions. The priorities set by the government with regards to investment in smart cities may vary between different cities, and legislation may play a role in this market (e.g., data protection laws, cybersecurity, etc.). The necessary features in the underlying system may highly depend on the individual case, and dedicated solutions may not be cost efficient. To economically realise as many benefits as possible, a common platform should desirably be established for device connectivity, analytics and management, while inviting for open innovations through use of APIs to access embedded features.

The network operators are already engaged in providing communication network infrastructure and services to utility industry to assist in efficient and reliable energy generation, transmission, and distribution. Utilities are evolving towards a distributed ICT environment aligned with the need to support distributed generation and field devices generating massive amounts of data. However, purely from a wireless network perspective, the opportunities for 5G exist in the support of premises-area, neighbourhood-area, and field-area networks, each of which has different performance and resiliency characteristics. Utilities also prefer a highly available, controlled, secure network environment, which 5G needs to accommodate. New business models are expected to emerge due to availability of massive amount of data from end devices (smart meters for water, electricity and other utilities, thermostats, home appliances, etc.) as well as advancement in smart grid and micro grid technologies, which provide network operators an opportunity to continue to be a major player in the utility industry with a flexible communication network infrastructure.

6 AGRICULTURE

Agriculture is undergoing transformation driven by a set of technologies that combines sensors, information systems, enhanced machinery, and informed management to enable efficient production.

6.1 Key drivers of industry change

The ongoing transformation in agriculture is driven by two key themes, namely:

- **Population growth** – In the first half of this century, as the world's population grows to around 9 billion, global demand for food, feed and fibre will nearly double while, increasingly, crops may also be used for bioenergy and other industrial purposes. New and traditional demand for agricultural produce will put growing pressure on already scarce agricultural resources.

- **Climate changes** – Solar radiation, temperature, and precipitation are the main drivers of crop growth; therefore agriculture has always been highly dependent on climate patterns and variations. Climate change is projected to have significant impacts on agricultural conditions, food supply, and food security. On the other hand, agriculture can also contribute to mitigation of climate change, by reducing greenhouse gas emissions.

- **Food quality** – Increasing attention to health and sustainability is driving desire to consume foodstuff produced locally according to environmentally-friendly and organic farming principles.

6.2 Market prospects and roadmap

With global hunger on the rise, the Food and Agricultural Organization (FAO) of the United Nations has stated that if global population reaches 9.1 billion by 2050, the world food production will need to rise by 70%, and food production in the developing world will need to double. Employing ICT in agriculture presents significant potential in enhancing food productivity to support the population growth, while at the same time providing sustainable management of resources. By capitalizing on the latest advancements in hardware and software, new systems of farming are being developed, relying on computing power and connectivity. To enhance productivity, systems that monitor air and soil temperature, wind speed, humidity, solar radiation, rainfall, and other factors, are used today to help farmers. All the agriculture data unique to a specific field, combined with other localized information (e.g., weather predictions), help farmers create a planting plan and also get better yield estimates. The global precision farming market is estimated to grow at a CAGR of 13 % from 2015 to 2022, to reach over $6.43 B by 2022, according to BIS research.

6.3 Relevant use cases

Some relevant use cases in agriculture where an operator could play a role are discussed below.

1. **Data-oriented farming** – Large-scale efficient farming and trading is needed to meet the growing demands cost efficiently. On the other hand, local fresh produce is valuable to improve/ maintain the quality of food we consume. In both domains, ICT could help improve efficiency and sustainability of farming. Based on maps and sensor data, which includes, e.g., yield information, soil tests, seed varieties, fertilizer types, irrigation outlines, etc. farmers can generate information such as a new planting map. All data is collected in the field and then transferred to the farmer's cloud of choice. Actuators can be remotely controlled in real-time e.g., for watering. Sensing is not only applicable to crop fields but also to livestock, e.g., for remote shepherding of the flock. Sensors can also be used to remotely monitor the temperature of cows that are about to deliver a calf, so that the farmer can be on the spot to prevent accidents during delivery. Telcos can provide a platform that serves various cases regardless of the scale. Data transmission is typically narrowband and the latency requirement depends on the application, e.g., crop field applications may tolerate minutes/ hours of delay, whereas livestock applications may require real-time monitoring in the order of seconds. In many cases the requirements could well be supported by legacy technology, but extended coverage and battery efficiency would be key to expand application. As agriculture is mostly annual activity, the time it takes to gain useful data insights may be a challenge, and thus, trials are needed with farmers and ICT providers.

2. **Automated farm machinery** – Farm machinery is increasingly being automated. Tractors, harvesting machines, and crop loaders autonomously drive through farms under close coordination, alleviating the need for a human driver. Farm machinery can report various sensor data, such as soil condition and crop growth, so that the farmer can remotely monitor the farm condition and control machinery. The type of communication involves both device-to-device communication, when different machines in the farm communicate with each other to send information, and device-to-network communication, when the data

is uploaded to the cloud. The communication between the devices is time sensitive and happens while the machines are moving through the farm. Control and coordination of an autonomous field vehicle fleet, possibly assisted by drones for field surveillance will require short latency. Data upload to the cloud is not time sensitive, and can be done in off hours. Today these systems use Wi-Fi and/ or proprietary protocols for communication between machinery (device-to-device communication) and some use 3G cellular technology for uploading data to an application server, which is used by the farmer. Compared to smartphones, farm machinery have very long lifetimes (in the order of 15 years) which makes it essential to have technologies that will remain relevant and/ or easily upgradeable over a very long time frame. Moreover, as farm machinery can often be leased, the compatibility of the embedded device for the technology and spectrum bands for the intended region must be ensured. As such, technology and spectrum harmonization is important and flexible devices that can cope with various regions and migration are desirable.

From the above use cases, at least the following opportunities could be foreseen:

- Massive connectivity for sensors and actuators
- V2X for cooperative farm machinery (tractors, combine harvesters, irrigators, etc.)

6.4 Required capabilities

The capabilities highlighted in Table 6 are relevant for agriculture. In addition, the following are identified as required connectivity capabilities to support agriculture:

1. Simpler and cost-effective devices (e.g., complexity of 4G modems today is not needed)
2. Easy switch between mobile operators
3. Better coverage in rural areas
4. Technology that remains relevant for a long period of time (~15 years)

Table 6: Capabilities required for relevant agriculture use cases

Use case attribute	Massive connectivity for sensors and actuators	V2X for cooperative farm machinery
Description	Monitoring of farm conditions (e.g., soil, water level, livestock) and actuation of machinery (e.g., sprinklers, feeding)	Coordinate trajectories among farm machinery for coordinated operation/manoeuvres, etc.
Need for 5G	Wi-Fi, LPWA, 4G, 5G?	Wi-Fi, 4G, 5G?
Experienced data rate	In the order of 1 Mb/s or less	- 5 Mb/s per link - CAM/ DENM: few 100 byte/msg, 20 Hz (according to current standards - could increase for higher level of automation) - Planned trajectory: ~2.5 Mb/s (32 byte/coordinate, 10 ms resolution, 10 s trajectory, 10 Hz) - Coarse driving intention: ~0.05 Mb/s (few 100 bytes (e.g., 500 byte) /msg, 10 Hz)
Latency	In the order of seconds to minutes	10-30 ms end-to-end
Reliability (IP packet delivery within latency bound)	Not critical	Critical
#Devices	10^4/ km^2	~10 in vicinity (few 100 m ~ 1 km)
Battery	15 years for wireless sensors	Not critical
Coverage	Important	Critical - Up to 300 m range
Mobility	Stationary to pedestrian speeds	Up to 50 km/h
Interwork/ roaming	Interworking and roaming not needed for fixed sensors.	Interworking and roaming needed (as farm machinery can be leased)
Security	Critical (data integrity, privacy)	Critical (authentication, data integrity)

Positioning	Not critical for applications where device location would be known (e.g., fixed devices)	30 cm – 1 m

6.5 Outlook

Large deployment of sensors and big data analytics using telco and IT vendor platforms are already helping to realize different services for agriculture today. The connectivity component of these solutions has low margins as the big data platform contributes significantly to value creation. Farm machinery is also undergoing automation and even autonomous coordinated operation based on proprietary solutions from equipment vendors. Here, the equipment vendors are using such capabilities to differentiate and create additional value. The next step in this transformation in agriculture will require the ability to support massive scale, new connectivity needs and many more different (including region-specific and niche) applications in a scalable and cost efficient manner. Telcos could leverage their existing relationships to understand and provide propositions that combine connectivity and big data platforms to address the varied needs, employing solutions that enable quick and cost efficient scaling as well as customization. Standardized connectivity solutions, data formats and interfaces to platforms could help to quickly achieve scale, enable partnerships and potentially reduce costs as a result of economies of scale. The ability to leverage existing infrastructure can also reduce time to market and the required investments.

Due to the long life cycles of farm machinery and equipment, special considerations should be given to deployment and eventual migration strategies. Technology solutions must remain relevant for long periods of time. In the absence of such longevity and relevance, workarounds to achieve interoperability with and/ or easy migration to new solutions will be critical and should be carefully considered. Since accumulation of data (and hence the ability to draw useful insights) can take rather long in the agriculture context (which operates on bi or annual cycles), portability of big data with time and technology would be quite important.

7 CONCLUSIONS

Even though a large number of vertical industries, each with many different use cases, have been identified, common themes emerge in terms of the required capabilities to support the use cases, the relevant roles that telco operators could play and also externalities that must be taken into account.

Different capabilities are needed to support different use cases even within a single vertical industry. While some use cases require very high data rates, others rather emphasize the support of massive number of low-cost low power devices to transmit intermittent low-rate data. Still others require low to very low latency coupled with very high reliability to enable real-time command and control applications. Hence, it becomes obvious that not all capabilities are needed at the same time, and ways to cost-effectively and efficiently tailor the network capabilities to the use case will be crucial.

Some use cases are already implemented to some extent based on existing technologies and are supported by an evolving ecosystem and a growing understanding of viable business models. Other use cases are not mature and require some time to develop the business models and ecosystems. At the same time, existing technologies are evolving to improve or enable some of the required capabilities (e.g., support for massive number of low-cost low-power devices). Thus, the required capabilities that must be supported by a new technology as well as the timing of those capabilities must also take into account the evolution of existing technologies as well as the anticipated maturity of the use cases that will depend on those capabilities.

Telco operators have demonstrated strengths in wide area connectivity provisioning using licensed spectrum. This is useful for use cases that require wide area coverage, mobility, or some level of guaranteed quality of service. In such use cases, telcos are expected to play a relevant role in connectivity provisioning using an evolution of existing cellular technologies or a new technology depending on the required capabilities and the economics of providing the desired coverage. Use cases that require only local coverage, limited or no mobility support or best effort, could also be addressed with technologies that utilize unlicensed spectrum. Thus, opportunities exist in this space for telcos and other players (e.g., system integrators) to provide connectivity solutions either alone or in partnerships. In particular, the ability to provide a one-stop service with global connectivity (including all necessary roaming agreements), billing and other higher layer capabilities (e.g., identity management) would be a strong value proposition. Nevertheless, many of these use cases are being addressed or will be addressed with evolution of existing technologies by the time a new technology is ready for large scale commercial deployment. Given network impacts as well as the long life cycle of equipment refresh in many vertical industries, the practicalities of migrating to new technologies will not be trivial and must be carefully considered.

Besides connectivity, higher layer management platforms and applications (e.g., for big data collection and analytics) provide significant value in many use cases. This relies on close cooperation among different stakeholders to fully realize the end-to-end benefits. In particular, open interfaces and portable data formats will be critical to unleash the power of big data collection and analytics. Established and consistent legal frameworks (e.g., data protection, liability, etc.) across different jurisdictions will also help to provide certainty as well as economies of scale. Nevertheless, this space and the associated issues are not tied specifically to a new technology and are relevant to existing technologies as well.

8 REFERENCES

[1] NGMN Alliance - NGMN 5G White Paper, February 2015