NEXT G ALLIANCE

An ATIS Initiative

6G Roadmap for Vertical Industries

ABSTRACT

This report addresses the journey to next-generation communications systems in the context of the NGA's earlier report about North America's ***Roadmap to 6G*** which outlined a vision and set of audacious goals for North America. This vision is one of a distributed cloud, computational, and communications architecture that offers much more than a ubiquitous communications fabric for users. This report explores the demand side of the ecosystem. It focuses on eight industry verticals and their application and technology expectations for 6G. The report outlines the issues and opportunities associated with 6G and all that implies for policymakers and long-range planners in government and private sector agencies.

INTENDED AUDIENCE

The target audience for this report is intentionally broad. This reflects the importance of informing entrepreneurs who might create markets using 6G as a key enabler. As NGA members learned from research in producing this report, there is also an appetite for insights from academic and vertical industry organizations, as well as government agencies and policymakers. 6G covers a range of topics that will be new to organizations in the communications and related information technology sectors. Their representatives are also part of the target audience.

The report describes promising 6G opportunities, vertical industry needs, and technology dependencies at a general level. Where appropriate, the material delves into technical detail and structural aspects of the communications industry, notably where this concerns ITU coordination and 3GPP standardization.

There is a special emphasis on North American government because of the opportunity to take action to strengthen the region's leadership impact. There is considerable scope to cultivate cross-sectoral partnerships and to move forward on delivering the goals and priorities established by NGA membership.

FOREWORD

As a leading technology and solutions development organization, the Alliance for Telecommunications Industry Solutions (ATIS) brings together the top global ICT companies to advance the industry's business priorities. ATIS' 150 member companies are currently working to address network reliability, 5G, robocall mitigation, smart cities, artificial intelligence (AI)-enabled networks, distributed ledger/blockchain technology, cybersecurity, IoT, emergency services, quality of service, billing support, operations and much more. These priorities follow a fast-track development lifecycle from design and innovation through standards, specifications, requirements, business use cases, software toolkits, open-source solutions, and interoperability testing.

ATIS is accredited by the American National Standards Institute (ANSI). ATIS is the North American Organizational Partner for the 3rd Generation Partnership Project (3GPP), a founding Partner of the oneM2M global initiative, a member of the International Telecommunication Union (ITU), as well as a member of the Inter-American Telecommunication Commission (CITEL).

For more information, visit www.atis.org. Follow ATIS on Twitter and on LinkedIn.

The ATIS 'Next G Alliance' is an initiative to advance North American wireless technology leadership over the next decade through private-sector-led efforts. With a strong emphasis on technology commercialization, the work will encompass the full lifecycle of research and development, manufacturing, standardization, and market readiness.

TABLE OF CONTENTS

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The communications industry's progress toward a vision for post-2030 systems foreshadows a rising swell of economic and technical change centered on 6G. The implications for policymakers, researchers, service providers, vendors, and a wide range of consumer, defense, and industrial sector users are expected to be far reaching.

Because of 6G's economy-wide impacts, the strategic needs of vertical industry segments will be critical to the success of 6G systems both in terms of enabling capabilities and shortening the time to commercial realization. Therefore, this report focuses on vertical industry needs and builds on the NGA's earlier *Roadmap to 6G* publication. Within the communications industry, expectations are high for new value creation opportunities in the vertical domains over the coming years, both with 5G and 6G.

Through this initiative, the NGA aims to help the communications industry to reach out to the broadest range of stakeholders. In preparing for future application opportunities, it begins by exploring the North American dynamics and needs of eight industry verticals.

The insights in this report are the result of research and interviews with sector experts to understand the long-term drivers of change in different verticals. Experts expressed their needs for future communications systems by talking less about technologies and more about vertical-specific use cases and enabling applications. The NGA's interpretation of these ideas provides the basis for actionable research, market development, and standardization initiatives.

The NGA aims to have a positive and tangible impact on North America's prospects. That involves government agencies taking immediate action in concert with public and private sector entities including academia pursuing collaborative research opportunities and partnering within or across disciplines. The foundation for future actions rests on four conclusions from the NGA's research.

1. Organizational matters are as critical as technical ones. ICT and vertical industry representatives saw value in, and expressed a desire for, greater cross-industry collaboration. Discussions revealed the opportunities to synchronize ICT and vertical industry roadmaps. For example, roadmap planning in the automotive industry has a similar, decade-long horizon as 6G. Other approaches involve a continuing dialog to shed light on vertical industry needs, and collaboration to test latent demand for new 6G capabilities and innovative services.

2. On technical matters, vertical industry representatives offered two viewpoints. The first deals with technology for connectivity needs in areas such as massive and energy-efficient collection of Internet of Things (IoT) data, Artificial Intelligence (AI)/machine learning (ML), optimization for new classes of device, increased interoperability across public and private networks, and seamless experiences linking terrestrial and non-terrestrial networks to extend coverage. Their second viewpoint applies to technology to enable new service offerings. These are important for their potential to unlock innovative applications via novel operational or business models. There could be, for example, a market for sensing and centimeter accuracy positioning and tracking services. These could enable applications such as precise, autonomous coordination between farm machinery and vehicles or the supervision of dementia patients living in their communities.

3. The range and diversity of vertical industry needs spans a mix of evolutionary and revolutionary technologies. Evolutionary topics continue themes that are integral to existing 3GPP roadmap and research commitments. Revolutionary topics encompass breakthrough technologies and research that are likely to require new funding sources and new initiatives. There is no single approach to advance these technologies. Some lend themselves to cross-industry, proof-of-concept (PoC) demonstrators while others involve combinations of research, standardization, and testbed activities. A sample of the technology topics raised by interviewees illustrates a spectrum of evolution and overlap between categories.

4. Capturing industry needs and converting them into technical requirements remains a challenge, especially over the time period associated with 6G. Moreover, learning across industry boundaries cannot be a one-off exercise. For that reason, closing the loop on vertical industry needs will be critical for the ICT sector to manage expectations about capability breakthroughs, their timing, and the maturity of new propositions.

Acting on these research conclusions, the NGA is targeting three goals to advocate for North American interests and to influence global ideas on developing various aspects of the 6G market.

1. **Translate North American needs to technology outcomes:** Build upon the NGA's initial vertical industry engagements to translate 6G adopter perspectives into technical needs aiming for strong 6G market adoption in North America.

2. **Target shared investments in 6G PoCs and testbeds:** Evolve the technology assessment and application KPIs to a framework of 6G PoCs that are oriented to vertical industries, adopter needs, and societal goals. A shared investment model in breakthrough areas such as AI, digital twins, multi-sensory applications, and others will allow industries to participate in cooperative PoCs, resulting in a collective win for North America.

3. **Connect North American 6G needs to marketplace:** Advance and advocate North American needs and use cases with other regions of the globe as part of a pre-competitive/pre-standardization framework. An early and innovative approach will create a blueprint for standardization and position North American industries for the future 6G global market.

1 INTRODUCTION

The momentum behind 6G continues to increase, with profound implications for policymakers, researchers, service providers, vendors, and a wide range of users spanning the consumer, defense, and industrial sectors. Across the world, there is evidence of more organizations participating in its development. Simultaneously, the pace of research and investment commitments shows no sign of slowing. Exploratory approaches are converging on formal structures in the communications industry.

Through solicitations for input and a series of workshops, the ITU intends to publish a global vision for 6G in 2023. The timing of this publication does not prevent industry participants from moving forward. Already, many nations and regional blocs have announced their 6G intentions for the coming decade. There are also discussions within 3GPP on prerequisites for the 6G vision. Examples include study items for Integrated Communications and Sensing (ISAC) and AI/ML integration at the Radio Access Network (RAN) and service architectures. Edge computing (EDGEAPP) is another such work that seeks to prepare for the impact of distributed cloud and compute on communications systems.

This report represents North America's views and intention to exert a leading role in shaping 6G developments and market adoption, both locally and globally.

1.1 North America's Roadmap to 6G – the Next Stage of the Journey

The NGA, which was established in November 2020, is an initiative led by the private sector. It has grown to over 100 members and represents North America's collective interests and market development priorities for next-generation communications systems, beginning with 6G. NGA membership spans the economic spectrum and brings together a unique mix of expertise across academic, public, and private sector interests. Representatives across these groups are united in promoting North American leadership in 6G technologies across key consumer and industrial sectors to strengthen the region's economic interests, both locally and globally.

The NGA operates a working group (WG) model under the oversight of a Steering Group. WGs span topics that cover the National 6G Roadmap, Applications, Technology, Green G, Societal and Economic Needs, and Spectrum. Each of these groups publish insight reports about various aspects of 6G. To address the strategic research agenda, members published a set of research priorities and launched NGA's Research Council in 2022. This will leverage key NGA findings and lay the groundwork for cooperative efforts among government, industry, and academia. The NGA is also active on the international scene, fostering cooperation through liaisons with international initiatives in Europe, Japan, and Korea, for example.

Figure 1.1: NGA's Audacious Goals for 6G

In February 2022, following a multi-month study, NGA members framed the strategic priorities for North America in the *Roadmap to 6G* report. [1] These priorities identified six audacious goals and explored industry opportunities related to 6G applications, technologies, spectrum, and societal needs.

The issues and ideas across these study areas crystallized a fresh way of thinking about the evolution of communications systems. Past generations of communications systems focused on densification and raising performance standards around network coverage and capacity. However, 6G will shape a different dynamic around application and use case diversity. Diversification will be a key trend that drives 6G technology over past generations that have prioritized densification. There will be a need for new architectures to support more diverse use cases rather than the industry's historical emphasis on adding capacity and coverage. Diversification will also lead to a proliferation of device types. Examples include wearables, climate-sustainable sensors, and devices with multi-sensory capabilities, among many other possibilities.

The proliferation of uses in smart homes, smart cities, and industrial environments, among others, will place new requirements on 6G systems. Trusted, secure, and resilient communications will need to function in flexible factories of the future and distributed agricultural lands, for example. These will require some combination of innovative technologies to facilitate device cooperation through advanced side link and multi-hop mesh communications. There will also be a need for innovation in localization and sensing, and advances in cellular communications to support distributed computing paradigms, among other technical possibilities.

1.2 Vertical Sector Needs and Their Implications for 6G

Building on the work of NGA's *Roadmap to 6G* report, this publication focuses on the diversity of application opportunities arising in different industry verticals. The aim of this report is to trace the implications of vertical-specific use cases into applications that 6G can enable and then highlight the promising technologies that need to be researched and engineered into operational systems. To this end, members of NGA's Roadmap WG researched these issues through interviews with vertical industry leaders and market representation groups. The implications for North America's roadmap action plan draw on a synthesis of research findings and high-level statements of vertical-sector needs (Figure 1.2).

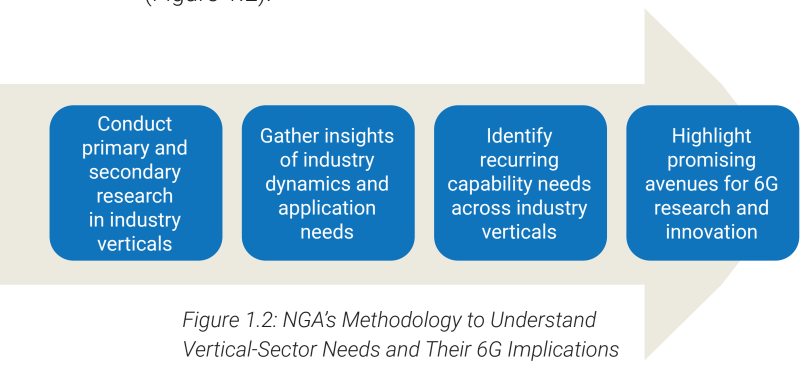


Figure 1.2: NGA's Methodology to Understand Vertical-Sector Needs and Their 6G Implications

A critical component of these conclusions draws on the early initiatives launched in the academic sector. The intention is to build on the work of NGA's ***Roadmap to 6G*** report by focusing on the diversity of application opportunities anticipated in different industry verticals. The aim of this report is to trace the implications of vertical-specific use cases into applications that 6G can enable and then highlight the promising technologies and a plan for commercial realization.

1.3 Favorable Policy Tailwinds

This report is the consequence of outreach toward several industry sectors that will benefit from specific policy initiatives that are contemporaneous with the 6G era. These will transform the U.S. over the coming decades and have ripple effects across the globe. Passage of the CHIPS and Science Act and the Inflation Reduction and Infrastructure Act send an important market signal. Massive funding and financing instruments aim to foster new markets in the future economy and onshore high-technology manufacturing.

A fundamental aspect of these initiatives is the emphasis on collective approaches that leverage government direction setting, significant investment capacity, and an aspiration to crowd-in private sector resources. The climate for public-private collaboration, backed by significant investments and multi-decade ambition, resonates with the NGA's roadmap for 6G and its ambitions for North America.

By spanning the boundaries between the communications and adjacent industry verticals, this second ***Roadmap*** report lays the foundations to improve bidirectional information sharing. Our members seek to add momentum to a process that inspires different user communities and fosters strategic thinking about innovative use cases and their 6G technology dependencies. Success will help to accelerate the standardization cycle while improving time-to-market and commercialization prospects.

1.4 NGA and Report Objectives

Although it can be tempting to focus on the latest in technological advances, the priority for the NGA's Roadmap WG is to reach out to the broadest range of stakeholders from vertical sectors to academic and applied researchers, service providers and vendors. There is a special emphasis on North American government, which can take action to strengthen the region's leadership impact by cultivating more partnerships building on the NGA membership's goals and priorities.

We want readers to learn from our research insights and to act on the long-term potential of 6G. To have a positive and tangible impact on North America's prospects, we want government agencies to take immediate action. We also want public and private sector entities to seize the opportunities for collaborative research, partnering within and across disciplines or becoming an NGA member.

1.5 Structure of this Report

The report begins by setting the context and motivation for this report in chapter one. Chapter 2 describes the research and analysis methodology followed by members of the NGA in assessing the landscape, needs, and technology implications from different sectors of the economy.

Then Chapters 3 to 10 deal with each of several industry verticals. There follows a synthesis of commonalities and recurring needs identified through the research process in Chapter 11.

The report concludes with Chapter 12 which identifies the NGA's priorities and recommendations to move forward with North America's action plan for the roadmap to 6G.

2 CAPTURING AND INTERPRETING VERTICAL INDUSTRY NEEDS

One of several themes in the NGA's *Roadmap to 6G* report dealt with the need to close the information gap between the communications industry and adjacent vertical industries. The latter contains users who will innovate to create new markets and business opportunities. A cross-boundary dialog seems essential to understand the pressures driving different verticals, as well as major trends in how they use communications systems. Knowledge gained from these discussions provide the basis for insights into example applications and how communications systems are expected to be used. It is unrealistic to expect experts from industry domains to specify communications needs that relate directly to 6G. Technologists therefore need to reach across the divide to identify candidates for 6G research, innovation, and solution offerings.

2.1 Research Approach

NGA members examined eight industry verticals based on their economic importance and expected reliance on next-generation communications systems. Table 2.1 summarizes these focus areas.

Table 2.1: NGA Explores Potential 6G Use Cases Across Eight Industry Verticals

VERTICAL INDUSTRY	IMPORTANCE IN THE 6G CONTEXT
Agriculture	Representing over 5% of the economy of each of Canada and the U.S., the agriculture sector can benefit from advances in computing technologies and energy-efficient wireless IoT sensors to improve sustainability, increase efficiency, and streamline logistic operations.
Automotive	Connected car developments are likely to unleash innovation and commercial opportunities that touch everyday living on a scale that compares with the arrival of the smartphone ecosystem and technologies.
Education, Gaming, and Entertainment	Individually, the education, gaming and entertainment sectors are large markets that contribute significant value to the North American economy. Advances in 6G communications and immersive technologies will fuel continuing growth of these sectors as they leverage a common set of technologies and applications.
eHealth	Representing 15-20% of Canada's and the U.S. gross domestic product (GDP), the health sector is a significant opportunity for connecting the promise of 6G to the societal needs, economic interests, and strong policy goals of North America
Industrial	The importance of Industrial IoT (IIoT) (which is the pillar of the 4th Industrial Revolution) is in extending IoT concepts to address larger economic opportunities by linking communications, information, and operational technologies.
Mining	Mining is a significant North American industry, supplying resources for other sectors of the economy in addition to being a major contributor to economic and employment activity.
Public Safety	Public safety use cases offer an obvious avenue for use of commercial off-the-shelf (COTS) technologies that can bring essential societal needs into the broadband era, including those benefits offered by 6G in a variety of areas like immersive communications, robotics and sensors for crime prevention and enforcement, for emergency services and rescue, and for disaster relief.
Smart Cities	Cities have a variety and interdependency of architectures involving many aspects, such as supplying energy, transportation, water, public health, and other services. A critical aspect of interdependency stems from the data associated with each infrastructure. 6G provides an opportunity for synergizing these aspects to increase efficiency and optimize productivity.

For each vertical, NGA members combined literature research and interviews with industry experts to gather information on industry drivers and 6G needs. In addition, members of the academic community held internal discussions to explore topics at the intersection of academic research and industry vertical needs.

Research and interviews helped paint a picture of current and anticipated vertical applications. The challenge for NGA's researchers was to interpret this information to identify the range of capabilities and enabling technologies required from future communications systems. These insights then form the basis to plan for 6G research, innovation, and standardization activities. In some cases, interviewees highlighted non-technical issues. These are just as important for market development activities.

Interoperability and scale are important characteristics of the communications industry because of their impact on ubiquitous access and affordable services. The next stage of analysis for this report explored commonalities across verticals to distill a set of strategic actions for the NGA.

3 AGRICULTURE AND 6G

The agriculture sector spans a broad array of activities. It extends well beyond farming and encompasses a range of farm-related industries including food service and food manufacturing. In 2020, agriculture, food, and related industries contributed $1.055 trillion to the U.S. GDP, representing a 5% share of the economy according to the U.S. Department of Agriculture.[2] Sectors related to agriculture include food and beverage manufacturing; food and beverage stores; food service and eating and drinking places; textiles, apparel, and leather products; and forestry and fishing. On average, spending on food amounts to 12% of household budgets. Canada's agriculture and agri-food system accounted for one in nine jobs and generated around 6.8% of Canada's GDP in 2021.[3]

Beneath the surface of farming resources and activities, there are clearly many different provider, supply-chain, and consumer facets where the communications industry is present and can function as an economic enabler.

6G for agriculture has the promise of leveraging advanced computing technologies (big data, the cloud, edge computing) and energy-efficient wireless IoT sensors to improve sustainability, increase efficiency, and streamline logistic operations. Implementation of ICT technology based on 4G/5G/5G-A is already underway in this sector.

The agriculture vertical touches five of NGA's Audacious Goals:

- **Sustainability and Cost Efficiency:** Making access to equipment and crops more sustainable and energy efficient by increasing efficiency and reducing emissions by optimizing remote access to farm equipment and crops.
- **Distributed Cloud and Communication Systems**: Putting key data in to the cloud, anonymizing usage to allow greater overall efficiencies for the supply chain.
- **Increasing Trust, Security, and Resilience**: Creating secure systems with near- and real-time updates
- **Digital World Experience (DWE)**: Integrating all these aspects in to the agriculture sector for a robust digital world experience. Uniquely, 6G technologies will create a robust portfolio of opportunities for the agriculture sector.

3.1 Agriculture Sector Landscape

In discussions with agricultural experts, the starting point for any analysis begins with farming. This is presumably because its role fans out to several segments in the wider agriculture and agri-food sectors.

A key observation is that modern-day farming is a logistics business driven by data science. That means data sourcing, access to granular data, and availability of time-series data are essential building blocks for the future of the sector.

Cost economics are also a driver that heightens the need for data, analytics, and decision-making capabilities. A case in point involves labor productivity, which is linked to the industry's trend for larger farms serviced by bigger machinery. However, the industry faces real-world constraints in the form of road widths that impede or slow the movement of machinery and equipment breakdowns. These necessitate backup solutions such as mobile repair crews that are dispatched to resolve breakdowns.

The pressure to reduce labor costs has an outlet in solutions intended for moving machinery autonomously. Although this reduces the dependency on crews, it creates requirements for high-rate communications and situational awareness capabilities. A related but different example of moving machinery involves a harvester working in tandem with load-hauler. This illustrates a peer-to-peer use case with implications for the underlying systems for communication and coordination. Local processing techniques are relevant because of the reliance on high-speed communications. Cloud computing is currently not on the agenda because it is better suited for slow data applications, which are unable to support autonomy. There remains a level of resistance to cloud computing because of disputes over data ownership. In any case, full autonomy is currently not a complete solution because machinery jams can still require a repair to be dispatched.

Another industry driver is agronomics, which uses data to help farm managers decide what to plant and when.

A key driver is knowledge of input costs relating to fertilizers, movement of machines to sites, and the total cost of loading machine configuration data remotely. Many of the topics depend on communications system capabilities.

3.2
Societal Needs

In keeping wider societal developments, sustainability, and energy efficiency have an important bearing on the agriculture sector. At the farming level, this is most evident in how to improve the use of water resources.

There is also a significant overlap between farming and road infrastructure. Movement of vehicles and the machines used by repair crews have an impact on the traveling public. Farm managers are also conscious about better uses of fuel, an issue that has material impact when planning route for large machinery on rural road networks.

Reactions to society's concern over environmental conservation are another consideration. This manifests itself in the way that farm managers optimize the use of fertilizer treatments and mechanisms to irrigate plants close to their roots to reduce evaporation and conserve resources.

Part of the solution to each of these societal imperatives depends on trustworthy and resilient connectivity in rural and remote locations. Furthermore, a greater reliance on data for decision-making depends on massive sensing and remote actuation capabilities. These are typically associated with IoT technologies and ubiquitous connectivity.

3.3
Enabling Applications

Five types of suggestion emerged in the research for enabling applications in the agriculture sector. The first of these is organizational, with a desire that agricultural machinery be included in the 5G Automotive Association's activities scope. In addition to harmonization benefits, such a development would help the agri-vehicles ecosystem leverage the industry representation presence and scale of the automotive industry.

A second set of suggestions fell into the category of sector drivers. This is an encouragement for the communications sector to explore capabilities that will enable greater uptake of autonomous functionality. Through industry interviews, a trend to reduce the size of machines was cited in the context of a farm manager shifting from one large machine with its support crew to 10 smaller, autonomous ones.

The third type of suggestion arose from questions about communications system capabilities. For example, are there ways to further improve coverage, even temporarily, with mobile cell support and using both terrestrial and non-terrestrial network (NTN)?[4] One example need is for highly precise positioning information from cellular networks. Positioning need not be ultra-precise for all use cases. The target for planting is cm-level precision. Finally, in mesh or peer-to-peer configurations, there is a need to lower multi-hop latency.

Capabilities associated with IoT technologies were a fourth category. With increased reliance on remote sensors and their data, there is a desire to increase the use of zero-power sensors. Although LoRAWAN is now a default technology, its performance is limited. Long-term planning should focus on scaling up data rates and reducing latency. There is also a need to extend the capability for remote software management. This calls for greater intelligence in performing updates and managing software patches to avoid ineffective updates when service providers are aware of poor coverage and when network coverage is unexpectedly lost.

A greater use of robotics in farm settings illustrates the final category of application use cases. Robotics could revolutionize the management of tree crops and deliver labor savings.

Digital twins provide many opportunities for the agriculture sector. One example is analysis and remote repair of equipment, which is especially important in remote areas where in-person diagnostics may not be readily available. Another example is remote analysis of crop conditions in real- and near-real time.

Figure 3.1 shows many different types of data and communication interactions that occur in the agricultural space.

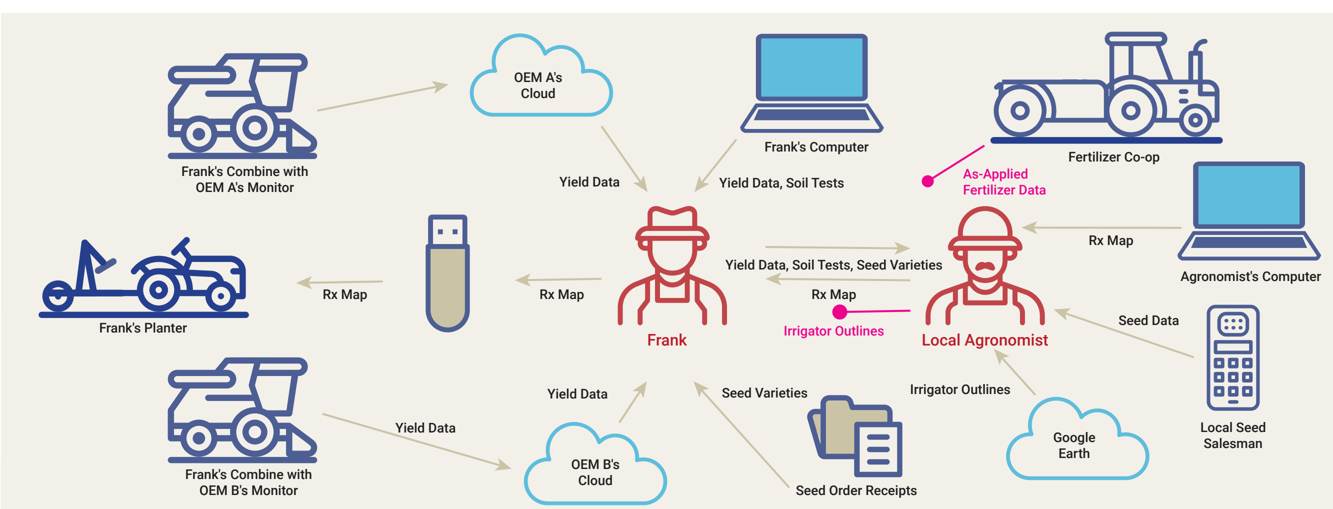


Figure 3.1: Trends in Ag Internet of Things: Edge-Fog-Cloud and QoS Demands for Networking (Source: Prof J. Krogmeier, Purdue University)

3.4 Key Technologies and Challenges for the Agriculture Sector

There is a need for innovation across several key technology categories to address the demands of current and emerging use cases in the agriculture sector.

The importance of granular and dependable data for decision-making makes sensor devices and sensing mechanisms a key technology category. Although the installation of sensing devices is important, what will drive adoption is the ability to control and improve their decision-making capabilities. The use of sensing data for decision-making should consider the important goals for the agricultural industry; that is, generating revenue and saving time. Another aspect to consider is leveraging sensing technology, UAVs, and autonomous tractors using the existing network infrastructure instead of deploying private networks. This would integrate new technologies more quickly in the agriculture sector. With different network operators, making multi-network environments accessible, affordable, and ubiquitous is a critical step for sensing technology integration.

Advances at the intersection of computing and coverage are a key technology area for the agriculture sector. For example, accessibility of edge data, which arises in cases of peer-to-peer image sharing and Light Detection and Ranging (LIDAR), requires higher computing capacity.

A second key technology category applies to data and data-sharing platforms. Data sharing is an opportunity for agriculture that has yet to be implemented. The main reason for this is concern about data security, especially when dealing with competitive aspects within the agricultural sector.

Better and innovative uses of data will require technologies that facilitate data sharing between applications to establish a thread for analytics and decision-making. An example given by industry representatives involves predictive guidance for the next season's planting. This relies on historical profiles about planting and harvesting in one season and information about resources and growing conditions for the next one.

An increased use of tele-operation and autonomous vehicles makes latency reduction a third key technology category. With decision-making at different timescales, latency requirements in agricultural applications can vary greatly. For irrigation systems, latency may be measured in minutes; similarly, when a field is drying, the latency can be in the order of days. However, for autonomous vehicles, the combination of low latency and high reliability is critical.

Connectivity is a fourth key technology area for the agriculture sector, especially as many farming, animal husbandry, and haulage activities span vast distances. In some use cases, the users may not need network connectivity 95% of the time. Network connectivity may be required only during farming and possibly only a few hours per year with certain machines. It is difficult to justify costs for network expansion if they get little or only sporadic use. From a mobile operator perspective, it is challenging to prioritize services and devices only for farm use. This means that 6G research needs to explore mechanisms to provision need-based services with suitable levels of investment. Network connectivity needs to consider ease of field installations and maintenance.

3.4.1 Non-Technical Considerations

While wireless companies aim to improve rural network services, there remains a need for major capital investment for more agricultural use. With different network operators, the challenge of making networks accessible, affordable, and ubiquitous is a critical step for technology integration.

Another consideration applies to the pace of adoption. Improved decision-making and automation are key domains. They are candidates for investment in advanced wireless research and development and pilot applications. Leveraging sensing technology, UAVs, and autonomous tractors using the existing network infrastructure instead of deploying private networks can help to integrate the new technologies faster in the agriculture sector.

Finally, the agricultural sector needs policies to enable 6G technology research and development. This means regulations that are purposeful in encouraging less wasteful irrigation and water use. There also needs to be more avenues for stakeholder engagement.

4 THE AUTOMOTIVE SECTOR AND 6G

The smartphone embodies a range of technical innovations and organizations responsible for connectivity, content, and services that have touched the lives of an unprecedented number of consumers. This has delivered incredibly rich user experiences that have been transformational over the past decade. The Connected Car presents a similar opportunity for the modern era by extending rich user experiences into vehicles while creating a trusted and secure environment that improves driver safety.

For the smartphone, the rich experience was enabled by a convergence of innovation in Human Machine Interfaces (HMIs) and a broad services ecosystem. For the automobile, convergence takes the form of three innovative trends in connectivity, autonomy, and electrification that are driving industry transformation. Automotive connectivity holds several research and engineering implications for 6G, including advancements in technologies such as NR sidelink and NTNs. Other areas include positioning, ISAC, distributed computing, air interface, security/privacy, and smart materials. Combinations of these technologies and a wider automotive-industry ecosystem will make many new use cases possible.

Three of the NGA's audacious goals are of greatest relevance for meeting the demands of the automotive sector. The potential for rich user experiences, which are related to the **Digital World Experience (DWE)** goal, stems from the availability and expected increase of vehicle communication (V2X) and sensing tools (radar, LIDAR). As the number of onboard computing applications increase in automotive, **Distributed Cloud and Communications Systems** will enable flexibility across edge and cloud resulting in increased performance and resiliency for Connected Cars. Finally, Connected Cars have specific requirements for security to maintain vehicle safety and user privacy, which align with NGA's **Trust, Security, and Resilience** audacious goal.

4.1 Automotive Sector Landscape

The automotive ecosystem involves participants from different fields, as illustrated in Figure 4.1.

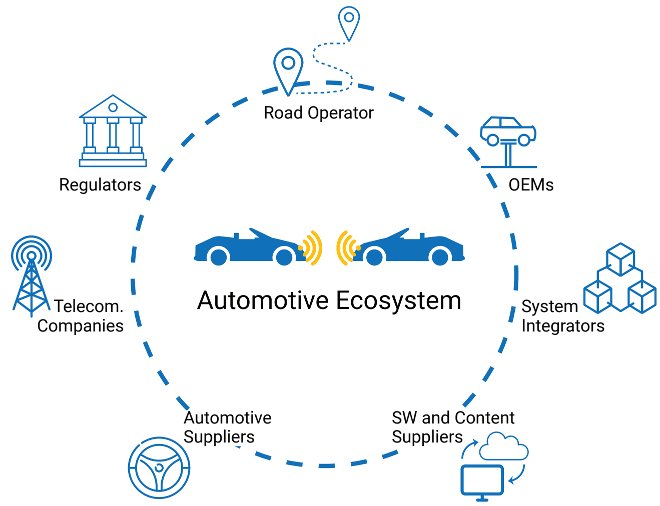


Figure 4.1: Evolved ecosystem of automotive industry

New entrants and incumbents in the expanding industry ecosystem have accelerated the pace of innovation. Many of the new automotive capabilities enable safer and more efficient road trips, with a growing dependency on connectivity technologies and systems. These accomplishments build on initiatives to promote collaboration and interoperability within a widening ecosystem via industry alliances, which provide a forum to exchange ideas with a focus on key industry issues, and via standardization bodies.

Examples of industry alliances with differing sector priorities include the following:

- **5G Automotive Association (5GAA):** The association set out to bridge auto and telco sectors, notably in the context of 5G and beyond systems to promote and develop Cellular Vehicle-to-Everything (C-V2X) as a unified technology platform for cooperative, connected and automated driving. Membership currently includes more than 130 automotive manufacturers, tier-1 suppliers, chipset/communication system providers, mobile operators, and infrastructure vendors.
- **Connected Vehicle Trade Association (CVTA):** Currently, more than 220 members have joined this non-profit business league to promote the value of the connected vehicle by identifying the opportunities for ecosystem participants,

establishing and maintaining dialog with public and private decisionmakers, and promoting the corresponding solutions.

- **Alliance of Automotive Innovation (AAI):** The Global Automakers and the Alliance of Automobile Manufacturers merged in 2020 to create the AAI. Its focus is providing information to policymakers on key issues affecting the automotive sector, support related state and national legislation, and offer industry-oriented content.
- **Automotive Edge Computing Consortium (AECC):** This organization primarily focuses on the network compute aspects of the evolution of current network architectures and computing infrastructures for the automotive industry.

From a technology development perspective, several international standards and associations have engaged to enable interoperable solutions across the ecosystem:

- IEEE 802.11bd Standard: Dedicated short-range communications (DSRC) is based on IEEE 802.11p, which was approved in 2010 as the first communication standard for V2X. Recently, IEEE 802.11 standards work finished developing IEEE 802.11bd to leverage the evolved wireless local area network (WLAN) technologies to future proof DSRC. Published in March 2023, IEEE 802.11bd provides the foundation for a variety of new applications, such as higher throughput, higher reliability, and extended range in the intelligent transportation system (ITS) radio service band. In November 2020, the FCC reallocated all DSRC spectrum for other uses, citing lack of adoption, with 45 MHz going to the neighboring 5.8 GHz ISM band and the remaining 30 MHz to use by Cellular V2X.
- 3GPP C-V2X Technical Specifications: 3GPP has extended the cellular standards applicability to support V2X services in both 4G and 5G systems. In addition to enhancement necessary to support V2X use cases using cellular-based solutions, 3GPP introduced short-range communication technology for V2X (i.e., NR-sidelink communication in 3GPP terminology) for basic road safety use cases in 4G systems, as well as more advanced V2X use cases in 5G systems.

3GPP is currently the forum to address technical issues systematically through its roadmap plan. It is essential to maintain cross-sector dialog to feed the requirements into the standardization and solution/technology development communities.

4.2 Societal Needs

North America is the world's second largest automobile market, with 16.6 million vehicles sold in 2021 across the U.S. and Canada. China is the largest market, with 21.5 million sales.[5] The U.S. has the world's highest number of cars owned per capita and the highest kilometers traveled per capita. [6]

North America's continuing reliance on cars — for reasons that range from local convenience to longer-distance commuting — heightens the importance of developing 6G automotive technology. One target for this is to enable greater safety.

Over the past 45 years, there have been significant changes in the statistics for deaths on U.S. roads, as shown in Figure 4.2. The clear downtrend since 2003 is mainly due to increased use of safety features such as airbags, seatbelts, cameras, and lane departure sensors. On the other hand, motorcycle and pedestrian deaths are on the rise, which points to a need to be considered for 6G technologies.

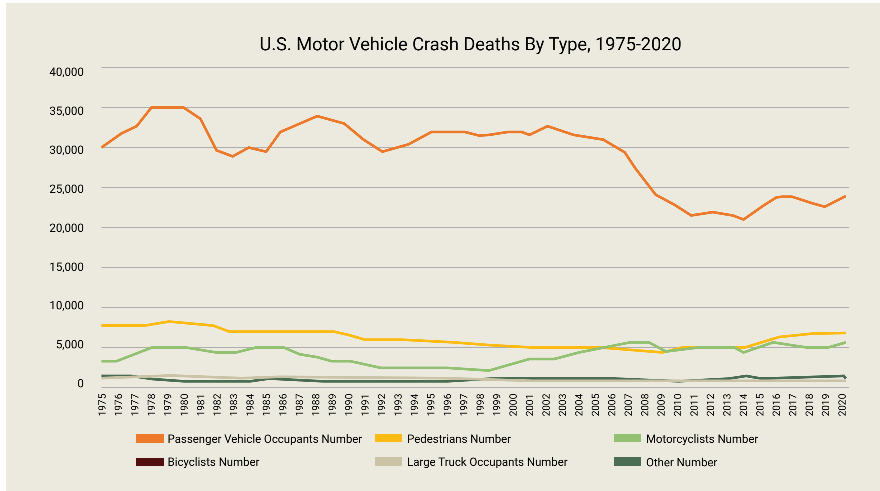


Figure 4.2: U.S. Motor Vehicle Crash Deaths by Type 1975-2020 [7]

Technologies such as C-V2X within 5G can improve safety at the network level. In 5G and 6G, features like NR-sidelink can enable information sharing between vehicles while still allowing network assistance via C-V2X. This helps meet the objective of enabling more autonomous driver-assistance features, such as emergency braking, speed modification, traffic guidance at intersections, traffic light control, and fuel management, among others.

4.3 Enabling Applications

Today's automotive services depend heavily on mobile connectivity. Future use cases and applications will require higher speeds and lower latency, and the integration of computing and sensing services with connectivity systems.

Table 4.3 presents four categories, each illustrated with example applications. The first deals with safety-related applications. For example, V2V and V2P can improve safety on roadways, while infrastructure can provide vehicles with greater awareness of the environment, thereby making accidents exceedingly rare. The second category encompasses autonomy solutions. As technology progresses over time, available connectivity options can enable complete control of vehicles in platoons. They can also enable individual vehicles to operate on controlled paths, in designated areas with reliable and secure coverage. In better defined settings such as factory campuses, mines, and warehouses, remote vehicle operation can reduce the reliance on human drivers. Some situations may also be amenable to fully autonomous operation of robotic vehicles to move people and goods. A third category applies to energy management based on the use of sensors in both traditional and electric cars. Another efficiency benefit involves sensor diagnostics to automate communications with maintenance workflows. For the final category, cellular technologies will continue to offer better forms of infotainment to passengers, while Augmented Reality (AR) features can improve the attention of drivers to driving conditions.

Category	Application	Description
Safety	Accident Reporting	A time-windowed recording of vehicle systems data, rich sensory information, environmental conditions, and any available camera views is sent to government and private data centers.[8]
	V2P Communications	Vehicle-to-pedestrian communication to exchange warning information.
	Safe Intersection Crossing	Vehicles receive a message when they are approaching an area in which the pedestrian intends to cross and send an acknowledgment when they have begun to slow down.[6]
Autonomy	Autonomous Driving	There are five levels of autonomous driving: 1) Driver Assistance 2) Partly Automated Driving 3) Highly Automated Driving 4) Fully Automated Driving and 5) Full Automation. The initial levels can be implemented independent from communication systems. However, moving to the higher levels of automation will require communication systems that can continuously update data about situational awareness, coordinate with other vehicles, and receive software enhancements.[9]
	Autonomous Parking	Drawing on to 5GAA studies, consider two usage scenarios. In Type 1, the vehicle communicates with the parking facility to admit the vehicle for parking, verify the position of the vehicle, and send a wake-up call when it is ready to leave the facility. In Type 2, the vehicle also receives its Vehicle Motion Control (VMC) message through a wireless link and is remotely controlled by the parking lot infrastructure using the wireless network.[8]
	Remote Driving	Remote driving allows the vehicle driver to hand driving off to a remote driver who can provide the appropriate trajectory and maneuver instructions to navigate to the destination efficiently and safely.[6]
	Coordinated Driving	Coordinated Driving is when a driver wants to perform a certain action (e.g., lane change, exit highway, U-turn, etc.) and shares this intention with other traffic participants potentially involved in the maneuver.[6]
	Curbside Passengers Pick-Up	The pedestrian and vehicle indicate to their respective devices (e.g., vehicle, smartphone, etc.) that they are looking for each other. The curbside area is part of a managed traffic management system that has knowledge of all active pick-up sessions. The designated pick-up zone is communicated to both the vehicle and the pedestrian, which then both communicate with each other directly until pick-up is confirmed.[6]
	Urban Air Mobility (UAM)	UAM will enable novel air transport services within urban and suburban environments using small, uncrewed aircraft operated between vertiports in a specific metro area. Low-latency and highly reliable communication systems are needed to support the navigation and collision-avoidance functions.
Efficiency Management	Real-Time Situational Awareness	Understanding the surrounding around the vehicle 360 degrees in real time.
	Navigation with High-Definition 3D Maps	Roadmaps with inch-perfect accuracy and a high environmental fidelity that contain information about the exact positions of pedestrian crossings, traffic lights/signs, barriers, and more.[10]
	Platooning	Platooning enables a group of vehicles to drive near one another in a coordinated manner. The lead vehicle in the platoon is responsible for coordinating other vehicles in the group. By sharing status information (such as speed, braking and acceleration) between the platoon members, the distances between vehicles, fuel consumption, and overall costs can be reduced.[6]
Info-tainment	Infotainment	Services to passengers continue to be expanded given higher availability of compute and connectivity. Music, video streaming, textual information, in-vehicle shopping, and new services provided by app stores will enable a rich infotainment experience.

Table 4.3: Usage Categories and Example Applications in the Automotive Sector

4.4 Key Technologies

Research insights suggest that 6G's key technology advances should provide more capabilities for automotive sector use and improve the use of spectrum resources.

Critical automotive applications — such as advanced driver safety, remote/autonomous driving, public safety, or other critical V2X applications — will place higher demands on low-latency and highly reliable communications. There will also be a need to apply distributed computing techniques. In part, this is to support mobility services at the network edge and provide distributed AI. That calls for enhancements to the edge computing infrastructure and an expansion of the suite of orchestration of services built on top of it.[11]

The very high computing workloads associated with autonomous driving and advanced safety require a high-capacity power supply. The addition of AI tasks into the vehicle's compute operations may push power requirements significantly further. These are factors that can reduce the driving range in the case of Battery Electric Vehicles (BEVs). The cost of high-power compute aboard vehicles might undermine affordability in mass-market segments. For several reasons, there is a requirement to seamlessly offload selected "on-vehicle" compute tasks to "edge cloud" and "central cloud" locations. A key step in engineering new technologies is to define, evaluate, and monitor the KPIs that will meet the offloaded task's requirements for a given network deployment.

Joint Communications and Sensing (JCAS) is the capability to sense the environment for mobility applications. Its use will benefit both user/environment perception and communications systems performance. In addition to low latency and reliable communications, improved situational awareness for connected vehicles also depends on high-fidelity sensing and localization.[12] Joint communications and sensing will enable distributed perception capabilities. These allow a system to create and update a feature-map of the environment to assist navigation services for safe and efficient robot/vehicle mobility.[11] Improvements in situational awareness will facilitate numerous uses of position-based services, as well as advanced V2X applications.[12]

Full coverage of wireless connectivity is needed across the road network to support critical use cases. This goal requires a set of network technologies with coverage significantly beyond the expected 5G terrestrial network coverage. The combination of innovative technologies to improve accessibility include NTN, mesh connectivity, and advances in NR-sidelink communications. NTN and "network of networks" technology are candidate solutions for expanding network coverage in a cost-effective way. This is because the deployment of sufficient cell towers to provide full road coverage may not be cost effective. Although the technologies associated with NTN are being developed in 5G specifications, the service KPIs (e.g., data rate, handover time, mobility performance) may not fully meet future automotive use case requirements. 6G has a role to plan in enhancing NTN integration.

NR-sidelink device-to-device communication (e.g., V2V, vehicle to user equipment (UE), or vehicle to infrastructure) was initially developed as a part of 4G (as PC5 broadcast-only mode) and enhanced in 5G (as NR-sidelink with feedback and groupcast/unicast possible). 6G can enhance NR-sidelink performance to meet extended requirements (e.g., range, capacity) or enable new connectivity solutions (e.g., for intra-vehicle connectivity of various sensors and devices). Mesh networks can also provide efficient solutions for ad-hoc coverage extensions. Meta/refractive surfaces on vehicles also offer promising benefits for improved in-vehicle coverage.

The automotive industry has specific requirements for security that are derived from strict requirements and definitions for safety in a vehicle. The increasing role of communications systems in automotive applications makes E2E trustworthiness a critical capability for 6G to address. If driving tasks make direct use of information coming from wireless connections, then the security of the wireless connection must be assured to ensure the whole driving task is secure from external interference (e.g., deliberate attempt to affect the driving of the vehicle).

In addition, vehicle data such as occupant identity, locations visited, and driving behavior might introduce data privacy implications. This might be the case where vehicle occupants require certain privacy levels (i.e., data sovereignty) to be maintained. Current 5G systems offer both security and privacy for data. However, in the "post-quantum" world, this may not be sufficient. Security and privacy features in 6G will need to ensure sufficient capability to meet the needs of new classes of automotive use case.

4.5 Spectrum Implications

In the area of spectrum enhancements, existing bandwidth allocations at 5.9 GHz for V2V do not support future use cases where high-bandwidth data (e.g., raw sensor sharing data) is exchanged between vehicles. The same is true of use cases where high-bandwidth data is shared to infrastructure (e.g., vehicle maintenance and updates). To address such issues, the first step is to investigate methods for making higher frequency bands (with more spectrum available) suitable for V2V applications. There is also a need to address issues such as propagation loss and non-line-of-sight capabilities. Finally, the common scenario of many vehicles caught in traffic can lead to congested radio environments and require innovation in providing ultra-high-reliability communications.

5 EDUCATION, GAMING, AND ENTERTAINMENT AND 6G

A solid track record of wireless communication and immersive technology innovations provides the foundations for continuing growth in the Education, Gaming, and Entertainment (EGE) sectors. Individually, each sector represents a large market that contributes significant value to the North American economy. For example, by some estimates the educational apps market is poised to grow to $38 billion by 2028 at a Compound Annual Growth Rate (CAGR) of 25%.[13] Meanwhile, the mobile gaming market is estimated to reach $80 billion by 2030 with a CAGR of 12%.[14]

For strategic reasons, there is a strong connection between EGE sectors because they leverage a common set of technologies and applications. Cellular technologies underpin the gaming and entertainment industries in the form of streaming services and interactive cloud-based gaming applications. These developments have consequences in the education vertical through online training, simulations, and interactive virtual schools, among other applications. This interrelationship and other commonalities account for the NGA's inclusion of education within this broader vertical.

The EGE Industries are important in the context of 6G planning as evident from three of the NGA's audacious goals. In **Digital World Experiences (DWE)**, 6G will improve human interactions across physical, digital, and biological worlds, which will lead to more realism in EGE experiences. **Cost Efficiency**, a second audacious goal, is critical in education to enable access for hard-to-reach learners in remote locations. The strong presence of North America in global educational rankings[15] means that 6G technologies can leverage cost savings to increase the reach of top-tier education to a broader regional and global population.

Finally, **Trust, Security, and Resilience** encompasses the topic of identify management. This is of critical concern to support secure identification of users and their rights to access digital assets. In addition, within the EGE setting, managing access to age-appropriate content and experiences will become more complex with increased access to digital objects and across virtual worlds.

5.1 Education, Gaming, and Entertainment Landscape

Mobile gaming is nowadays the most popular form of gaming, having overtaken console and PC/laptop gaming. It represents an important dynamic over time and across EGE sectors. This is where interactions between providers and users have evolved from physical to console and then to online-mobile platforms. Smartphones enable new types of applications such as "hyper-casual" games, which are lightweight and instantly playable. They also offer the ability to interact with other remote players anywhere in the world.

More sophisticated game applications and new device types, such as AR/Virtual Reality (VR) glasses, enable hyper immersive and multisensory Extended Reality (XR) experiences. XR is an umbrella term that covers immersive technologies ranging from VR to Mixed Reality (MR) and AR. In VR, users are totally immersed in a simulated digital environment or a digital replica of reality. MR includes all variants where virtual and real environments are mixed as in the case where digital information is overlaid on images of reality viewed through a device. The level of augmentation can vary from a simple information display to the addition of virtual objects and even complete augmentation of the real world. These developments have expanded the traditional business of selling games to other monetization models, including advertising and in-app purchases.

The education sector supports a wide range of uses, from online training programs to virtual schools. Mobile applications help later generations to refresh old knowledge or acquire new skills. There are also operational uses for classroom management, to simplify university campus life, and for campus safety to locate friends or to send instant calls for help.

In addition to attracting international students, the wider educational ecosystem will benefit from opportunities to export immersive knowledge and learning applications.

> For North America's highly respected university sector, 6G offers a way to maintain state-of-the-art capabilities in technologies for education.

Several elements of 6G are key to achieving these goals. They include universal access to XR devices (e.g., AR/VR Head Mounted Displays (HMDs)), hologram receivers, handheld sensors), high-speed and highly reliable networks, and the availability of immersive educational content. The combination of 6G elements also offers a pathway to improve educational opportunities for disadvantaged communities that lack access to traditional educational facilities due to physical handicaps or other challenges.

When considered in 6G terms, the application scope is similarly expansive for the entertainment sector. Immersive VR/AR enables new forms of entertainment especially for longer journeys via aircraft, ships, and trains. Very-high-resolution, 360-degree video or 3D video, and augmented XR experiences can inspire innovative advertising, social media, and television offerings. There will be multiple ways to use VR devices to virtualize music and sporting events with immersive entertainment and virtual spaces. One advantage of virtual events over live venues is the global reach that becomes possible. Add-on services can transform virtual experiences and create new sources of value from interactions with other fans and digital merchandising.

5.2 Societal Needs

The education vertical addresses a key societal need to develop skills for a successful economy and better quality of life. The United Nations Educational, Scientific and Cultural Organization (UNESCO) report on Global Education lists several challenges that mobile technology[16] can address:

> **Access, Equity, and Inclusion:** This includes access for disadvantaged groups such that education can be provided to hard-to-reach learners in remote locations and those with disabilities. Access to content is also a challenge where digital formats on portable devices enable lower cost and wider availability.

> **Quality:** Mobile applications can improve the overall quality of education through improved communications with students and parents, and applications to augment classroom learning.

> **Technology Development:** Mobile technology is an educational subject on its own. Science, technology, engineering, and mathematics (STEM) education is a national priority in North America and many other countries globally.

> **System Management:** Data analytics from educational mobile applications can be collected and used to support educational decisions where learning is needed most or where there are deficiencies in teaching staff.

The challenge of addressing key societal needs across the EGE verticals depends on two necessary foundations that the mobile system can address. First, trust, security, and privacy are fundamental to successful proliferation of new applications in these verticals. Education and gaming require personalized services where digital identities must be maintained for the integrity of the service.

Second, there is a need to broaden access across the age population. For example, entertainment content today is mostly consumed by younger generations. Many of the video posts and live content contain material that is informative and educational to broader age ranges.

There is a balance in how changes and solutions to societal needs are managed. An example is the role of cellular technology in education, especially in K-12 classroom settings. New, cellular-enabled applications can facilitate learning, organization, and notetaking. They can promote social learning and collaboration and allow parents to stay in contact with children for emergencies. However, cell phones can be a classroom distraction. From research discussions with education experts, there is greater scope for cheating, as well as the potential to encourage negative communication and bullying. Furthermore, not every student has access to mobile devices or may have differentiated capabilities throughout the classroom. These are some of the reasons why 6G proponents are pressing for societal needs to be part of the non-technical considerations that shape the 6G development roadmap.

5.3 Enabling Applications

Today's 2D experiences are limited to sight and sound. Their evolution will deliver significant benefits to the gaming and entertainment markets. In standards groups such as Moving Picture Experts Group (MPEG), for example, television is becoming less of a key device and technology driver. Instead, HMDs are expected to be a key device type for AR, VR, and XR experiences thanks to 3D display rendering at high-resolution levels. Additive technologies related to tactile interfaces, as well as olfactory and taste sensing, will enable digital world experiences entirely unique from today's devices.

The applications, devices, and sensing technologies that support the EGE verticals are largely similar. XR devices and services are applicable in consumer, enterprise, and virtual settings. They can transform how families and friends communicate with one another. They are already changing how working professionals collaborate in offices and industrial environments. Virtual trainers can conduct personal training sessions with people, including those affected by disabilities, for therapies that might not have been possible in the past.

In the broader world of social media, fashion, and digital assets, growing interest in metaverse concepts is likely to usher a transformative set of application enablers and EGE applications. Key enablers include 3D-rendered experiences, avatars, digital objects, and abilities to travel virtually across portals from one experience to another. Metaverse applications are expected to rely heavily on HMD devices, with less demanding use cases continuing to be satisfied by 2D viewing.

Digital economies are a type of enabling environment within the metaverse, based on digital assets that improve the appearance of a person's avatar, for example. Capabilities to create and share content in digital worlds are other examples of enabling applications.

Discussions with industry representatives found that simulation and digital twins are critical drivers of 6G technologies to support metaverse and digital world experiences. Simulation requires physical accuracy and real-time synchronization with real-world sensing, although these conditions can be relaxed in many gaming situations. Digital twins enable experimentation and learning with digital representation of objects such as the design of a building or surgery. XR brings the benefits of high-fidelity simulators to the complexities of medical education. The higher levels of interactivity in domains like anatomy, ultrasound scanning, and surgical simulators improve understanding. The variety of unique modalities of XR, such as tactile inputs, helps elevate the performance bar on instructional goals.

EGE industry representatives drew attention to several key requirements:

> **Reliability** is essential to provide consistent experiences in terms of data rate and latency. Seamless handover is also necessary to avoid glitches that will destroy the realism of the experiences.

> **Latencies** less than 10 msec are needed, whereas today's gaming traffic requires approximately 50 msec. This lower latency is critical for the motion-to-photon latency that reduces the lag between a user's movement and the rendering of that movement on the display. Motion sickness can be triggered in some people when this latency is greater than 15 msec. In addition, simulation systems with real-time human interaction require latencies lower than 10 msec.

> **Flexible and smart computing** capabilities that support distributed computing from the cloud to the device are needed. For gaming, it can be impossible to render for millions of people in the cloud at once, and processing needs to be moved closer to the edge.

5.4 Key Technologies

Technologies to support the EGE verticals will involve multiple domains and system components. These include devices, radio, core, and transport network technologies, and optimization technologies that improve end user experiences. To take advantage of innovative capabilities, service providers in the application layer need a deeper understanding of the technologies they use. Examples include network-based media processing, dynamic rendering, digital twinning, and spatial computing servers, to enable next-generation experiences. Key technology advances fall into three categories: devices, connectivity technologies, and open standards and APIs.

In the short term, the types of device to enable mobile XR experiences are expected to include smartphones, tablets, and HMDs or glasses. These will enable VR, entertainment, and gaming applications. Over the longer term and 6G timeframe, device enhancements are expected to raise challenges in areas related to higher performance holography, inter-device and inter-sensor connectivity, more energy-efficient technology, and higher processing power.

One family of key technologies for connectivity and media delivery addresses the capabilities to support extremely reliable and low-latency communication technologies in a scalable and sustainable manner. These are important pre-requisites for real-time immersive and multi-sensory communication and services such as XR or metaverse. In interviews, Metaverse Standards Forum experts indicated that real-time simulations demand more stringent low-latency requirements compared to gaming, which implies the need to reach sub-10 ms latencies. Furthermore, 6G should improve network performance to deliver a consistent and reliable experience at scale. Network coding is one example of a solution that can improve connectivity reliability and latency over lossy channels. Specifically, it is possible to tune coding parameters to suit delay-throughput-reliability requirements of the services as a means of optimizing network performance.[17, 18] In the case of education-related use cases, the emphasis for connectivity and media delivery technologies is on providing Quality of Experience (QoE) to a large coverage area at a lower cost.

It is also essential for the network to allocate resources tailored to the characteristics of any given application, such as video, audio, and multimedia. This depends on devices and networks learning about an application's characteristics by monitoring its performance over time and by learning from the characteristics of transferred data. Tailoring the QoE framework and resource allocated for a given application is essential for two reasons. One concerns the user experience, and the other is to improve network capacity utilization.

Specific media technology enhancements, targeting upper layer techniques, should provide further benefits to future multimedia applications. These include AI-based media processing and distribution, improved compression efficiency for dynamic visual data (2D and 3D), optimized media coding for sensors or new media devices, and energy-optimized media delivery.

Edge computing and distributed computing are key enablers for several applications. Lightweight XR glasses do not have the real estate, power capabilities, or the cooling capacity to support high-performing CPUs and GPUs. Applications will depend on edge resources to offload compute-intensive tasks, to meet QoE requirements, and to preserve battery power. NR-sidelink is another important technology enabler for HMDs that require connectivity with a user's smartphone and/or other wearables.

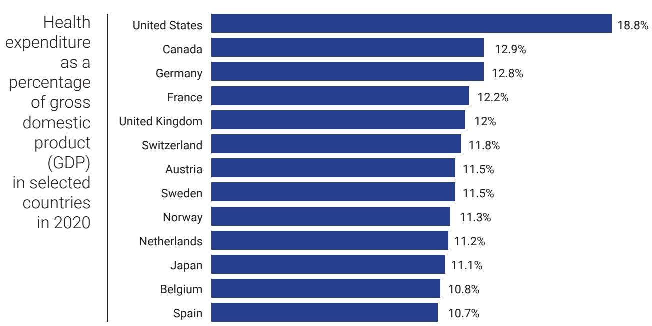
Another set of technology requirements arises from the need for devices and networks to become cognitive systems. This involves the ability to sense, reason, acquire new knowledge, and act more efficiently. The key enablers for this evolution are data-driven operations, distributed intelligence, continuous learning, intent-based automation, and explainable and trustworthy AI.

The XR ecosystem relies on many different technology sectors and components to be cost effective and provide a global scalable solution. One of the significant challenges for the developers is to create next-generation solutions using APIs that are network and device agnostic without requiring knowledge of cellular technology or device inner-workings. While open standards and APIs may be a proven path to ecosystem scale and end user affordability, additional security and privacy concerns need to be addressed.

Applications can use APIs to determine network resource availability related to bandwidth, latency, and coverage characteristics. Such information provides the basis to optimize user experiences intelligently and dynamically. For example, an application could use bandwidth information to program the encoder at the optimum rate. It could similarly use latency information to make the right offloading decision.

6 EHEALTH AND 6G

eHealth represents a significant opportunity for connecting the promise of 6G to the societal needs, economic interests, and strong policy goals of North America. In economic terms, the health care sector currently represents almost 15-20% of the U.S. and Canada's GDP, setting a high benchmark relative to other comparable economies across the world.



Pubished by Stastista Research Department, July 27, 2022

Wealthier health care provider systems can invest in future technologies. A comprehensive adoption of eHealth solutions will require significant improvements in the use of information and the delivery of quality health care outside of traditional facilities. These factors make mobility an essential component to the success of health care in 2030 and beyond. 6G technological developments will be important for several reasons. They will help to replicate traditional patient-provider experiences in remote environments and create a new paradigm for patient access to value-based health care *any time/any place*. Public-private collaboration will be a critical factor in achieving positive outcomes. It will be important for governments to partner with the private sector to significantly improve the availability and delivery of eHealth solutions to the marketplace.

The integration of AI into remote health care delivery models and the increasing use of AI's data synthesis capabilities for eHealth can effectively leverage one of the NGA's key goals: **AI-Native Wireless Networks**. The use of trustworthy AI is also part of a larger need for a secure and private conduit between health care providers and patients that traverses the physical, virtual, and biological worlds and depends on **Trust, Security, and Resilience**.

Enhancements to the patient-provider experience through innovative forms of interaction and data-intensive approaches to care delivery are recurring themes in the eHealth sector. This is also a theme that maps to one of the NGA's audacious goals: **6G Digital World Experiences (DWEs)**.

6.1 Health Sector Landscape

Research discussions with health care experts finds that the industry has undertaken a significant digital transformation over the past decade. One such change is the transition to electronic health records. This has positively affected how doctors interact with patients and how patients can independently manage their own health trajectory.

But the vision of high throughput patient connectivity is hampered by uneven access to quality health care across all of society. There are also gaps in joining together the many different elements surrounding a patient's health and quality of life. For example, a patient could go to a lab for testing, go online for their therapist, use an app for nutrition, see a particular specialist at the hospital, and get a routine blood pressure check at a local pharmacy. Without these elements being linked, there will be gaps in care.

As health care providers continue the journey to 2030 and beyond, pressure on available resources and escalating costs will accelerate the need for innovative approaches to remote patient care and monitoring outside of traditional health care models. Consider medical training, which is resource and knowledge intensive. There is a ripe opportunity for medical training using VR and AR tools that use ultra-high-bandwidth/low-latency experiences across mobile environments.

Health care is well-positioned to gain from deep investments in the development of 6G applications that incorporate capabilities such as digital twins, XR experiences, imaging and holographic services, and 6G as a network of networks. The intersection of health care needs with 6G applications will create new opportunities for both the health care industry and North American society, including health care partnerships with the communications and technology sector.

Another area of opportunity relates to health care data, where volumes are doubling every six months.[19] These include digital health records on genomic data, computed tomography, claims, and socioeconomic data. Health care organizations want to leverage this massive amount of data for better clinical and financial outcomes while expanding care to remote and at-risk populations. There are significant opportunities and benefits to be gained from coupling AI and 6G (especially metaphysical integration) capabilities to deliver safe and remote care for patients. For patients receiving care, the combination of AI's data synthesis capabilities and use of XR designs and products can optimize the patient experiences in various health care venues and potentially reduce providers' operational costs.

Discussions with industry experts identified four promising areas (Figure 6.1) at the intersection of the eHealth, the communications industries, and early conceptualization initiatives around 6G.

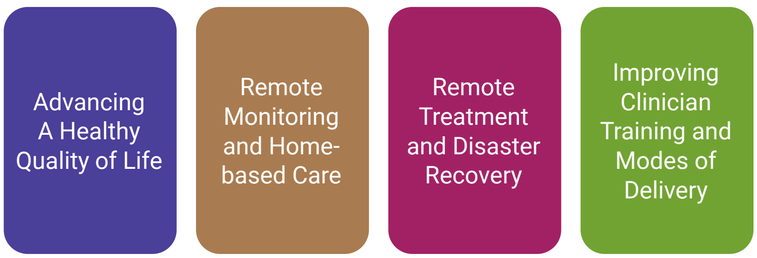


Figure 6.1: Four Promising Areas at the Intersection of eHealth and 6G Innovation

> **Advancing a healthy quality of life** involves better use of data and advances in the use of wearables, implanted devices, and in-body networks. Greater data availability in smart hospitals and AI-enabled patient digital twins will provide a medium to monitor and create a common view between providers, patients, and their caregivers.

> **Remote monitoring and home-based care** involve the delivery of care beyond physical, hospital confines. Example developments include concepts such as virtual hospitals or hospitals at home, as well as systems for ambient assisted living and home-based patient care.

> **Remote treatment and disaster recovery** introduce the ideas and technologies associated with remote scanning, as well as robotic surgery. The implementation of these capabilities will also rely on the use of patient digital twins and augmented situational awareness.

> **Improving training and modes of delivery for clinicians, patients, and caregivers** is important to enhance the quality and productivity of care delivery staff. Smart hospitals, patient digital twins, and wearable devices to capture patient information and deliver educational content are some of the required developments.

6.2 Societal Needs

Human longevity is one of society's most pressing considerations. The eHealth industry has a tremendous opportunity to address diverse needs across our life spans. As we live longer, how do we continue to age well and contribute to society? The Department of Labor (DOL) and Bureau of Labor Statistics (BLS) conducted a study that found the only age group increasing in the U.S. workforce falls in 75+ [20] category. The World Health Organization (WHO) estimates the number of people with dementia will rise to 78 million in 2030, 90.3 million by 2040, and 139 million in 2050. [21]

The American Association of Retired Persons' (AARP's) Longevity Economy® Outlook study found that demand from older adults for technology goes beyond smartphones and apps. Their enthusiastic adoption of smart home assistants, strong interest in automobiles with computerized driving assistance, and enrollment in computer-based distance education suggests that business leaders in technology would do well to pay them greater attention.

Another societal need is to improve the delivery of care services. One early-stage concept that responds to this demand is "virtual first primary care," where patients have their first health-provider interaction as a virtual experience, either with a bot or a nurse. Then, if they need in-person care they would visit a facility. Another promising opportunity is remote surgery. The capability for remote surgery is important because it extends the equity in care to disadvantaged populations by aggregating life-saving expertise and offering it across various physical distances that meet achievable latency requirements, for example.

As individuals recuperate and age in place, another societal need is for remote care. This is an area where communications networks and future 6G capabilities can improve the monitoring of people and devices outside of a facility by connecting medical devices directly to cloud architectures. Remote monitoring allows for increased mobility because these devices will no longer require a fixed connection. An expansion to the scope of remote care introduces the possibility for remote intervention. EOS Intelligence studies[22] show that AR navigation for minimally invasive surgical procedures achieves 85% accuracy versus 64% in conventional techniques. Increasing remote surgical procedures using AR could cut hundreds of thousands of days in hospital stays and save hundreds of millions of dollars annually. Traditional methods of training elder care facilities' employees can be in the thousands of dollars per employee, while VR training tools could bring the cost down to tens of dollars. In addition, VR-based training tools tend to raise medical trainees' retention levels to 80% as opposed to 20% with traditional teaching.

As the number of individuals being monitored remotely grows, there is a need for high-acuity and low-latency 6G capabilities. Next-generation networks must have the capacity to deliver remote monitoring data so that urgent notifications and location identifications can be made available to potentially dispatch emergency personnel.

6.3 Enabling Applications

DWEs encompass a variety of multisensory experiences that transform human interactions across physical, digital, and biological worlds. Innovative human-to-machine interfaces and synergies resulting from machine-machine communications are enablers of more expressive DWE interactions. Inter-personal application DWEs can improve the quality of everyday living (e.g., augmented situational awareness, ambient assisted living, wearables) and improve the quality of critical roles (e.g., virtual hospitals, remote surgery and scanning, home-based patient care). Another example of a DWE that improves the quality of living or critical roles is when remote sensing, haptic feedback, and actuation are combined to enable XR interactions with distant or inaccessible objects. This might arise in cases of remote surgery or when an industrial technician cannot obtain hands-on access to repair a faulty machine.

There are several application areas and components involved in the delivery and application types of DWEs, including the following illustrative examples.

eHealth Areas	Real World Applications
Multi-Sensory Extended Reality	Immersive experience, digital twins, MR telepresence, holographic imaging
Distributed Sensing and Communications	Wearables and implantable devices, in-body networks, augmentation for sensory impairments, mobility, activities of daily living
Network-Enabled Robotics and Autonomous Systems	Robots and autonomous systems interacting with humans, address issues of isolation and the provision of support
Personalized User Experience	Real-time secure personalization of patient/provider relationship, using situational context of patient to enable treatment (in transit or field)
VR Health Experiences for Psychological Treatments	Treating generalized anxiety, Post-Traumatic Stress Disorder (PTSD), quitting smoking

Table 6.3: Illustrative applications in 6G-enabled eHealth areas

Multi-sensory XR allows for advances in clinician training using VR and 3D modelling. XR can provide visual instructions for caregiver training for specific medical procedures (e.g., caring for catheters, stoma bags) and consumer cognitive training. Emerging technologies that address the high acuity needs of caregivers, clinicians, and patients are finally becoming technologically feasible.

The fusion of distributed sensing and computing will support rich visualization of the environment among many sensing nodes and significantly improved positioning performance. This will enhance important eHealth applications that depend on human presence and proximity detection, gesture recognition, obstacle proximity, and a range of other multisensory functions. Wearable and implantable devices can alleviate sensory and mobility impairments to improve daily living activities. Prevention will also be improved with distributed sensing, while computing also offers preventative benefits through earlier detections of fall risks, mobility challenges, driver safety, cognitive decline, and sleep activity monitoring.

Network enabled robotics and autonomous systems perceive their surroundings using sensors such as Global Positioning System (GPS), LIDAR, radar, sonar, and odometry. The interaction of in-body networks and wearables with the surrounding environment and a health care support network will revolutionize the field of health and wellness for patients outside of physical health care facilities by becoming smarter service systems that redefine the patient/provider-in-the-loop models. The emergence of exteroceptive and interoceptive wearables will provide new opportunities in continuous care models. Examples of the underlying technologies include sensor fusion with HD cameras and the use of 6G for video/sensor feeds requiring higher bandwidth via 6G.

The need to care for a global surge in aging populations has led to studies in robot therapy for dementia care. Elderly residents in long-term-care facilities need to receive positive social and emotional stimulation. However, caregivers need to free their time to perform required functions. Human-interactive robots were evaluated in trials[23] across 30 countries, including the US, Japan, and Denmark. In these trials, the robot was designed to be soft, warm, and capable of learning names, with favorable behavior based on reinforcement learning. Studies were conducted across cultural and religious differences. Results showed that the robot was accepted as a pet and as a therapeutic device, with interactions such as stroking, hugging, and talking. Behavioral improvements were quickly observed: Dementia patients who often tried to leave the facility stopped doing so. This improved their safety and reduced the stress levels of nursing staff. Countries like Japan and Denmark established subsidies to purchase more of these therapeutic robots to help reduce the financial burden on the municipalities that provide insurance for long-term care.

Worker shortages make efficiency and flexibility in mobile technologies key to personalizing user experiences and making the health care experience easier. Advances in electronic records and sharing allow for real-time, secure personalization of patient-provider relationships both in the office or via telemedicine.

When medical teams and patient care teams meet to review scans pre-op, they use 2D scans to try to form a 3D picture in their minds. XR technologies that incorporate holographic features immediately provide a 3D image to the team and the surgeon. Several universities and world-renowned clinics are collaborating with industry-leading companies to bring mixed reality technologies to the training and remote care worlds.

Some of these headsets allow multiple participants in separate locations to see and experience what the headset wearer is seeing. This allows experts from around the world to participate in treatment. Additionally, when there is a heightened risk of infection, XR capabilities reduce the risk of exposure for medical personnel while providing the patient with the benefits of different protocols and treatments from around the world. In some experiments, patients were reported to be more relaxed talking to one person in the room than having a whole team of white coats surrounding their bed.

In a paper published in "The Future Healthcare Journal,"[24] the authors conclude that XR technologies have unique attributes that can improve learning outcomes when compared to traditional learning methods. XR is not intended to replace but rather enhance learning in the context of health care. XR brings the advantage of high-fidelity simulators (e.g., tracking level, frames per second, field of view) to the complexities of medical education. Studies show that VR immersion increases the process of understanding the material through higher levels of interactivity in domains like anatomy, ultrasound scanning, and surgical simulators. The variety of unique modalities of XR, such as tactile inputs, helps elevate the support of the instructional objectives. XR could provide higher interactive learning for larger masses from fewer instructors, possibly at a lower cost.

In addition to remote surgery options, immersive VR health experiences can be used in patient treatments to induce a physical reaction with measurable changes in blood pressure and other physiological parameters. The U.S. Department of Defense (DoD) in partnership with Veterans Affairs (VA) are exploring advances in veterans' care using VR. Early studies[25] show that Virtual Exposure Therapy (VET) was effective in reducing alcohol and nicotine cravings among heavy users. Virtual exposure guided by therapists bore encouraging results of decreased fixation time for substance-related markers.

Several results suggest that immersing subjects in virtual environments related to an addiction can combat many issues regarding craving assessment.[26, 27] VR has proved to be effective in triggering craving in both substance-use disorder and behavioral addiction for such assessment. Specifically designed to be immersive, the VR multisensorial cue exposition can drive cue attentional bias in order to report cognitive distortion related to addiction and trigger interoceptive reactions such as heart rate variation. Additionally, social interaction with avatars can efficiently induce cravings for multiple substances, mainly assessed in cigarette smoking and alcohol studies.

6.4 Key Technologies

The advent of 6G technologies will greatly enhance existing capabilities in networks systems and devices. They will usher in the next generation of remote monitoring and in-home care, remote surgery, and clinician training. Ultimately, new 6G technologies can be used to create a secure and reliable health care channel between patients and health care professionals, well beyond existing web portals. 6G will join together the physical, biological, and virtual worlds.

The following is a list of 6G key technologies that will enable eHealth applications:

- 6G connectivity in smart hospitals and remote monitoring
- 3D display components, devices, and systems
- Enhanced 3D imaging for more accurate/detailed visualizations
- Native AI/ML integration
- Cognitive systems supporting Digital World Experiences
- Trustworthy AI to support user authentication, access, and privacy
- Near-zero-energy devices
- User-centric privacy to support secure communications and collaboration
- Advanced data analytics
- Micro-networks surrounding patients

7 INDUSTRY, IoT, AND 6G

The fourth industrial revolution (Industry 4.0) will create new economic value through radical transformation of multiple industries. One agent of change is the convergence of information technology, operational technology, and communication technology domains. Their intersection characterizes the industrial sector and distinguishes the IIoT from the more general IoT.

Communication technologies will play a crucial and functionally rich role in transforming IIoT. This will continue a trend that began with the use of 4G Long Term Evolution (LTE) and more recently by 5G New Radio (5G NR). While the initial 5G deployments primarily focus on enhanced mobile broadband (eMBB), future deployments are expected to target IIoT, V2X, Fixed Wireless Access (FWA) and XR uses. These will take advantage of key 5G NR features such as Ultra Reliable Low Latency Communication (URLLC), 5G positioning and its enhancements, and time-sensitive communications (TSC).

The NGA audacious goals that are of greatest relevance for meeting IIoT demands are **Digital World Experience (DWE)**, **AI Native,** and **Distributed Cloud and Communication System**. With DWE, expectations will shift to more innovative and transformative use cases, such as smart factory automation, collaborative robots, and uses of digital twins, requiring fully immersive XR/VR experiences. Future solutions will also depend on distributed cloud and communication systems, which will enable distributed architecture principles that separate hardware and software. There will also be a greater reliance on edge computing, enhanced positioning capabilities, and end-to-end operational intelligence using AI/ML technology. The mission criticality of new applications will call for higher performance thresholds in fundamental communications areas including data rates, capacity, latency, and reliability of communication links.

Within the North American context, passage of the CHIPS and Science, Inflation Reduction and Infrastructure Acts in the U.S. send an important market signal. Massive funding and financing instruments aim to foster new markets in the future economy and to onshore high-technology manufacturing. IIoT technologies and communications enablers are critical pillars for national policy objectives and NGA's audacious goals. Specifically, IIoT in a 6G future depends on the delivery of DWE enabled by Distributed Cloud and Virtualization technologies and AI-Native Wireless Networks.

7.1 IIoT Landscape

The IIoT ecosystem comprises of participants from a wide variety of industry verticals including manufacturing, telecommunications, distribution, public infrastructure, utilities, and mining, agriculture to name a few. Coordination will be critical to capitalize on synergies between information technology, operational technology, and communication technology entities.

Representation of industrial sector interests is typically organized through trade associations and industry consortia. A key organization that is working on connected factories of future is the 5G Alliance for Connected Industries and Automation (5G-ACIA), which focuses on where manufacturing and process automation intersect with wireless technologies. Other industry bodies include the Industry IoT Consortium (IIC), Open Platform Communications Foundation (OPCF), World Economic Forum (WEF), and Open Industry 4.0.

Groups such as OPCF represent sector interests and address the technical standardization of industry-specific capabilities. Within the communications sector, 3GPP has been working extensively on 5G support of IIoT requirements, features, and capabilities. It continues to evolve in that area with 5G-Advanced and beyond.

7.2 Societal Needs

Society can look forward to many more industrial applications that deliver economic value, enhance safety, and improve resource sustainably. Projections for this future estimate populations of 1 million IoT devices per square kilometer and more than 10 million base stations, as illustrated in Figure 7.1. Such devices will require universal, high-speed broadband networks, coupled with AI and ML applications that can consume IoT data. Networks will mediate between a wide range of devices, from in-home thermostats to computer-guided manufacturing in factories.

More granular sensing in smart buildings and cities will help to optimize the use of power, water, transportation, and other resources. This will involve a better and more dynamic understanding of usage patterns, such as use of transportation networks and electrical power consumption. Better feedback and dynamic pricing signals will help users modify their consumption patterns.

Monitoring longer-term patterns can help detect water supply leaks and spot gradual damage to roads, bridges, transformers, and other critical infrastructure. These can pre-empt expensive emergency repairs and enhance sustainability.

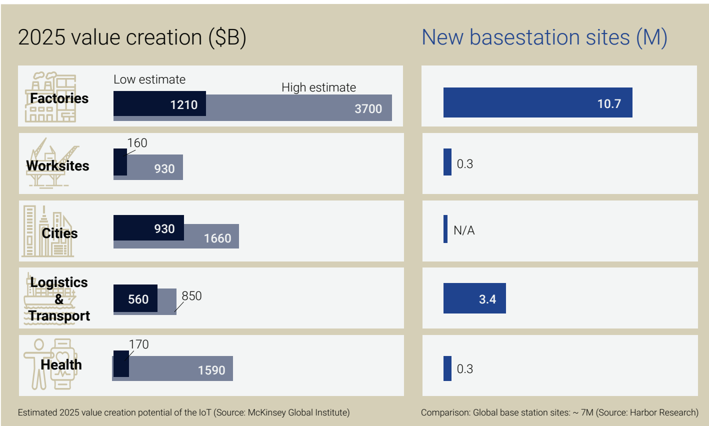


Figure 7.1: IIoT Value Creation

7.3 Enabling Applications

Figure 7.2 illustrates the variety of IIoT application opportunities in a manufacturing setting. Many such applications are possible in logistics hubs, public infrastructure, mining locations, and shipyards. Some of these are attainable with 5G capabilities while others will benefit from 6G's innovation potential and development timeframe. Example applications include:

- **Factories of the future** with industrial sensors, automatic guided vehicles (AGVs) using high-definition video, and AR/VR/XR.
- **Logistics and transport**, which will see massive use of AI-managed AGVs for maximum throughput, resilient and secure control systems, and massive instrumentation to ensure minimal carbon footprint.
- **Remote mining operations**, especially heavy trucks operating in open pit mines where these vehicles can be monitored and controlled from a central location.

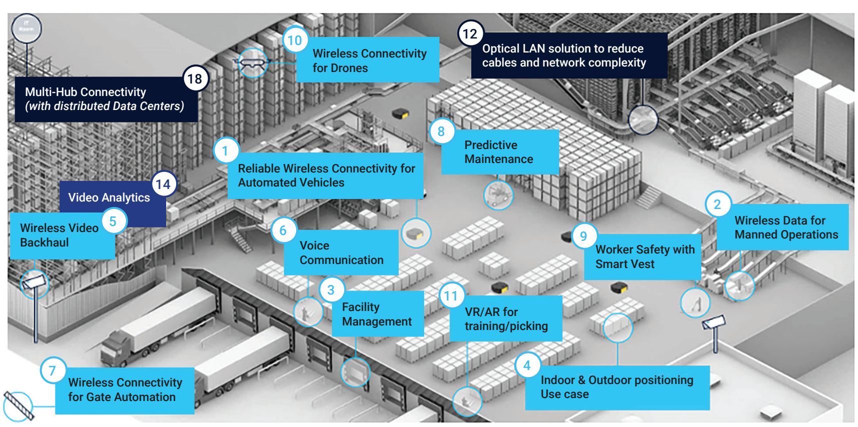


Figure 7.2: Example of IIoT Use Cases (Source: Nokia, 2022)

Reliable connectivity provided by the underlying network is a critical enabler. However, successful IIoT applications rely on additional enablers. These include front-end sensors or actuators for data detection and control, effective HMIs, and back-end analytic capabilities. These might be less evident compared to the more visible elements of IIoT, which include wearables such as glasses and helmets. This will be enhanced with XR capabilities to support view-through or high-definition displays to provide realistic working views.

7.4 Key Technologies for IIoT

New capabilities in 6G systems will build on earlier generation standards (4G and 5G) and deployment experiences. Industrial-sector feedback suggests that 4G/5G systems support mobility on a wider scale and with fewer nodes when compared to Wi-Fi. More can be achieved with advances in technology. This is where a closer dialog between the communications industry and industrial sector can promote early discovery of priority use cases. To project a desired trajectory for 6G research and new drivers of value, it is important to build from the existing technology base.

7.4.1 Existing Technologies

Two 4G cellular technologies are available to support massive IoT: LTE for Machine-Type Communication (LTE-M) and Narrowband IoT (NB-IoT). LTE-M is intended for mid-range IoT applications and can support voice and video services. NB-IoT can provide very deep coverage and support ultra-low-cost devices.

Many IoT devices have exceptionally long service lives, such as water and power meters requiring support for 10-15 years or more. This requires operator support as networks transition from 4G to 5G. The evolution to 6G calls for LTE-M and NB-IoT support on NTNs (e.g., satellites, High Altitude Platform Systems). This is to ensure global connectivity via either terrestrial or NTNs using cellular IoT technology. Anecdotal evidence suggests industry expectations are that 6G will be backward compatible with 4G/5G.

For broadband IoT, 5G eMBB features can be used to support these services. In addition, the introduction of Reduced Capability (RedCap)[28] devices supports mid-range IoT use cases such as wearables, industrial sensors, and video transmission. RedCap devices have smaller bandwidth, a single antenna, and may be half-duplex. Industry sector users view RedCap as a solution for cost efficiency.

Finally, for critical IoT, 5G URLLC features are available to support URLLC use cases requiring ultra-reliable and low-latency communication, such as the sub-msec latency required for industrial robot motion control. These features include short slot length, slot structure designed for fast processing, fast acknowledgement, flexible slot structure, pre-emptive scheduling and multiplexing of data, multi-slot repetition, high-reliability modulation and coding scheme, and data duplication.

7.4.2 New Technologies for 6G

6G technologies for factory of the future requirements fall into two categories. One applies to goal-oriented priorities. These include cost efficiency, distributed-architecture systems, uses of AI/ML, and delivery of enhanced digital experiences. The second applies to breakthrough technologies expected from leading-edge research topics.

The technology considerations for cost-efficient solutions include lowering the cost per bit by increasing spectral efficiency per unit area, increasing coverage reliability, and reducing deployment cost through innovative network architectures and standard interfaces (e.g., open and virtualized RAN). 6G will need to function as an intelligent network, using AI/ML, to handle complexity while containing costs. Distributed systems built on cloud and virtualization technologies will enable the separation of hardware and software. By supporting distributed compute resources, data processing can be moved between data centers, intermediate clouds, edge clouds, and device edges. The increased use of AI/ML techniques opens a paradigm of AI-native 6G networks. In addition to improving the deployment, management, and operation of network and device functions, factory-level AI techniques, via digital twins, are expected to improve operational performance and minimize maintenance. Digital experiences based on XR depend on advances in network technologies. These are to support high-quality interfaces, minimum latency, data personalization, application optimization, and privacy protection. Their effectiveness in industrial uses depends on numerous physical-world sensors to update digital-twin representations in real time. New device classes will range from zero-energy embedded sensors to immersive interaction devices.

Innovation at the intersection of materials and spectrum-related technologies promises new capabilities for JCAS. This would entail integrated network and devices having the capability to perform both communications and sensing (i.e., recognition of the environment and objects within the network). In factory settings, JCAS can be used for precise location, with indoor location accuracy of sub-1cm, and to track the movement of objects (e.g., AGVs, asset management) and people (e.g., virtual safety zones) for health monitoring and accident detection purposes.

Heightened awareness of trustworthiness means that 6G systems will be expected to provide intelligence, ever-present connectivity, and full synchronization for the cyber-physical continuum. This will depend on technological advances that allow networks to withstand, detect, respond to, and recover from attacks or disturbances. Confidential computing solutions, secure identities and protocols, service availability, and security assurance and defense are four important building blocks for trustworthy systems.

Network adaptability will also play a key role in making 6G networks efficient, resilient, and sustainable. New technologies include mechanisms for dynamic network deployment, higher levels of device and network programmability, network simplification, and cross-RAN/CN optimizations. Enhanced topologies and radio technologies include use of sidelink, UE-to-network relays, smart repeaters, and multi-beam transmission reception point (TRP) techniques tailored to specific factory deployments or connectivity needs. These will include the use of industrial-grade private wireless networks.

Future 6G technology will have to ensure deterministic communication for end-to-end flows across multiple, heterogeneous domains (i.e., wired, and wireless communication infrastructure) and leverage a collaboration between networks and applications. Interworking might involve AI-enabled plug-and-play Non-Public Networks (NPNs) serving local factories or enterprises inter-connected to public networks. Interworking and integration with existing technologies is of paramount importance because many industrial sites host brownfield installations that operate with much longer cycles compared to the consumer sector.

7.5 Spectrum Implications for IIoT

6G will meet the challenge of an ever-increasing capacity demand through a combination of new spectrum, higher spectral efficiency, more spectrum reuse, and efficient use of licensed, unlicensed, and shared spectrum. The lower frequency bands (up to about 15 GHz) will remain important in the 6G era, as well as the millimeter wave frequency bands in the 24 GHz to 71 GHz range. Advanced sharing mechanisms enable opportunities in the 7 GHz to15 GHz range, which is currently being used for non-cellular communication. Above 71 GHz, up to the sub-THz range, can be exploited for extreme data rates and extremely low latencies (e.g., direct device-to-device or point-to-point communication) and will further complement lower frequency ranges (e.g., for in indoor applications, hotspots, or dense-cell deployments).

8 MINING AND 6G

The mining sector represents a significant North American industry. It functions as a supplier for a wide range of raw materials that other sectors of the economy consume in addition to being a major economic and employment contributor in its own right. Through exports, its reach is global.

Dynamic and complex by nature, the sector is already evolving to leverage data insights, digitalization, and robotics to address productivity, efficiency, environmental and safety requirements, which touch on three NGA audacious goals: **Trust, Security, and Reslience, Sustainability,** and **Cost Efficiency**. COVID-19 further accelerated the need for automation, digitalization, and remote operation. However, this journey is not without complexity. Advances in enabling technologies still need to overcome challenges related to the speed and phases of change, legacy systems, and an ingrained culture. There is also a need to match increasingly distributed operational and business models and to manage the shift in workforce skills.

The advent of 5G and the growing trend toward digital transformation have started the process of addressing these challenges. The design of 6G's enabling environment should continue in this journey with expanded and new capabilities. The goal of intelligent and trusted digitalization and automation built on economic and environmental sustainability principles will be key to this new environment. While these align with three NGA audacious goals, the NGA's ambitions for native AI, digital experiences, and distributed cloud-based solutions will also play significant roles in enabling the mining sector's future transformation.

8.1 Mining Sector Landscape

For example, a snapshot of Canada's mining sector conveys its importance as a key source and supplier of natural resources to the economy. Canada is the world's largest supplier of potash and its tenth largest supplier of copper.

In between there exists a range of other materials that are important to other segments of the economy and international markets. Canada ranks third in the world for graphite, whose applications include lubrication, batteries, and steelmaking, among others.

> Canada ranks among the top five countries in the global production of minerals and metals.[29]

8.2 Societal Needs

Mining involves a unique communication and operational environment, deep underground with potentially hard-to-access or -see areas, clusters of tunnels, and narrow passages within hard walls. This causes communication, safety, and security challenges, including potential accidents. Ensuring safety and well-being, along with reliable and trusted connectivity with high resilience, are important requirements that contribute to wider societal needs.

Furthermore, there has been a growing demand and opportunity for productivity, linked to cost-effectiveness. The mining operation can inherently become expensive, complex, or in multiple silos, putting pressure on capital expenditure, operational expenditure, and labor. These issues demand a drive towards more cost-effective solutions.

Energy efficiency and environmental sustainability have also been among the key needs in the mining industry. Improving energy efficiency and reducing negative environmental impact have great societal, environmental, and economic incentives. Mining requires reduction and hopefully elimination of harmful impact on environmental biodiversity, soil, and water systems.

In addition, the shifts in remote working and remote operations, automation, and the need for new skills demand strategies to address societal needs, such as well-being, empowerment and upskilling, and opportunities. In a mining context, this concerns the existing workforce, attraction and creation of new talents, changes in distribution of on-site operation, remote-near-site operation, and intelligent centralized or anywhere operation.

8.3
Enabling Applications

Mining involves exploration, extraction, management, processing, and transportation, along with associated governance, supply chain, and planning activities. As such, there is an increasing need for digitization with an integrated platform that is data-driven and leveraging distributed intelligence concepts. This digitization journey has already started and addresses fundamental needs connected with safety, productivity, and environmental sustainability.

With 6G, expanded usage scenarios will involve integrated AI, joint sensing and communication, and critical communications technologies. There will also be a focus on environmental sustainability and the use of immersive DWEs to address emerging needs and advance the mining industry's prospects. Although many of the enabling applications have started to appear in 5G-based solutions, the roadmap of underlying technologies requires continuing expansion and evolution to meet rising expectations for safety, efficiency, environmental protection, and commercialization.

Tele-operation is a key use case, such as for drilling and sampling, particularly of newly located ores. Drones and AGVs will increasingly be used for inspection, particularly in hazardous conditions such as following blasts and for loading and transportation.

Real-time monitoring and streamlining of (machine-type) operation will be essential features of the future mining environment. 6G is expected to support massive connectivity and digital-twin replicas. These will enable smart design for safety, mobility, and access. Furthermore, real-time resourcing, diagnostics, predictive analytics, and updates will contribute to the prevention of accidents and hazards.

Growing use of tele-operation and autonomous machine interaction will drive demand for imaging, mapping, tracking, and localization capabilities. These are critical enablers for object recognition, mobility, and robotics.

8.4
Key Technologies

There are three families of communications technology where advances through 6G can have a beneficial impact on mining applications and usage scenarios.

The first applies to connectivity adapted to the mining sector's unique communication and operational environment and the dynamic nature of fields and tunnels. In addition, 6G is expected to enable massive sensor connectivity for use in monitoring and gathering insights. Massive sensor connectivity will also aid in the merging of digital and physical worlds to enable digital-twin replicas and XR communications, adding another dimension to the mining sector's connectivity needs.

Critical, autonomous, and machine-type communications are a second family of key technologies. This is because mining involves tele-operation for safety and productivity. It increasingly involves robotics, drones, and autonomous vehicles to streamline operations intelligently. As in many other smart industry applications, industrial control in mining demands critical communication, including time-sensitive, precise-positioning, and high-reliability communication.

Tracking, localization, imaging, object identification, and recognition are capabilities required for remote operations and to enable interactions between robots and autonomous vehicles. Mobility and the ability to ensure coverage and computing over widespread areas make JCAS a third important category of key technologies.

9 PUBLIC SAFETY AND 6G

Public safety involves protecting the general public to help community members feel secure when facing imminent threats from natural calamities to manmade incidents. This also includes the work of providing remedies and assistance to help the public recover from disaster situations. Provision of a trustworthy first responder system depends critically on a communication system to provide necessary information to coordinate the actions of responder agencies.

Three of the NGA's audacious goals that are of greatest relevance for meeting public safety demands are **Digital World Experience (DWE), Cost Efficiency,** and **Trust, Security, and Resilience**. Advances in technology have led to a rise in public safety applications. Examples include enhanced location positioning systems and the ability to retrieve vital information from radio access systems. Improved cellular coverage in remote villages, deserts, mountains, canyons via NTN increases the application scope. Real-time video streaming, AI, and drone technologies are new tools in the emergency responders' toolkit.

Over the coming years, AR/VR platforms, the omnipresence of IoT devices, and advanced AI/ML will help first responders operate more safely while building higher levels of confidence in public safety operations. Several factors are also raising the profile of public safety in the economy. The pervasive rise of digital technologies is driving exponential growth of cyber threats and increasing awareness about the importance of security.

The progression to more innovative uses depends on 6G pushing beyond 5G's operational limits. This will enable support for mission-critical services, the provision of immersive communications, and the capacity to connect billions of omnipresent devices and sensors. 6G can also open new application frontiers that combine sensing and holograms to link physical and digital worlds.

Four technologies will be important in driving public safety in the 6G era:

> Immersive communications using XR and AR enabled by AI/ML, which is covered by DWE.

> Technology for connecting billions of devices and sensors using edge-to-cloud architectures.

> Increased cellular coverage, which relies on the integration of terrestrial (TN) and NTN including UAVs in a cost-efficient way.

> Technologies for precise location and NR-sidelink.

9.1 Public Safety Landscape

Public safety relies heavily on Land Mobile Radio (LMR) systems that have been the foundation of the first responder and emergency worker communities for over 40 years. Although LMR continues to be a foundational staple for public safety, the advent of broadband public safety enablers and applications running on wireless networks (LTE and 5G) provides advanced communications and features that were previously unavailable to the first responder community. Many countries across the world are beginning to deploy LTE/5G wireless public safety systems.

Public safety users traditionally relied on voice, including push to talk, as the main communication method. They now have access to video, data, analytics, live body cameras, drones, the cloud, traffic monitoring, enhanced user location/tracking, and nationwide connectivity. These critical enhancements will continue to evolve to aid public safety users for real-time situational awareness that requires increased spectrum and bandwidth demands, as well as ubiquitous, resilient, and reliable network deployments.

In the U.S., the First Responder Network Authority (FirstNet) is a prime example of a nationwide mission critical broadband network designed to meet the increasing demands of public safety professionals. FirstNet continues to target advanced situational awareness requirements to keep first responders and communities safe.

To enable ubiquitous deployments, standards development for public safety applications and enablers, particularly in 3GPP, began around 2015 (Release 13). 3GPP continues to advance public safety standardization, working toward new and enhanced public safety features, architecture, and interoperability to address evolutionary mission-critical requirements.

9.1.1. Diverse Range of Users and Service Needs

The public safety community comprises many organizations and user types with varying needs. These examples illustrate the range of features and services each user group prioritizes.

> **Emergency Response Managers:** Improved tracking and management of equipment, personnel, and resources.

> **Fire Service:** Use of 3D location services for tracking personnel inside of buildings and for coordinating and communicating across the different public safety organizations.

> **Emergency Medical Services (EMS) Personnel and Paramedics:** Sending critical data and images and communicating with medical resources while on scene and during transport to provide better care and to have medical facilities better prepared when the victim arrives.

> **Medical Facilities and Personnel:** Hospitals and medical staff can get real-time updates and incoming patients' vitals and receive images and streaming updates on types of injuries to be better prepared when the victim arrives. The use of medical IoT devices and tracking patients and vitals will also allow better in-home care.

> **Law Enforcement:** Better access to databases and images for verifying information and registrations, and real-time coordination of pursuit in locating criminals. Ability to securely upload and retrieve files and crime scene information.

> **911 Operations Centers:** Quicker and more accurate communications with 911 personnel for dispatch and management. Speeds up response times to locate and helps emergency personnel with critical information.

9.2 Societal Needs

Societal expectations for public safety services are on an ever-rising trajectory. Responders are expected to use the latest technologies while the underlying communications infrastructure needs to attain ever higher levels of service quality. This implies coverage and/or capacity that exceeds the parameters for commercial services. Mission-critical services must be delivered immediately, regardless of whether the UE, which might be above or below ground, is within terrestrial network coverage.

In multi-user settings, first responder communications take priority over resources during emergencies. This relies on the ability to preempt lower priority communications when lives are in danger, for example.

9.3 Enabling Applications

Group communications are the primary class of application used by first responders, public safety, utility workers, transportation/trains, oil/gas/mining, retail, and production to manage communications among professional users.

Group communications are also known by the term Mission Critical Communications (MCC) within 3GPP where the transition from the LMR to broadband-based technologies (LTE and 5G) was initiated. Use of newer capabilities in 3GPP technical specifications has made video, image, file, and content-sharing services available for professional users on a reliable and secure basis. As outlined through interviews, for example, the fire service could establish a clearer operational picture and share data with other public safety agencies and jurisdictions. With asset management, a fire service can manage and deploy its mission-critical assets, supplies, and personnel with real-time tracking and mapping. Drones can be deployed to search large areas and send live stream footage of incidents to the command centers. And with improved location accuracy, they can follow and locate firefighters with full 3D tracking.

The evolution to broadband MCC will support further service enhancements based on a variety of AI, VR/AR/MR algorithms, text-to-speech/speech-to-text, and location-based (e.g., geofencing) solutions. The evolution will also support applications associated with the Internet of Life Saving Things applications that take advantage of a range of sensor, data, and control automation capabilities.

Public safety applications that take advantage of these capabilities depend on a range of devices such as:

> End user devices (e.g., XR, HMD), implantables, wearables.

> Robots for rescue that are engineered for use in hazardous environments.

> UAVs for real-time situational awareness or medical deliveries.

> Use of connected ambulances with support from remote medical expert and connected police cars.

9.4 Key Technologies

LTE and 5G networks support a lot of the functionality required for public safety applications. These include capabilities to handle priority and preemption, as well as mobile broadcast. Nevertheless, there remain shortcomings in achieving 100% coverage and 100% network reliability to support mission-critical operations. Such issues include the following:

> Group communications should be reliably available and secure across all "geographies" – land, maritime, aerial, satellite – which requires support across all communications media.

> Full coverage is impossible if network coverage maps have holes in them.

> Direct mode (also known as NR-sidelink) communications is required in situations where the network goes down.

> First responders require full in-building communications.

> 3D location with improved accuracy.

From an operational perspective, 6G also needs to provide seamless integration of different connectivity options like NTNs, UAVs, and NR-sidelink with terrestrial and on-demand connectivity. A secure, flexible, reliable, and cost-effective deployment of communication services with AL/ML-based real-time situational awareness is desirable.

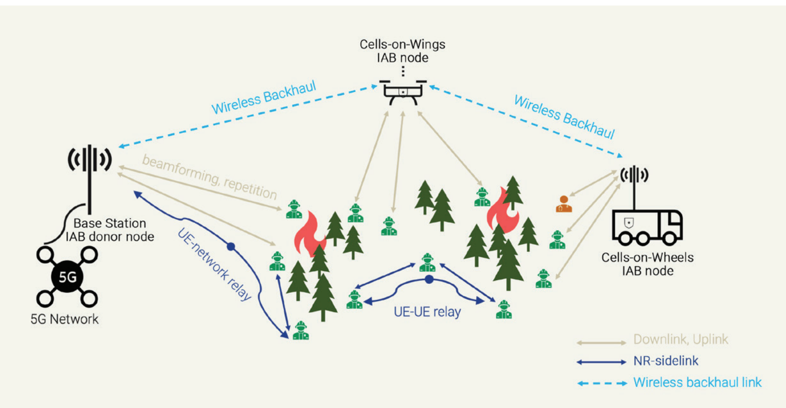


Figure 9.1: 5G Nr Coverage Solutions to Provide Limitless Connectivity for Public Safety

9.4.1 Coverage Technologies to Provide Limitless Connectivity

Building on the 3GPP standardization roadmap, new 6G technologies need to build on foundations in 5G. 5G/5G-Advanced NR technologies have several technologies designed to improve coverage. These include using beamforming to increase the signal strength for intended UEs in a specific area, applying repetition to transmit the same data multiple times, configuring a UE with high-power classes to enable higher-power signal transmissions, and using integrated access backhaul (IAB) for multi-hop network relaying or for enabling deployable networks.

In addition, NR supports NTN and NR-sidelink, including NR-sidelink-relaying to provide coverage in areas where network infrastructure is not available or damaged. Mobile IAB and smart repeaters, being studied in 3GPP Release 18, can also enhance coverage. In 6G, all these different coverage and resilience solutions need to seamlessly work together in a dynamic changing environment to secure the mission-critical service availability and connectivity necessary for public safety networks.

9.4.2 3D Positioning

Enhanced 3D positioning and ranging are important in outdoor and indoor settings to enable precise location of within 1 meter for horizontal and 2 meters for vertical accuracies for outdoor, and sub-meter level accuracy for indoor situations. This corresponds to a floor-level resolution in a multi-story building. The situation is more challenging where first responders are operating in a burning building.

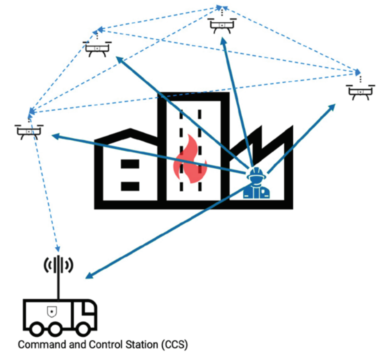


Figure 9.2: Use of Drones as Positioning Reference Nodes

As depicted in Figure 9.2, one possibility is to use deployable base stations (e.g., drones) to provide additional communication links and positioning infrastructure. The use of multiple drone-BSs can act as positioning reference nodes (PRNs) for location tracking purposes. Furthermore, AI-assisted positioning can improve location accuracy. For real-time situational awareness, 3D positioning in 6G should support reduced latency and improved availability and reliability.

9.4.3 AR/XR and Video Feeds

When responding to an emergency, AR headsets or glasses are preferable to viewing information on cell phone screens. A heads-up display inside a firefighter's face shield leaves their hands free to deal with fire suppression, search-rescue situations, and other tactical functions.

Self-contained breathing apparatus (SCBAs) refers to the personal protection equipment (PPE) worn by firefighters (turnout gear). The evolution of SCBAs will include augmented and hyper-reality fire helmets with a heads-up display system that superimposes on-demand information onto the objects in an actual scene. This provides users with more in-depth information and better situational awareness when integrated with data from surrounding IoT devices that are expected to proliferate in the 6G era. 6G technologies will also need to support multiple information exchanges ranging from access to building floorplans, locating individuals in multi-story buildings, or providing directions to responder personnel.

UAVs and robots can also help public safety personnel gather information while maintaining a safe distance from immediate danger. 6G will need to support a tightly integrated communication environment where video feeds from drones and robots can be relayed in real-time to public safety personnel.

9.4.4. AI/ML-Based Situational Awareness

Assistive AI for automated decision-making can equip key personnel with additional relevant, real-time, actionable information. AI/ML can fill operational blind spots, predict failure and jamming events, automate network configuration, and enable traffic differentiation or prioritization.

AI-based analytics can offer situational awareness and a picture of surrounding risks based on data collected from different sensors.

Interviews determined that there is a growing need for situational awareness solutions. For 6G, this will involve the processing of data from a smart city or building infrastructure or other sensors like UAVs and robots to provide a robust picture of surrounding risks.

9.4.5 Network and Communications Security

Network and communications security prevents both internal and external adversaries from gathering or manipulating private or otherwise restricted information or data within a public safety network. Identity and access management, including local and federated identity solutions, must be implemented to ensure access and level of authority are given only to authorized users.

Furthermore, the level and methods of protection (encryption, authentication, verification, and authorization) for users, data in transit, or data at rest must have an evolutionary roadmap to meet the needs of advancing hacking techniques and technologies. Zero Trust Architectures (ZTAs) support access, authorization, and identity control and should be considered. Higher bit-rate encryption, algorithms, hashes, and keys must be utilized with an emphasis on evolution well beyond today's accepted "safe" security architectures. Quantum-safe and quantum-resistant solutions should be considered in 6G (e.g., increasing the symmetric/asymmetric key sizes).

9.4.6 Flexible, Cost-Effective Deployment

Support for new types of public safety and mission-critical services in future networks will require simplified deployment models. End-to-end orchestration and end-to-end segregation/prioritization of mission-critical traffic are two key enablers. Others require near instantaneous reconfiguration or classification of mission-critical traffic with ongoing service assurance enable an agile public safety framework that can respond to fast-changing mission requirements. A topic emphasized through interviews is the importance of reducing cost, increasing coverage, adding resilience in harsh conditions. This requires integration of services across all available bands and a robust NR-sidelink capability that has adequate range to meet the needs of public safety user communities.

Network slicing with associated on-demand prioritization and automation tools are expected to play key roles in enabling flexible and cost-effective deployments and service availability.

9.5 Spectrum Implications

The provision of mission-critical services will place higher demands on spectrum. A representative forest fire scenario illustrates the spectrum implications for 6G systems. The scenario involves 50 Mission Critical (MC) push-to-talk (MCPTT) users per cell, 10 MC data users per cell, 10 MC video users per cell, and 5 MC AR users per cell. Figure 9.3 shows the estimated bandwidth needed for different MC services, considering two different spectral efficiency cases (i.e., 0.5 bps/Hz/Cell and 1.5 bps/Hz/Cell). As expected, MC video and AR/VR are the most spectrum-intensive services.

There are several options for public safety network solutions, depending on the deployment scenario, spectrum availability, feasibility of spectrum sharing, and regulatory constraints:

- **Option 1:** Dedicated spectrum only for public safety UEs, which also can use spectrum for commercial UEs if needed.
- **Option 2:** Dedicated spectrum for public safety UEs, but this spectrum can be shared with commercial UEs when not in use by public safety (FirstNet model) and public safety UE can use commercial spectrum as needed.
- **Option 3:** Fully shared spectrum for public safety UEs and commercial UEs, with proper prioritization of public safety UEs.

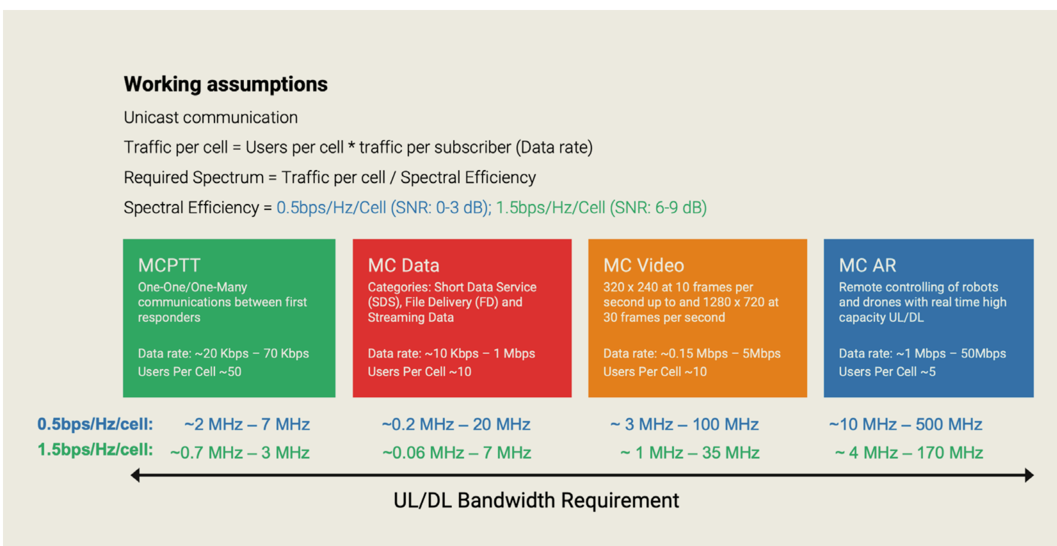


Figure 9.3: Bandwidth Requirements for Different Mission-Critical Services

10 SMART CITIES AND 6G

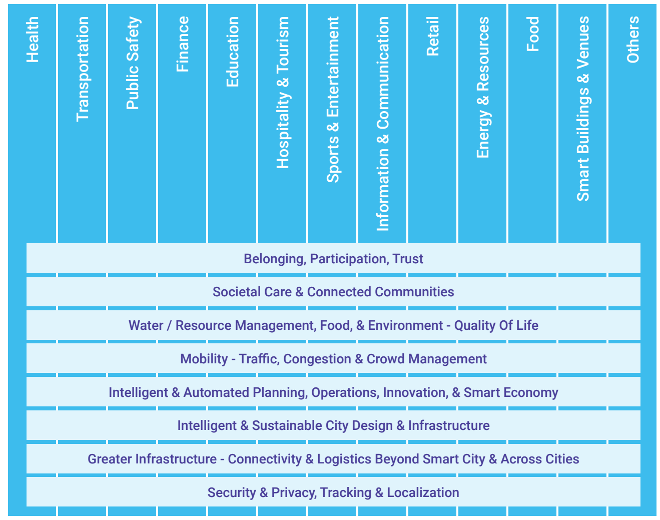


Figure 10.1: Illustration of Complexities and Service Dependencies in Smart Cities

Cities consist of many components, services, and stakeholders. Examples include public safety, transportation, utility services (e.g., energy and water), analytics, health, and environmental services.

A smart city is a municipality that uses ICT in multifaceted ways. One is to increase operational and resource efficiency. Another is to share information with the public and improve both the quality of government services and citizen welfare.

For smart city designers, a noteworthy feature is the variety and interdependency of architectures involved in supplying energy, transportation, water, public health, and other services, as Figure 10.1 illustrates. The NGA audacious goal of **Distributed Cloud & Communications Systems** addresses this aspect. Another critical aspect of interdependency is the data associated with each infrastructure. There can be spillover benefits from using energy data in the management and governance of other infrastructures such as transportation. These offer municipal managers a range of opportunities for more efficient resource use. Consider, for example, how an analysis of transportation patterns might be used to mediate the use of electrical energy associated with electric vehicles and public transportation systems – a good example of how **AI-Native** computing can greatly improve efficiencies system wide.

Overall, **Trust, Security and Resilience** is key to ensuring safe and trustworthy systems and services. It is an extremely important part of any smart city overall architecture.

Smart city environments are not static. They are under continuing pressure to adapt to technical innovation, multiple uses of information, and changing expectations on the part of local businesses and citizens. Consequently, cities will continue to employ forward-looking technologies enabled by the next generation of wireless capabilities. Such technologies will support better trust, security, and resilience, leveraging AI-enabled services in a distributed cloud and communications system.

10.1 Landscape of Smart Cities

Nations across the world are experiencing a trend toward urbanization. According to World Bank data,[30] 56% of today's global population is concentrated in cities, and this number is expected to grow to 70% by 2050. North America is the most urbanized continent, with over 80% of its population concentrated in dense urban locations such as Boston, Miami, Philadelphia, San Francisco, Vancouver, and numerous other cities with populations exceeding 100,000.

With 80% of global GDP generated in cities, it is important to provide opportunities for improving productivity and also to enhance sustainability. The importance of sustainable cities and communities is recognized in the United Nations' Sustainable Development Goal 11.[31] 6G can be a key enabler with its enhanced performance and energy efficiency.

Below the surface of the latest technologies and novel citizen services, the smart city landscape is characterized by a jigsaw of different stakeholders. Each group has their own service needs and timing priorities. Smart city citizens who consume resources related to energy, transportation, water, public health, and law enforcement will look to smart cities for more cost-effective provision of these resources. Local businesses will have additional priorities around economic development, for example. Smart cities will also connect public utilities, owned by both the private and public sectors, to one another.

Data and information sharing are central to this landscape. Long-range planning will involve public officials from local and regional agencies sharing information and establishing common goals to make better investment and governance decisions. Citizen advocacy organizations will use public data to justify community needs for infrastructure and other public services. Law enforcement and public health stakeholders will depend on being able to analyze activity patterns to decide on investment and resource allocations. The ability to source, analyze, and share smart city data also has ramifications at the national level in terms of attracting inward investment, enabling business formation, and growing a skilled workforce.

10.2 Societal Needs

Rising population densities intensify the use of city infrastructure and resources. City residents, businesses, and visitors will have higher expectations from smart cities, including infrastructure that is modern and fit for purpose. Smart city services will inevitably make greater use of data for efficiency, convenience, and quality of living reasons.

Society will also expect higher levels of security and privacy around local services and the handling of data. Strengthened security is needed to ensure that critical and interdependent infrastructures operate without compromise. Without such security, embedded within next-generation communications systems and the information architecture associated with each infrastructure, services can be disrupted or even mismanaged deliberately.

Given the dense and rapid production of data used by their citizens, smart cities' need for privacy is of vital important to ensure citizen confidence in services and governance.

10.3 Enabling Applications

Cities include many vertical industries and segments with specific concerns, such as finance, education, retail, transportation, and health. With urbanization and growth of communities, there are, however, common and horizontal needs to address sustainability, well-being, inclusion, infrastructure and interconnectivity, and success and progress of the cities and communities as a whole.

Urbanization challenges become increasingly pronounced for several reasons. Increasing urbanization goes hand in hand with higher levels of congestion, as well as population and infrastructure density. Another factor is the choice of policies involved in developing and allocating the use of often limited resources. The design of smart cities should address these challenges on the one hand and provide equal opportunities, growth, and advancement on the other. By nature, this requires collaborative planning, sharing, and management within and across smart cities and communities.

Over the 6G time frame, enabling applications and usage scenarios will both expand on the ongoing and emerging prospects to build smart cities and create new enabling opportunities. These include:

> AI-powered and secure distributed intelligence for intelligent and autonomous operations, innovation platforms, and data sharing.

> Digital world experiences and multi-sensory communication for telework, teleoperation, tourism, and entertainment, leveraging digital replicas for design, prediction, and management.

> Energy efficiency and reduction of carbon and water footprints.

> Joint communication and sensing for imaging, localization, and pattern/mobility recognition.

These possibilities need to factor in security and privacy priorities, with particular reference to the multi-stakeholder landscape that characterizes all municipal environments. This is where cross-vertical collaboration and data sharing will be routine. Four enablers will play a key role in facilitating multi-stakeholder collaboration and encouraging data sharing across operational boundaries.

> Identity management is essential so that multiple stakeholders can reliably identify what connected items and sources are providing the data that enable smart city decision-making and operations.

> Authentication is an enabling service that helps stakeholders confirm whether identifying data can be trusted and verified.

> Privacy and usage controls give data providers control over how, where, and when data can be used by intermediary and end user communities. Usage controls are important for reasons that range from cost allocation for data-sharing infrastructure to schemes to monetize data and decision-making.

> Economic considerations are important to create incentives between data providers and data consumers.

10.4 Key Technologies for Smart Cities

The cross-cutting communications and data-sharing infrastructure to enable a smart city involves a considerable number of technologies. This is to be expected, given the scope of possible applications in verticals and sub-verticals and across verticals.

An understanding of key technologies begins with a functional depiction of a smart city data-sharing ecosystem. This includes city-owned data sources and connected devices that may operate in citizen, business, or third-party domains.

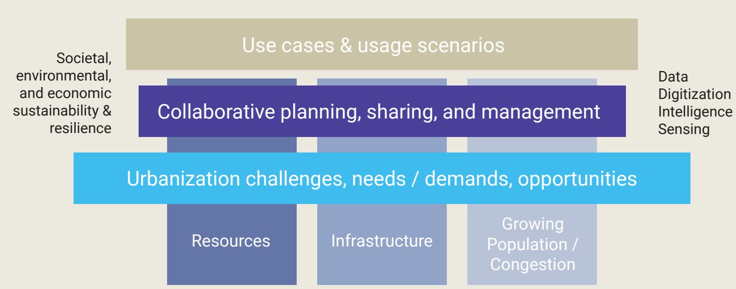


Figure 10.2: Importance of Collaborative Planning, Sharing, and Management in Smart Cities

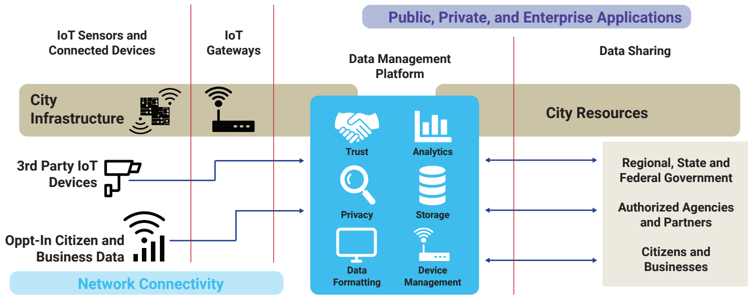


Figure 10.3: End-to-end Functional View of Smart Cities Data-Sharing Platforms

IoT sensors and connected devices are key because they originate the data required to power smart city systems. Sensing technologies are used to observe and collect data from an environment. In other words, these technologies include the sensors and applications that reflect physical reality. Examples include how many vehicles pass through an intersection, pressure in a water pipe, electrical load in a neighborhood, or passenger loading on public transport. These technologies and applications provide the smart city with digitally coded data that can be consumed by other applications used for infrastructure governance and resource mediation.

The technical capabilities underpinning the data management platform consist of six modules.

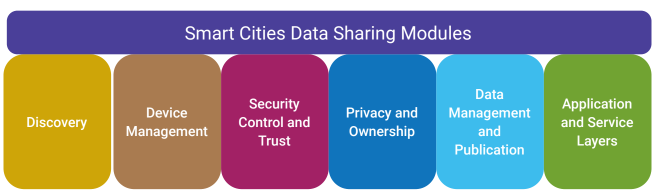


Figure 10.4: Smart City Data-Sharing Modules

The discovery framework for IoT-based devices — both within a set of city resources and with third-party or consumer/ business-owned devices — will play a major role in the success and scale of smart city applications. AI can facilitate the discovery framework. Device management focuses on maintaining reliable connectivity for each device and for monitoring its configuration and operational security. Security, Control, and Trust provide confidence in the source and usage policies of data generated from an IoT device. Without these capabilities and their underlying technologies, there is risk of constraining data sharing and undermining the integrity of the ecosystem, with consequences for business decisions and the management of critical infrastructure.

From a privacy-control level, the type of data used in smart city applications is fundamentally different from the open data sets that municipalities have published intermittently and at minimal cost from city resources or because of "freedom-of-information" obligations. Data management and publication acts as the core of any smart city data platform. It relies upon data acquisition and collection from data sources to provide several stages of value enhancement, including: (1) data processing (2) data storage (3) analytics (4) predictive actions and (5) publishing.

Application and service layers involve the technical capabilities that enable the exposure of applications to all the ecosystem participants. These include the entities that operate the smart city infrastructure and the developers that will leverage smart city data and citizens.

To achieve productive and effective outcomes, sense-making technologies are another important technology category. This consists of two sub-categories:

1. ML applications that gather, analyze, and become habituated to patterns of data from the physical environment observed by sensing technologies. ML applications "learn" to recognize recurrent and anomalous patterns, allowing the construction of predictive information models useful for resource allocation.

2. AI applications that make decisions using data collected by sensing technologies and used to create the smart city's information models to allocate resources. Such resource allocation decisions would include changes in water pressure in specific neighborhoods, allocation of power generation and distribution capacity, adding or diminishing surface or subsurface transportation services depending on traffic flow, and changing traffic lights based on traffic flow.

10.5 Spectrum Implications

Smart cities present three spectrum-related issues. Firstly, sensors will be an important component of the IoT ecosystem that enables massive machine-type communications. The introduction of zero-energy IoT devices within the 6G timeframe will increase proliferation and device density and by orders of magnitude compared to the present. These dynamics are likely to make cellular IoT an obvious choice for most developers, something not conceivable in previous generations of wireless communications systems.

Secondly, most city governments and municipalities currently depend on public networks based on licensed spectrum. There are some cases where private networks based on unlicensed spectrum are used to provide access to municipal services. This arrangement may not be sustainable when increasing numbers of smart city applications require greater reliability and a higher Grade of Service (GoS). Spectrum catering specifically to city services may require serious considerations. Critical functions associated with safety-of-life-services and automated tasks will depend on highly resilient network infrastructure.

There will also be a need to assure security and privacy. Potential solutions involve the use of private networks using dedicated spectrum or through network slicing over public networks. Additionally, as it applies to data, spectrum sharing across city government agencies might be required for resource-efficiency reasons. While city agencies provide transportation, health care and emergency services might require different network infrastructure and spectrum conditions. There might be opportunities to leverage a common pool of spectrum given the right network sizing.

Thirdly, suitably crafted spectrum policies can create a sandbox environment for 6G and spectrum evaluation in the context of governments providing a playing field for innovation. Building modern, sustainable, and reliable infrastructure is critical for meeting the rising needs of productivity and sustainability, but individual business cases are often hard to justify. Major investment challenges are often being met through public-private partnerships. City governments in many parts of the world are taking major initiatives to establish test centers, with a view to driving technology innovation and to involve innovators, suppliers, and users. One example is the city of Bristol, UK, whose local university showcased next-generation wireless technology in public urban environment.[32] A relatively small government investment can lead to a "virtuous cycle" of productivity and innovation that drives economic growth.

Spectrum made available by a government agency can be a key component of a sandbox. This type of environment allows local industries and entrepreneurs to experiment with spectrum and to create new technologies and services that benefit the community. Examples include the Netherlands' Dynamic Spectrum Management & Sharing (DSMS) pilot[33] and Norway's investigations that established options[34] for industry and verticals to get access to spectrum for 5G services.

11 CROSS-VERTICAL INSIGHTS AND AVENUES TO ADVANCE 6G

In the same way as electrons flow through an energy network, 6G innovations will power new and varied uses of communications systems throughout the wider economy. Traditional views about the use of communications networks will evolve to take advantage of a broader set of features enabled by end-to-end AI/ML capabilities and high levels of automation in distributed cloud and computing resources. While research and innovation outputs are expected to drive fundamental changes in core technologies, they will also deliver breakthrough technologies in the post-2030 timeframe. Moreover, some of these breakthroughs will be in response to new demands arising from environmental and societal needs.

These developments carry huge significance to organizations in the ICT ecosystem. They are equally important to a wider community of organizations because of 6G's economy-wide impact. These are some of the factors that motivated the strategic research and analysis reported in this report.

An additional rationale is the communications industry's desire to work more closely with entities from industry verticals. One of the goals of the NGA is to engage future 6G adopters early in the roadmap and leverage experts from adjacent industries to develop the 6G vision collaboratively. This early collaboration will allow all industries to foreshorten 6G's adoption and commercialization journey.

Engagement with adjacent industries will also help the communications industry to gain insights into the needs of industry verticals. This can provide the stimulus for public-private partnerships, as well as research, standardization, and technology-development programs. A first step in cross-industry collaboration is to apply a framework for capturing vertical industry requirements and synthesizing their 6G implications for the communications ecosystem.

11.1 Overcoming Requirements-Capture Challenges

Vertical industry outreach and research into 6G requirements are easier contemplated than done. There are at least two complications:

> **Time-horizon challenge:** Many providers in the communications ecosystem are currently focused on bringing powerful 5G solutions to the market. At the same time, the number of organizations contributing to the NGA as a forum to channel North America's efforts on Next G communications systems is growing. Their involvement focuses on the post-2030 timeframe.

> **Domain expertise:** 6G takes communications systems into adjacent ICT domains. 6G also holds significant promise in industrial and societal application areas. It is therefore important to research new application domains for insights into drivers of demand. Although industry representatives cannot be expected to articulate specific requirements or KPIs, they can express their industry visions and needs. These insights can bridge the information gap between ICT and vertical industry sectors. They allow communications industry experts to infer implications for enabling technologies. They also raise awareness about the importance of cross-industry dialog. This NGA research initiative provides a means of translating early insights into a collective set of technologies and applications that will drive 6G adoption.

11.2 NGA's 6G Research Findings

As illustrated in Figure 11.1, NGA members used a structured research approach to develop insights into the factors that should shape 6G developments. The step-by-step process builds on primary and secondary research across eight verticals to gather insights into industry dynamics and capability needs. Many vertical industry experts spoke in terms of future services and enabling applications. The subsequent tasks for NGA members were to interpret these insights and infer their implications both for 6G systems and future North American action.

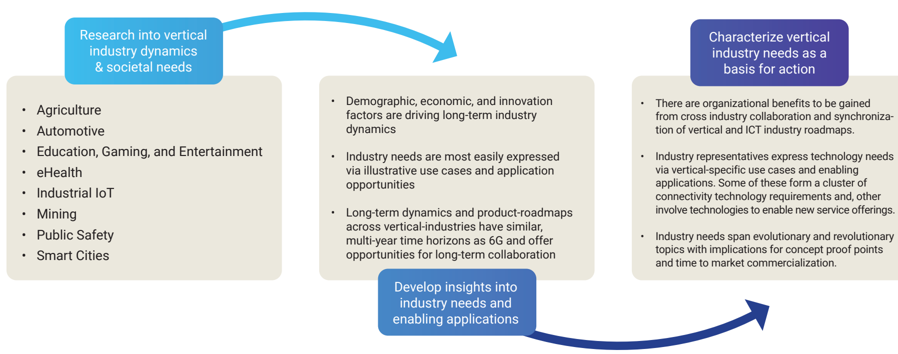


Figure 11.1: NGA Research Insights and Implications for Advancing 6G

Table 11.2 summarizes key industry trends for each vertical. There follows a set of enabling applications that industry representatives anticipate will help their ecosystems to address decision-making and operational needs. From industry interviews and research activities, NGA researchers identified a set of technology-related needs for each industry vertical. In some cases, interviewees referred to specific technologies. At other times, they described uses of technology to enable innovative use cases or requirements for improving the speed or quality of decision-making. Unsurprisingly, there are several cases where enabling applications and key technologies, such as digital twins and joint communications and sensing, are repeated across industry verticals.

	Trends	Enabling Applications	Key Technologies
Automotive	Integration of QoE in vehicle Connectivity Autonomy Electrification Safety and User Privacy	Maintaining vehicle data Autonomous driving/parking Situational awareness and 3D positioning Rich infotainment experience with compute/connectivity	Low latency/highly reliable connectivity Distributed computing JCAS NTN/sidelink communications E2E Trustworthiness
Industrial IoT	Convergence of IT/OT/CT Smart factory automation Collaborative robots Granular sensing and monitoring	Integration of sensors/AGVs, video and XR Massive use/integration of AI Data shared between sensors and wearables RedCap devices	Distributed cloud and virtualization Flexible compute resources Physical sensors updating digital twins JCAS Trustworthy networks and systems
Public Safety	Public safety enablement on wireless networks Beyond voice communications Improved coverage (multi-network) Internet of Life Changing Things	New XR, HMD, wearables Robots for rescueUAVs for situational awareness Highly connected ambulances, police cars	Coverage technologies for limitless connectivity Ultra 3D positioning AR/XR and video feeds AL/ML based situational awareness Highly reliable and secure communications
Smart Cities	Growing interdependency of municipal resources Increasing urbanization Broad range of stakeholders sharing of smart city data	AI-powered secure data management DWE and multi-sensory communications Energy efficiency and sustainability JCAS	Sensing technologies utilizing ML to analyze and predict AI-driven decisions to allocate resources Resilient networks to assure privacy and security Massive connectivity of IoT devices
EGE	Growth of streaming services and cloud-based gaming Hyper-casual gaming Integration of advertising and in-app purchases Merging EGE with education	Multi-sensory experiences Digital twins Real-time synchronization Real-world sensing	High performance holographic devices Cognitive-aware systems Application-awareness Ultra-low latency communications
Agriculture	Agronomics Autonomous machine movement Cooperative machine tasks Data-driven logistics Situational awareness	Cooperative robotics Extreme coverage Remote sensing Ultra-precise positioning	Connectivity on demand Data collection via low energy sensors Peer-to-peer communications Scalable latency
Mining	Digitization and robotics Communications and operational challenges Linkage to sustainability Contributor to national and global economies Improving energy efficiency	Autonomous operation Immersive DWE Digital twin replicas 3D imaging	Trusted connectivity JCAS Integrated AI Distributed sensing and communications Data-driven distributed intelligence Energy efficiency and environmental sustainability technologies
eHealth	Advancing a healthy quality of life Remote monitoring and home-based care Remote treatment and disaster recovery Improving clinician training and modes of delivery	DWE/multi-sensory experiences Distributed sensing and communications Network-enabled robotics and autonomous systems Personalized UE VR health experiences	In-facility and remote connectivity 3D devices, systems and imaging Cognitive systems supporting DWE Trustworthy AI Micro-networks surrounding patient

Table 11.2 Summary of Industry Dynamics and Key Technology Needs by Vertical

There are three key conclusions arising from the vertical industry research.

1. Cross-industry organizational matters are as critical as technical ones.
2. Vertical industry represents expressed two sets of needs: one related to technology connectivity and the second to technology to enable new services.
3. The range and diversity of vertical industry needs spans a mix of evolutionary and revolutionary technologies.

11.2.1 Need for Cross-Industry Synchronization and Dialog

Several industry representatives alluded to the value of cross-industry synchronization and the beneficial implications for long-term planning. Industry counterparties whose responsibilities encompass industry-strategy issues saw considerable value and benefits from future collaboration. In exchange, communications sector experts can gain an understanding of the financial, operating model, innovation, and timing factors driving different industries.

An illustrative example is the health sector's evolution to self-care, which will be exacerbated by financial pressures and a long-term shortage of care staff. From this perspective, the health care industry and future 6G marketplace are on complimentary trajectories to deliver new provider and patient experiences. There are several implications for the communications sector. One is that it will provide the technical foundations that enable individuals to self-monitor their wellbeing. Another is the possibility to leverage expertise across sectors. Here, the opportunity is for the communications industry to deliver the technology and services for gamified applications that encourage physical activity and social interactions.

The communications system will also need to equip care providers with the tools to interact with their patients. An example of a technical implication for 6G is dependable access to location data. This has a range of uses, ranging from situations when a person is at risk of falling to a dementia patient who gets lost during their daily walk outside of their home.

Another important insight into market demand conveys innovation and engineering implications for 6G systems. For example, mining, agriculture, and utilities are relatively modest components of the economy. However, there are substantial commonalities for cellular networks when serving these verticals in wide-area situations. In aggregate, there is value in addressing common service-capability requirements in the network with modest adjustments to address sector-specific variations.

While NGA researchers gained valuable insights from the industry interviews, industry representatives gained equal benefit. The discussions enlightened industry representatives about the potential of 6G and its likely development timeline. A key conclusion from these discussions is the importance of continuing dialog and the shared goal of synchronizing development roadmaps to maximize technical relevance adoption prospects. For example, the automotive sector's plans in areas such as autonomous driving, in-vehicle information services, and safety have timelines that are similar to those contemplated for 6G. Long-term coordination on topic such as proofs-of-concept, planning of product and service roadmaps, and experimental testing would benefit both automotive and ICT ecosystems.

Closing the loop on vertical industry needs will be critical for the ICT sector to manage expectations about capability breakthroughs, their timing, and the maturity of new propositions.

11.2.2 Implications for Technology Needs

The implications for 6G technology innovation cover a long and varied list of topics, as summarized in Table 11.2 above. Being based on high-level and early-stage industry discussions and research, this is not a comprehensive list. Nevertheless, it contains nuggets of ideas that can help organizations to shape their innovation activities in the growing 6G ecosystem.

A first step is to categorize the list of key technology suggestions, identifying categories that will be of use to researchers and innovators across the ICT ecosystem. The categorization process involves sorting and collecting each of the key technology items from Table 11.2 into topic areas. Any given item might fit into one or more topic areas. For example, the "physical sensors updating digital twins" item maps to AI/ML, IoT sensor devices, digital twin, and 2D/3D positioning topic areas.

Figure 11.3 shows the aggregated topic areas resulting from this synthesis. The size of each topic "tile" indicates its importance in the overall scheme. "Connectivity" and "AI/ML" feature most prominently because these topics encompass the largest numbers of key technology items. In the 6G communications context, their importance is understandable. "Connectivity" reflects the enablement of massive machine-type connectivity. Meanwhile, 6G's end-to-end "AI/ML" capabilities will power a wide variety of applications associated with data analytics and extreme automation of 6G systems.

It is important for technology developers and service providers to note that some of the broader topic areas aggregate several granular features. In the case of "connectivity," for example, industry representatives framed their needs using terms such as "extreme connectivity," "limitless connectivity," and "on-demand connectivity." Similarly, the "devices" category encompasses new classes of UE, IoT devices, new sensor types, AR/VR/HR headwear, and "personalized" UE to deliver a range of services and digital world experiences.

Although they seem to be related, "Sensing Technologies," "Sensing and Positioning," and "Positioning" appear as three separate topics. This is because the research suggests that each topic conveys different meanings, implying different needs from 6G systems. The first two topics indicate demand for technical innovation in relation to new and advanced forms of sensing. Some of these involve use cases where sensing is interlinked with positioning capabilities.

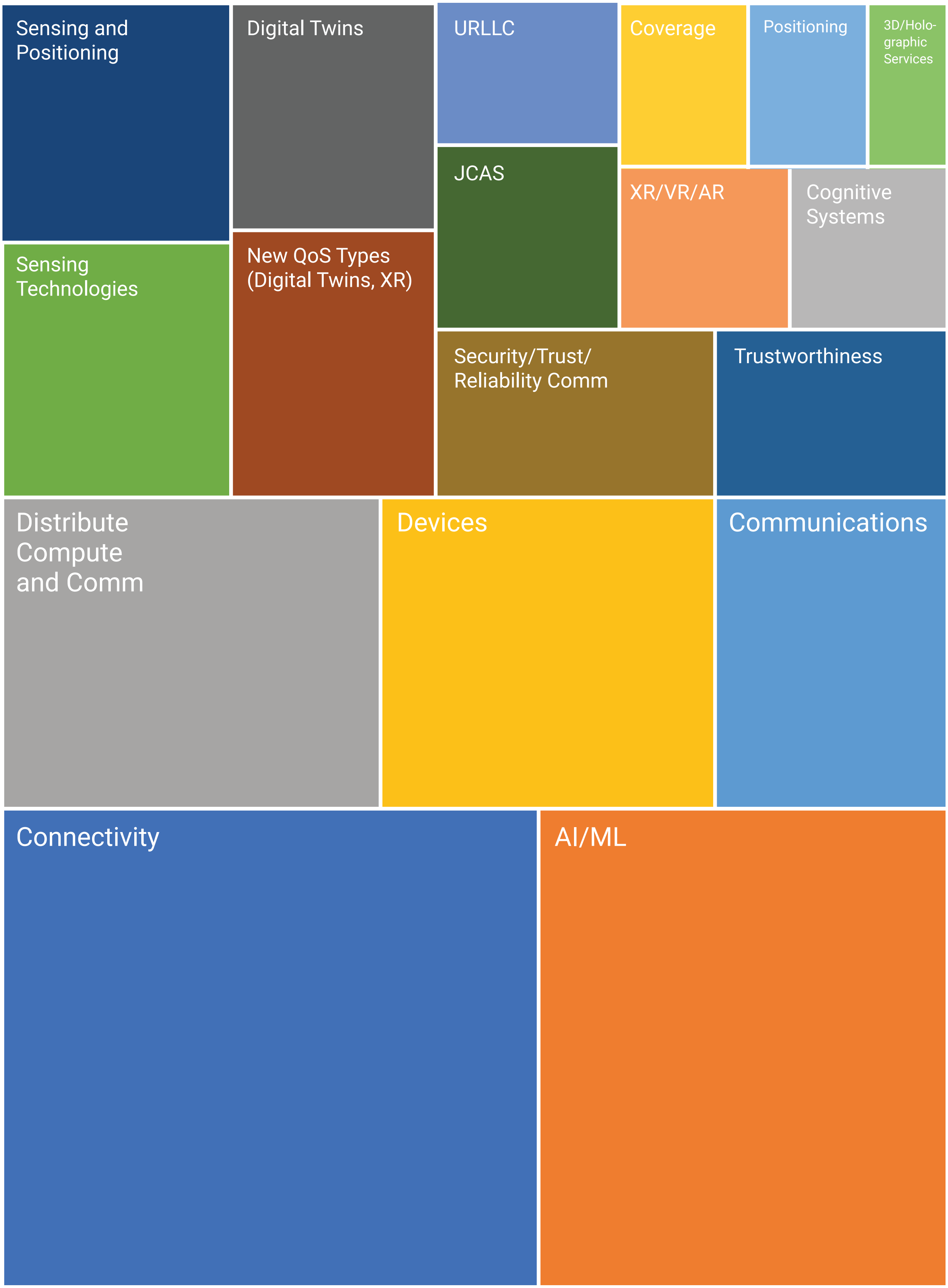


Figure 11.3 Vertical-sector Capability and Technology Needs for 6G

The reference to "Positioning" covers descriptions such as "extreme positioning," "3D positioning," and "precise positioning." Other research observations refer to positioning as a technology capable of enabling new service offerings that make an application use case possible. An example from the agriculture sector might involve a service that is reliably available in remote locations. It would help in in synchronizing the movement of a harvester and a separate load-carrying vehicle moving alongside the former. In the public safety arena, 3D and below-ground positioning information might keep a first responder safe. Or it could help to locate a vulnerable patient who steps outside for a walk and forgets their way home.

A second insight captured in Figure 11.3 is the interdependency between category topics. The delivery of 3D and holographic services, for example, involves several complementary building blocks. These include communications, connectivity, devices, and trustworthiness capabilities. 6G innovation should therefore not be viewed an isolated undertaking but one that meshes with capabilities and developments occurring in other parts of the technology ecosystem.

The economy-wide applicability of 6G means that its innovation footprints will increasingly spread to touch developments in adjacent industries. Advances in video processing and content-distribution technologies, for example, will have a bearing on how 6G headwear devices are developed and configured.

Similarly, autonomous vehicle developments are likely to drive unique demands for distributed computing and communications technologies in the ICT sector. Self-reinforcing innovation might then spill over into the design of solutions for movable machinery in the agriculture sector. The prospect of such long-term interdependencies reinforces the value of cross-industry dialog and roadmap synchronization.

11.2.3 Vertical Industries Need Evolutionary and Revolutionary Technologies

The categorization analysis on vertical industry needs yielded an additional set of insights about evolutionary and revolutionary technology needs. In terms used by vertical industry representatives, Figure 11.4 presents a mapping of the technology topics they raised in discussions with NGA members. The mapping approximates the spectrum of technologies for connectivity, weighing evolutionary topics to the left-hand side and revolutionary ones to the right. The vertical positioning of items groups technologies toward the lower end and draws a distinction, toward the upper end, about technologies that might enable new services in line with needs expressed by vertical industry representatives.

Evolutionary topics continue themes that are integral to existing 3GPP roadmap and research commitments. Since 6G is expected to evolve from prior "Gs," emerging industry needs and technical innovations will involve a technical progression. This might improve design modularity, for ease of use, or enhance one or more key performance metrics. For practical illustration, throughput rates will be higher, latencies lower, and coverage available in more locations. There is also an expectation that communications systems will evolve to be trustworthy and that 6G systems will make greater use of distributed computing capabilities.

Revolutionary topics encompass breakthrough technologies and research that are likely to require new funding sources and new initiatives. They might unleash completely new use cases and industry applications. Example developments linked to 6G include non-public networks, end-to-end AI/ML, and scalable latency. In addition, cognitive-aware capabilities are expected to deliver step changes in the performance of communications systems and the delivery of digital world experiences. The designation of revolutionary topics is important in guiding the communications industry and its partners, across public and private sectors, toward the need for new research or planning for longer engineering and commercialization time horizons.

There is no single approach to advance evolutionary and revolutionary technologies. Some lend themselves to cross-industry, proof-of-concept demonstrators while others will involve combinations of research, standardization, and testbed activities. The capabilities and service offerings in Figure 11.4 are strong candidates for cross-industry collaboration to prove their usefulness in enabling innovative applications and preparing the conditions for market adoption at scale.

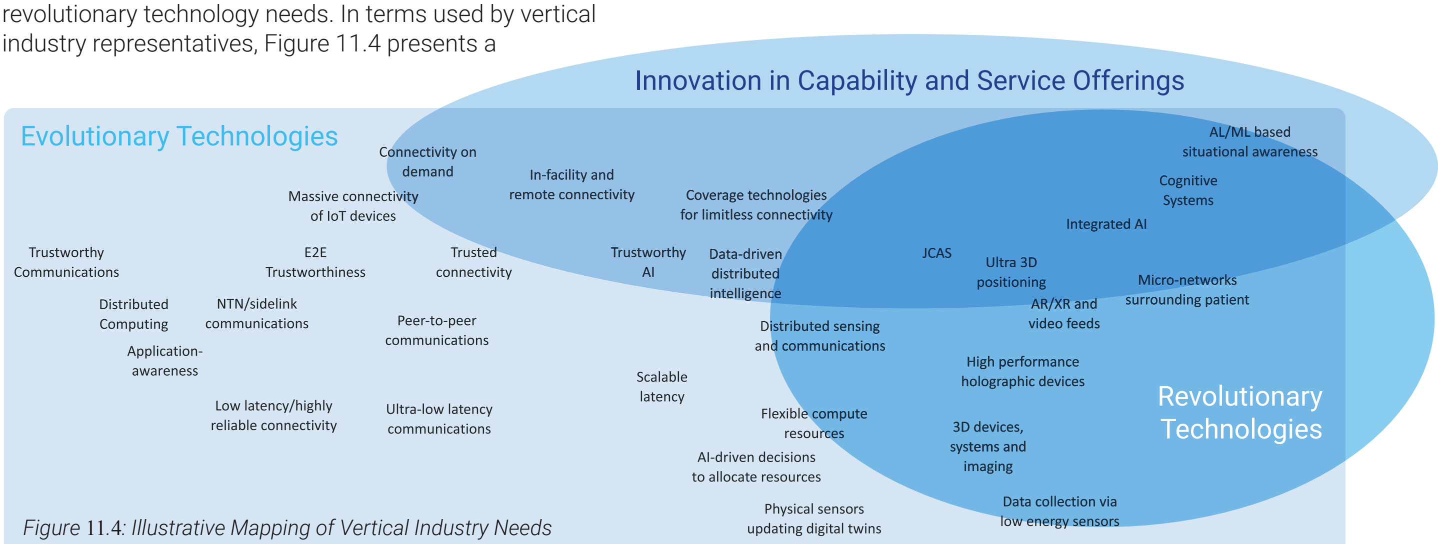


Figure 11.4: Illustrative Mapping of Vertical Industry Needs

12 IMPLICATIONS AND ACTION PLAN FOR NORTH AMERICA

The research for this report features a long list of industry needs and technical topics. While these pose significant research and implementation challenges, there is also a pressing need to bridge information gaps between the communications ecosystem, industry verticals and adjacent fields of technology. Efforts in these areas should lead to tangible outcomes that will propel the North American market towards commercial success. Of course, this pathway will depend on adequate funding through suitable public-private models for collaboration. NGA members identified three goals to achieve success.

Translate North American needs to technology outcomes: The NGA will build upon these initial vertical industry engagements to translate 6G adopter perspectives to technical performance needs and technology implications. Building upon this early assessment of 6G vertical industry needs, this work can be progressed to a desired set of performance attributes and technology advancements that will lead to strong 6G market adoption in North America. The early development and prioritization of 6G technology needs aligned with a North American centric research partnership will position the US and Canada for a robust 6G marketplace by 2030 and beyond.

Target shared investments in 6G proof-of-concepts and testbeds: The diverse membership of the NGA is well-positioned to evolve the technology assessment and application KPIs to a framework of 6G POCs that are oriented to vertical industries and adopter needs. This includes a societal-outcomes orientation that connects 6G technology to essential quality-of-life improvements and policy goals for North America. It is apparent from the vertical assessments that shared investments in important technological breakthrough areas like AI, digital twins, multi-sensory applications, and others will allow industries to achieve their vision in a cooperative set of POC undertakings, a collective win for North America.

Connect North American 6G needs to marketplace: The NGA should advance and advocate its perspectives on North American needs and use cases with other regions of the globe as part of a pre-competitive/pre-standardization framework. This represents an early and innovative approach that not only positions North American industries for the future, but also creates a blueprint for future standardization. Ultimately, the blending of North American vertical needs with other regions will allow North American companies to be well-positioned for the future 6G global market.

13

ABBREVIATIONS

3GPP .... 3rd Generation Partnership Project
5G-ACIA .... 5G Alliance for Connected Industries and Automation
5G NR........................... 5G New Radio
AAI .... Alliance of Automotive Innovation
AARP .... American Association of Retired Persons
ADAS .... Advanced Driver Assistance Systems
AECC .... Automotive Edge Computing Consortium
AGV .... Automatic Guided Vehicles
AI.................................. Artificial Intelligence
ANSI .... American National Standards Institute
AR .... Augmented Reality
BLS .... Basic Life Support
CAGR............................ Compound Annual Growth Rate
CITEL............................ Inter-American Telecommunication Commission
COTS .... Commercial Off-the-Shelf
CVTA .... Connected Vehicle Trade Association
C-V2X .... Cellular Vehicle-to-Everything
DoD............................... U.S. Department of Defense
DOL............................... Department of Labor
DSMS .... Dynamic Spectrum Management and Sharing
DSRC .... Dedicated Short-Range Communications
DWE.............................. Digital World Experiences
EDGEAPP .... Application Architecture for Edge Apps
EGE............................... Education, Gaming, and Entertainment
eMBB............................ Enhanced Mobile Broadband
EMS .... Emergency Medical Services
FWA.............................. Fixed Wireless Access
GDP .... Gross Domestic Product
GoS............................... Grade of Service
GPS............................... Global Positioning System
HMD .... Head Mounted Displays
HMI............................... Human Machine Interfaces
IAB .... Integrated Access Backhaul
ICT .... Information and Communications Technology
IIC.................................. Industry IoT Consortium
IIoT................................ Industrial IoT
IoT................................. Internet of Things
ISA .... CIntegrated Sensing and Communication
ITS................................. Intelligent Transportation System
ITU .... International Telecommunication Union

JCAS	Joint Communications and Sensing
LAN	Local Area Network
LIDAR	Light Detection and Ranging
LMR	Land Mobile Radio
LTE	Long Term Evolution
LTE-M	LTE for Machine-Type Communication
MC	Mission Critical
MCC	Mission Critical Communications
MCPTT	MC Push-to-Talk
ML	Machine Learning
MPEG	Moving Picture Experts Group
MR	Mixed Reality
NB-IoT	Narrowband IoT
NPN	Non-Public Networks
NTN	Non-Terrestrial Network
NR	New Radio
OPCF	Open Platform Communications Foundation
PoC	Proof-of-Concept
PPE	Personal Protection Equipment
PTSD	Post-Traumatic Stress Disorder
PRN	Positioning Reference Node
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RedCap	Reduced Capability
SCBA	Self-Contained Breathing Apparatus
STEM	Science, Technology, Engineering, and Mathematics
TRP	Transmission Reception Point
TSC	Time Sensitive Communications
UAM	Urban Air Mobility
UAV	Uncrewed Aerial Vehicles
UE	User Equipment
UNESCO	United Nations Educational, Scientific nd Cultural Organization
URLLC	Ultra Reliable Low Latency Communication
V2X	Vehicle-to-Everything
VA	Veterans Affairs
VET	Virtual Exposure Therapy
VMC	Vehicle Motion Control
VR	Virtual Reality
WEF	World Economic Forum
WG	Working Group
WHO	World Health Organization
WLAN	Wireless Local Area Network
XR	Extended Reality
ZTA	Zero Trust Architecture

14 REFERENCES

1. *Next G Alliance Report: Roadmap to 6G. Next G Alliance.* (February 2022). https://www.nextgalliance.org/white_papers/roadmap-to-6g/

2. *Ag and Food Sectors and the Economy*. U.S. Department of Agriculture. (26 January 2023). https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/

3. *Overview of Canada's agriculture and agri-food sector*. Government of Canada. (18 July 2022). https://agriculture.canada.ca/en/sector/overview

4. 3GPP TR 38.811: Study on New Radio (NR) to support non-terrestrial networks. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3234

5. *Car Sales by Country*. F&I Tools. (n.d.). https://www.factorywarrantylist.com/car-sales-by-country.html

6. *Transportation*. International Comparisons. (n.d.). https://internationalcomparisons.org/environmental/transportation/

7. *Fatality Facts 2020*. Insurance Institute for Highway Safety, Highway Loss Data Institute. (May 2022). https://www.iihs.org/topics/fatality-statistics/detail/yearly-snapshot.

8. *C-V2X Use Cases and Service Level Requirements Volume II.* 5GAA Automotive Association. (January 2021). https://5gaa.org/wp-content/uploads/2021/01/5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II_V2.1.pdf

9. *The Path to Autonomous Driving.* BMW. (21 October 2020). https://www.bmw.com/en/automotive-life/autonomous-driving.html

10. Dahlstrom, T. (20 July 2021). *The road to everywhere: Are HD maps for autonomous driving sustainable?* ADAS & Autonomous Vehicle International. https://www.autonomousvehicleinternational.com/features/the-road-to-everywhere-are-hd-maps-for-autonomous-driving-sustainable.html

11. *From 5G to 6G Vision – A Connected and Automated Mobility (CAM) Perspective*. 6G-IA. (June 2022). https://5g-ppp.eu/wp-content/uploads/2022/06/White_Paper_6G-IA_5G_for_CAM_WG_From_5G_to_6G_Vision_June_2022.pdf

12. M. Noor-A-Rahim et al., "6G for Vehicle-to-Everything (V2X) Communications: Enabling Technologies, Challenges, and Opportunities," in Proceedings of the IEEE, vol. 110, no. 6, pp. 712-734, (June 2022) https://ieeexplore.ieee.org/document/9779322

13. *North America Education Apps Market Forecast to 2028*. Business Market Insights. (April 2022). https://www.businessmarketinsights.com/reports/north-america-education-apps-market

14. *Mobile Gaming Market Size is projected to reach USD 338 billion by 2030, growing at a CAGR of 12.3%.* Straits Research. (11 July 2022). https://www.globenewswire.com/fr/news-release/2022/07/11/2477569/0/en/Mobile-Gaming-Market-Size-is-projected-to-reach-USD-338-billion-by-2030-growing-at-a-CAGR-of-12-3-Straits-Research.html

15. Pavel, Adina-Petruta. *Global University Rankings - A Comparative Analysis*, Procedia Economics and Finance, Volume 26, 2015, Pages 54-63, https://doi.org/10.1016/S2212-5671(15)00838-2.

16. *Global Education Monitoring Report.* Unesco. (n.d.). https://www.unesco.org/gem-report/en

17. Ho, Tracey, and Lun, Desmond. *Network Coding: An Introduction*. Cambridge University Press, (2008). https://pce-fet.com/common/library/books/34/1308_[Tracey_Ho,_Desmond_S._Lun]_Network_Coding_An_Int(b-ok.org).pdf

18. Cohen, Alejandro, et al. "Bringing network coding into SDN: Architectural study for meshed heterogeneous communications." *IEEE Communications Magazine* 59.4 (2021): 37-43. https://hdl.handle.net/1721.1/144020

19. *Modernizing healthcare technology for today's needs and tomorrow's possibilities*. IBM. (2017). https://www.ibm.com/downloads/cas/Y4KZVK5O

20. *Number of people 75 and older in the labor force is expected to grow 96.5 percent by 2030.* Bureau of Labor Statistics, U.S. Department of Labor, The Economics Daily. (4 November 2021). https://www.bls.gov/opub/ted/2021/number-of-people-75-and-older-in-the-labor-force-is-expected-to-grow-96-5-percent-by-2030.htm

21. *WHO Data Sheet: Dementia*. World Health Organization. (22 September 2022). https://www.who.int/news-room/fact-sheets/detail/dementia

22. *Driving Down Healthcare Costs with AR and VR Technology.* EOS Intelligence. (16 August 2018). https://www.eos-intelligence.com/perspectives/life-sciences/driving-down-healthcare-costs-with-ar-and-vr-technology/

23. T. Shibata. *Therapeutic Seal Robot as Biofeedback Medical Device: Qualitative and Quantitative Evaluations of Robot Therapy in Dementia Care*. IEEE. (August 2012). https://doi.org/10.1109/JPROC.2012.2200559

24. Logeswaran A, Munsch C, Chong YJ, Ralph N, McCrossnan J. *The role of extended reality technology in healthcare education: Towards a learner-centered approach.* Future Healthc J. (8 March 2021). https://doi.org/10.7861%2Ffhj.2020-0112

25. T. Segawa, T. Baudry, A. Bourla, J. Blanc, C. Peretti, S. Mouchabac, and F. Ferreri. *Virtual Reality (VR) in Assessment and Treatment of Addictive Disorders: A Systematic Review.* Frontiers in Neuroscience. (10 January 2020). https://www.frontiersin.org/articles/10.3389/fnins.2019.01409/full

26. A. Hone-Blanchet, T. Wensing, S. Fecteau. *The use of virtual reality in craving assessment and cue-exposure therapy in substance use disorders*. Frontiers in Human Neuroscience. (17 October 2014). https://www.frontiersin.org/articles/10.3389/fnhum.2014.00844/full

27. Pericot-Valverde, I., Germeroth, L. J., & Tiffany, S. T. *The Use of Virtual Reality in the Production of Cue-Specific Craving for Cigarettes: A Meta-Analysis*. Society for Research on Nicotine and Tobacco. (8 October 2015). https://doi.org/10.1093/ntr/ntv216

28. Veedu, Sandeep Narayanan Kadan and Mozaffari, Mohammad and Hoglund, Andreas and Yavuz, Emre A. and Tirronen, Tuomas and Bergman, Johan and Wang, Y. -P. Eric. *Toward Smaller and Lower-Cost 5G Devices with Longer Battery Life: An Overview of 3GPP Release 17 RedCap*. IEEE. https://doi.org/10.48550/arxiv.2203.05634

29. *Mining in Canada*. Mining Association of Canada. https://www.canadaaction.ca/mining

30. *Urban Development.* The World Bank. (6 October 2022). https://www.worldbank.org/en/topic/urbandevelopment/overview

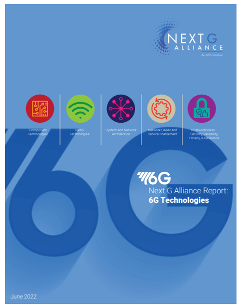
31. *Make cities and human settlements inclusive, safe, resilient and sustainable.* United Nations: Department of Economic and Social Affairs Sustainable Development. https://sdgs.un.org/goals/goal11

32. *World's first urban 5G experience hosted by University of Bristol and Watershed.* University of Bristol. (10 March 2018). https://www.bristol.ac.uk/engineering/research/smart/news/2018/5g-urban-showcase.html

33. *Netherlands launching 3.8GHz-4.2GHz Dynamic Spectrum Management & Sharing pilot*. CommsUpdate. (12 December 2022). https://www.commsupdate.com/articles/2022/12/12/netherlands-launching-3-8ghz-4-2ghz-dynamic-spectrum-management-sharing-pilot/

34. *Nkom has opened 3,8-4,2 GHz for local area 5G networks.* Norwegian Communications Authority. (18 January 2023). https://www.nkom.no/aktuelt/nkom-has-opened-3-8-4-2-ghz-for-local-area-5g-networks

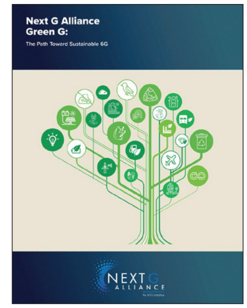
NEXT G
ALLIANCE
REPORTS



6G Technologies

6G Applications and Use Cases

Roadmap to 6G



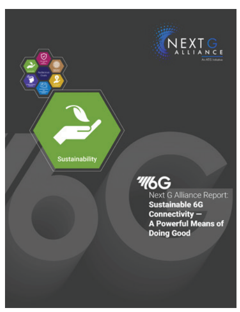
Green G: The Path Toward Sustainable 6G

6G Distributed Cloud and Communications System

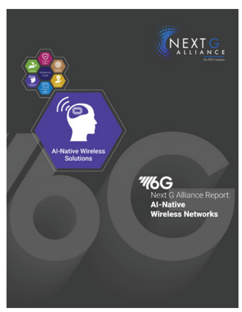
Trust, Security, and Resilience for 6G Systems

Digital World Experiences

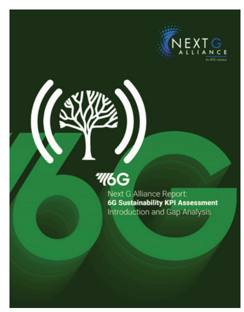
Cost-Efficient Solutions



Sustainable 6G Connectivity — A Powerful Means of Doing Good



Next G Alliance Report: AI-Native Wireless Networks



Next G Alliance Report: 6G Sustainability KPI Assessment Introduction and Gap Analysis

Next G Alliance Report: Multi-Sensory Extended Reality (XR) in 6G

Next G Alliance Report: Terminology for Frequency Ranges

Next G Alliance Report: Enabled Robotic and Autonomous Systems

6G Market Development: A North American Perspective

COPYRIGHT AND DISCLAIMER

Building the foundation for
North American leadership in
6G and beyond.

nextgalliance.org

NEXT G ALLIANCE

An ATIS Initiative