5G Technology and Applications

Harvard College Consulting Group

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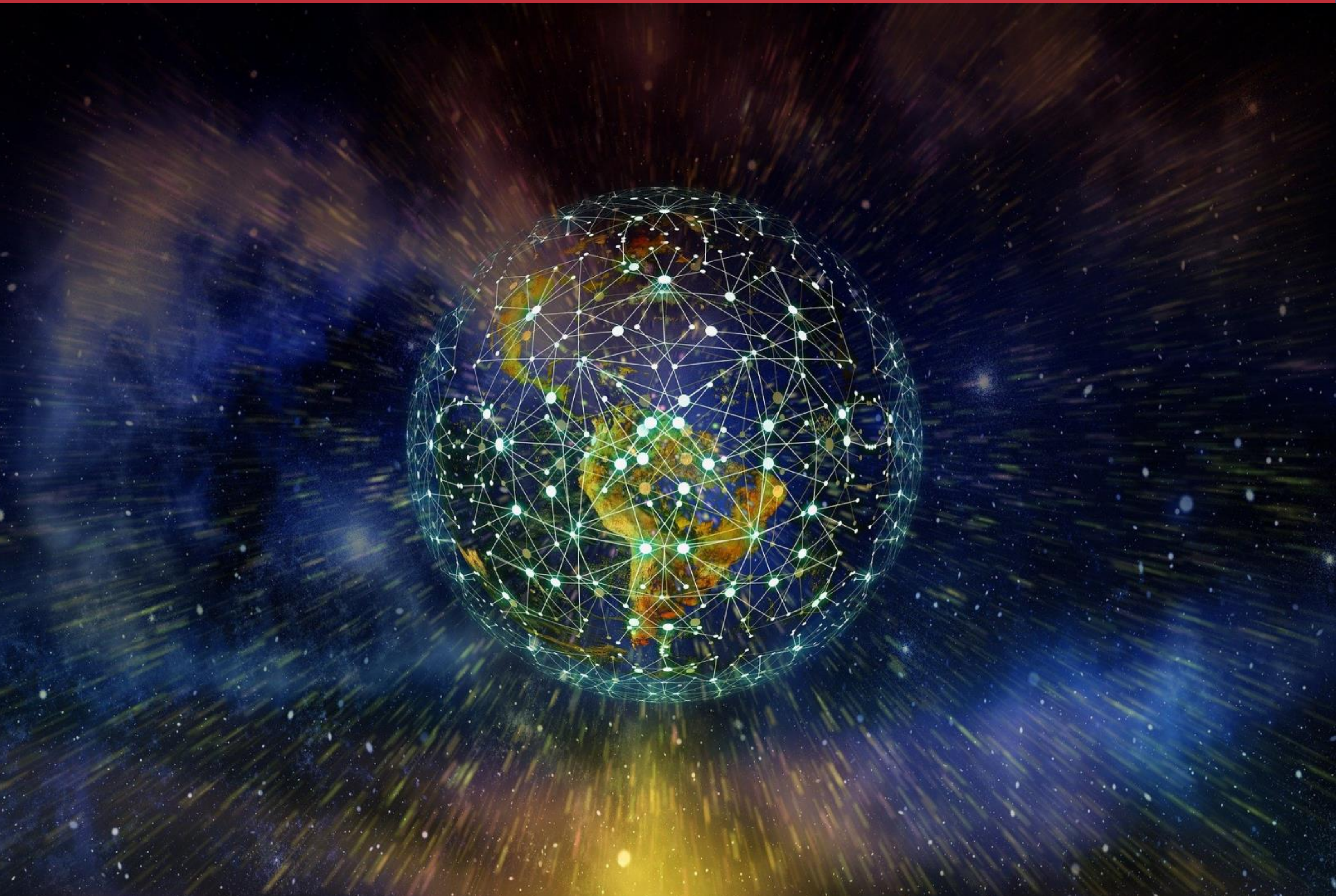

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2. Executive Summary

5G is the 5th generation mobile network standard. It **offers extremely fast speeds, low latency, superior reliability, and much greater network capacity**. Compared to 4G LTE, 5G is up to **100x faster** and **can support 250x more connected devices**. This higher performance and improved efficiency delivered by 5G enables a variety of new applications and products in nearly every industry.

AUTOMOTIVE

45%

of all global car sales could have **conditional automation or better** by 2030

5G will enable the **development of connected cars** that can communicate with other devices, such as other cars, traffic lights, and pedestrians' cell phones. This technology will give rise to **self-driving, autonomous vehicles, reduce pedestrian fatalities, commuting times, and pollution**.

Initially, connected cars will likely **face slow adoption into the market**, hindered by barriers such as government regulation and privacy concerns. However, once 5G technology is effectively integrated with automobiles, there will likely be **immense disruptions in the market, the environment, and society** at large.

SMART CITIES

5G is poised to enable the rapid development of smart cities through ubiquitous device connectivity, **generating huge amounts of data that will help improve the efficiency and sustainability of city services**. With 5G and big data, smart cities can take a targeted approach to **improve transportation, resource management, and security**.

However, these applications come at the cost of **reduced privacy for citizens**. For this reason, the integration of 5G in smart cities is facing substantial resistance in the status quo.

80%

of major cities worldwide **have plans to utilize 5G technology** by 2030

NATIONAL DEFENSE

"This is not just a race to 5G. It's really a race to the **large, complex data sets that 5G will enable.**"

- David Simpson, former Chief of the Public Safety Bureau for the FCC

Next generation networks will enable data processing at a scale that offers to **revolutionize wide-ranging military operations** in everything from drone deployment to efficient resource distribution. Additionally, 5G will **shift warfare from terrestrial combat to the realm of information networks**.

Security risks from **software intrusions such as cyberattacks**, however, pose a threat to the safe operation of 5G military network usage.

3. Introduction

Now more than ever, consumers are becoming increasingly reliant on network-connected devices to go about our lives, from socialization to entertainment, to even productivity. 5G, the fifth-generation network standard, offers remarkable improvements in speed, latency, reliability, and coverage over 4G LTE. As a result, 5G opens the door to numerous new possibilities. However, it's unclear which 5G applications will actually meaningfully impact consumers, businesses, and governments, or when they'll manifest. To that end, this paper discusses the applications, rate of adoption, and barriers of 5G technology in the automotive industry, smart cities, and national defense.

Methodology

The HCCG team conducted an extensive literature review of 5G technology and its applications within the automotive industry, smart cities, and national defense. Using these findings, the team was able to gain insights into the workings of 5G, its highest-impact use cases, and barriers to the implementation and commercialization of this technology.

In order to achieve an in-depth understanding of how consumers will respond to 5G, the HCCG team surveyed **305 respondents** about their attitudes toward potential 5G applications to understand the viability of these applications. 86% of respondents were college-aged Harvard affiliates. Insights from the survey were used to evaluate the importance and likelihood of success for the various consumer use cases of 5G.

Additionally, the team interviewed **9 experts on 5G** from Harvard Business School, Harvard Law School, Harvard Kennedy School, and Virginia Tech to better understand the implications of 5G at large and within each of the specific industries. Experts provided insights into the technical workings of 5G as well as the policy and market implications of the technology. Interviews focused on the impact and adoption of 5G technologies in the short-term and long-term.

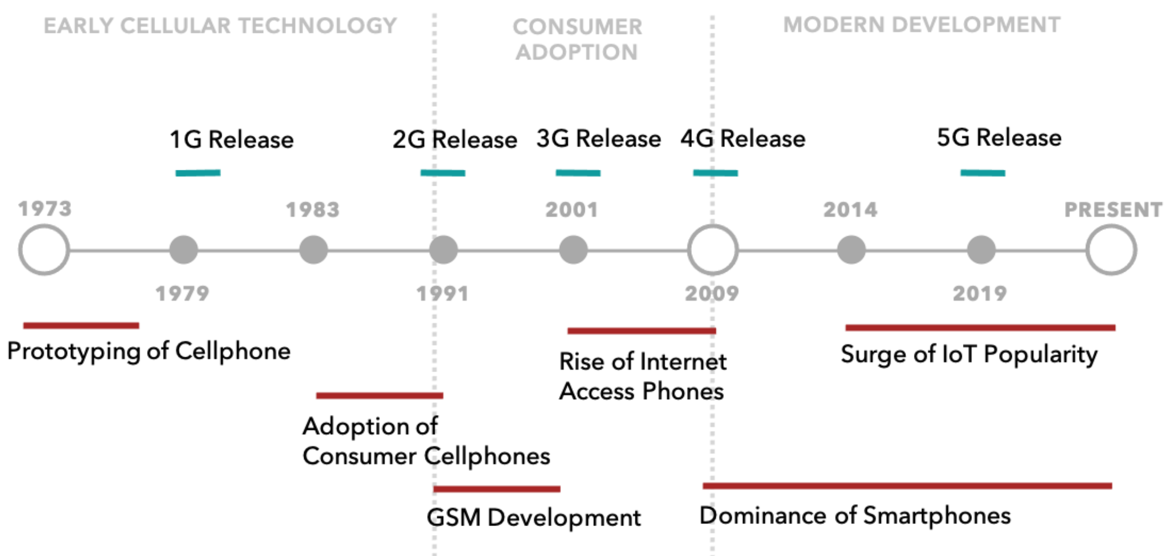
4. Background

5G refers to the fifth-generation telecommunication standard for broadband cellular networks, first deploying in South Korea in late 2019. The appeal of 5G is faster speeds, lower latency (reduced network delay time), and broader network coverage (more devices can connect).

4.1 History

The first mobile cell phone prototypes were developed in 1973. In 1979, Japanese company Nippon introduced the first-generation standard for cellular networks dubbed 1G. The premise of this technology was to use different frequencies of radio waves to pass information between devices. It wasn't until 1983, however, that 1G was commercialized when Motorola released the DynaTAC (often called "brick" phone due to its bulky size). These early devices used analog radio waves and had poor coverage, reliability, and security. In 1991, the next standard, 2G, was released. It used digital radio waves instead and **allowed for increased security and coverage**. It also allowed for better voice call quality and the sharing of digital information via bits, making texts, SMS, and downloadable ringtones possible.

Exhibit 1: Timeline of major events in the history of telecommunication networks



In 2001, Japanese company NTT DoCoMo released 3G, enabling better data streaming for emails, video playback, video conferences, and live video chat. It was responsible for the popularity of smartphones. To this date, "**40% of the world still uses 3G**" and many applications continue to use 3G due its current low cost.[1]

[1] Interview with Professor David Yoffie, Harvard Business School

Roughly a decade later, in 2009, the 4G standard was released, giving rise to **high-quality video streaming/chat, fast mobile web access, HD videos, and online gaming**. The 4G standard used a different underlying standard from predecessors, and mobile devices needed special hardware to use the new standard. The implementation of the 4G standard is through Long-Term Evolution (LTE) , which refers to incremental improvements made by TELCOs on existing 3G network infrastructure to achieve 4G performance. As of 2021, LTE continues to evolve and significantly outperforms 3G.

In 2014, Google acquired Nest, a smart home products developer, signifying a big shift into **the Internet of Things (IoT),** which are devices that communicate with each over the Internet. Millions of IoT devices have been created since and are largely powered by in-home WiFi. However, for IoT devices outside the home, such as for smart cities or defense protocols, cellular networks are necessary, and existing 4G cellular networks are unable to handle this volume of data reliably. Hence, in 2019, the 5G standard was developed. It uses a higher frequency radio wave and delivers faster speed with more coverage. Similar to 4G, 5G-enabled devices require special hardware to utilize 5G capabilities.

Exhibit 2: Comparison of the 5 networking standards on speed, latency, coverage, and features

	Network Standard				
	1G	2G	3G	4G	5G
Average Speed	24 kbps	64 kbps	2 mbps	25 mbps	**300 mbps**
Average Latency	> 1000 ms	500 ms	250 ms	25 ms	**< 10 ms**
Network Coverage	> 20	25	250	1000	**1M**
Key Features	Voice	SMS, Text	Email, Web	HD Video	**IoT**

* *Average Speed*: Amount of data that can be downloaded per second (kbps: kilobytes per second; mbps: megabyte per second)
* *Average Latency*: Amount of delay between requests in milliseconds
* *Network Coverage*: Number of devices that can connect simultaneously per square kilometer

4.2 5G Technology Principles

The core technology of 5G is to use the higher frequency region of the radio wave spectrum, which provides faster speed and lower latency. Within this region, there are three sections: low band (left most section), mid band (center section), and high band (right most section).

The low band has performance comparable to current 4G and will provide blanket coverage of 5G. Mid band is faster than current technology and will be targeted for major metro areas. High band is extremely fast and is the most promising component of 5G – it will be deployed in dense urban areas with massive population density.

The drawback of 5G technology is its limited range: while higher frequency bands of 5G deliver faster speeds, they also cover a smaller area. At the extreme of a high band, the average range is two street blocks and basic obstacles like buildings can dramatically decrease reliability. Hence, it requires cells or regions with network towers in much closer proximity, making it rather expensive to implement over broad geographical areas. Currently, **fast high band 5G only makes sense for areas with high population density** (i.e. places that serve huge numbers of people such as sporting and concert stadiums, convention centers, etc.).

4.3 Commercialization Structure

Exhibit 3: Consumer satisfaction with their existing internet plan[2]

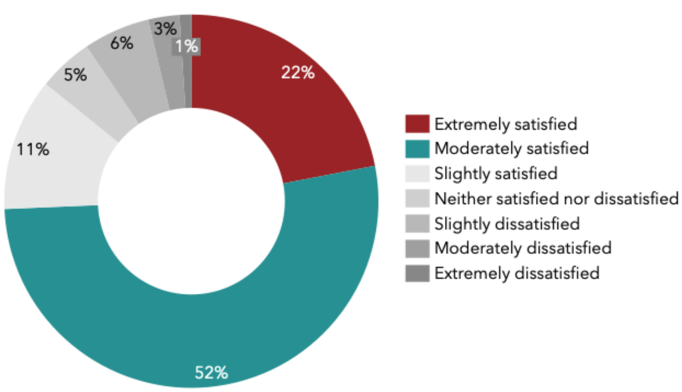
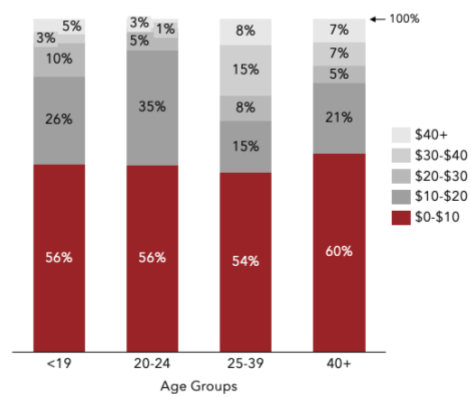


Exhibit 4: Amount of money consumers are willing to spend for faster internet speeds, segmented by age[2]



The challenge for telecommunication companies developing 5G is understanding the demand and price elasticity for 5G technology. HCCG found that over 70% of consumers are either moderately or extremely satisfied with their current internet plan; across all age groups, a majority would not pay more than $10 for faster internet speed than their current internet plan.[2] This demonstrates that the **demand for 5G, and its faster speed, among consumers and the price margin companies can charge is low**. This data aligns with Harvard Business School Prof. Alcacer's view that 5G won't initially appeal to the general consumer, as the improved performance is not perceived as being worth the cost.

Rather, in its initial phases, 5G will be best suited for corporate customers with larger user networks who will benefit from the improved latency, speed, and enablement of IoT devices.[3]

[2] HCCG's January 2021 5G Applications Survey

[3] Interview with Professor Juan Alcacer, Harvard Business School

The primary benefit of 5G networks will be IoT devices that can now reliably and seamless communicate with one another; these devices will mostly be used by corporations and governments. Examples of 5G-enabled IoT applications covered in this paper are vehicle to everything (V2X) communication for self-driving cars, public transit for smart cities, and heightened security protocols for national defense organizations.

The business model for 5G is cooperation-competition, with companies cooperating on developing the 5G standard but competing in various parts of the value chain such as consumer network coverage, 5G-enabled smartphones, and cloud-based software. 5G is difficult for TELCOs as their core audience is corporate customers, which demand customized solutions that may not ever be actualized nor are scalable. However, despite limited range and uncertainty of corporate clients, 5G development is not slowing down as TELCOs compete to avoid last mover disadvantage and the industry market cap is projected to increase by 75% by 2025.

5G Overview

5G is the fifth-generation telecommunication standard for broadband cellular networks. Compared to the existing standard, 5G utilizes **software-defined networking** and a **wider spectrum of radio bands**, enabling **faster speeds, lower latency, and greater network capacity**.

The 5G Radio Spectrum

<1 GHz

The **low band** will provide blanket coverage of 5G, with performance slightly better than current 4G

1 GHz – 6 GHz

The **mid band** will provide more coverage and capacity for highly urban and dense environments

6 GHz – 100 GHz

The **high band** will provide super-fast speed over short distances which is ideal for high-traffic areas

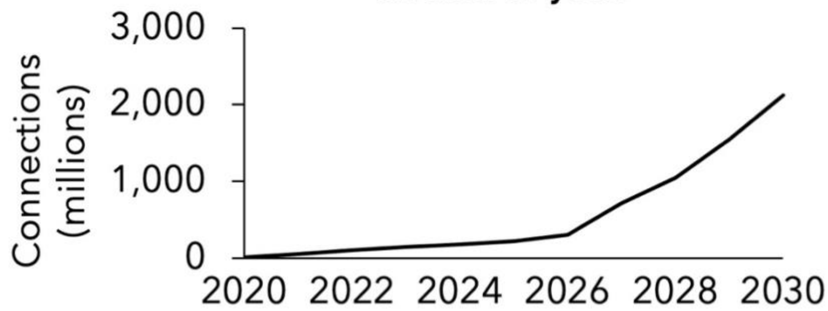
5G vs. 4G LTE

- Up to **100x** faster speeds
- Up to **10x** faster latency
- **100x** Improved network reliability
- **90%** less energy used per bit
- **250x** more devices supported

Adoption

Only **25%** of the world's population will have access to 5G by 2030 → Due to **high costs of implementation**, only **wealthy and developed areas** will access 5G in the next decade

Projected 5G adoption curve over the next 10 years



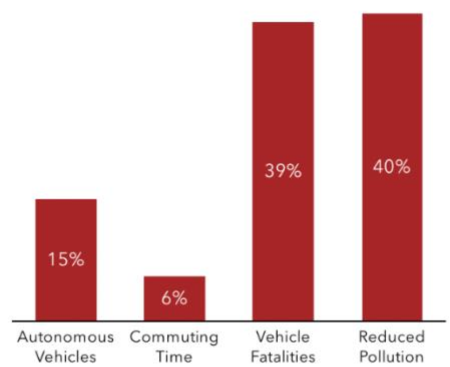
5. Automotive Industry

The introduction of 5G in the automotive industry has the potential to create huge disruptions and areas of new potential, with the development of **"connected cars"**: vehicles that have the ability to access data, send data, download software and **essentially communicate with other IoT devices**. Before 5G, cars generally only had access to the data produced by their personal sensors, since data was not able to be communicated between devices with sufficient speed and efficiency. However, the high speed and lower latency of 5G dramatically heightens the transfer of information, allowing a driver to be "connected" to the environment around them. This is known as **V2X**, or Vehicle to Everything, technology.

5.1 Applications

The development of connected cars has the potential to release an entire slew of benefits, including a reduction in vehicle fatalities, reduction in commuting time, improved environmental outcomes and the development of autonomous vehicles.

Exhibit 5: The majority of consumers believe a reduction in vehicle fatalities and pollution are the two most important benefits of 5G in the automotive industry[4]



Vehicle Fatalities

Cloud connectivity enables vehicles to access information provided by on-board sensors (cameras, lasers, etc.) from other vehicles and devices, enabling the provision of warning notifications to drivers**.** Furthermore, coordinated lane changes, intersection collision rate warnings, blind spot warnings and road hazard warnings would be entirely feasible. Through the integration of V2P (Vehicle to Pedestrian) and V2X technologies, vehicles would also have **heightened capacities to detect pedestrians and avoid accidents**, helping to avoid 6500 annual pedestrian fatalities in the US.[5]

Commuting Time

V2X enables vehicles to receive real-time data on the status of surrounding vehicles, as well as instructions from infrastructure like traffic lights. Through these V2X transmitters and receivers, information containing the driving speeds, route history and direction of drivers are exchanged. This data is then collected and analyzed, allowing vehicles to give extremely accurate information notifying drivers of **traffic**

> "Reduction in congestion could contribute to a total positive impact of **$1.2 trillion**…due to a reduction in commuting time."

[4] HCCG's January 2021 5G Applications Survey

[5] Governors Highway Safety Association

conditions and congestion well in advance. This reduction in congestion could potentially contribute to a total positive impact of **$1.2 trillion annually**, primarily due to a reduction in commuting time.[6]

Reduced Pollution

V2X and connected cars also have the potential to positively impact the environment through a reduction in pollution. Primarily, this is because a reduction in congestion will result in less time spent on the road and therefore a decrease in emission. Furthermore, smart routing, self-parking, and eco-driving, allows drivers to make **environmentally efficient driving decisions**. Connected cars and low latency communications also enable high-density platooning, the creation of closely spaced chains of multiple vehicles on highways. This method of transportation improves highway flow while reducing fuel consumption.

Autonomous Vehicles

Exhibit 6: There are 5 levels of automation as they relate to automotive vehicles, with Level 1 including cars that can automate one task, and Level 5 including cars that are completely automated.

V2X not only offers capabilities that allows us to produce connected cars, but actually **holds the key to level 5 automation** (See Exhibit 6). This is because autonomous vehicles function through machine-learning, wherein as the car drives more, they can understand patterns that will allow them to perform the correct functions at the correct moments. **Without 5G, AV cannot be operated**, as the information transfer simply requires too much bandwidth. V2X will allow vehicles to process and store magnitudes more information, accelerating the development towards full autonomy. Sales of autonomous cars is expected to reach 21 million units per annum in 2035, with nearly **76 million vehicles** with some level of autonomy sold by 2035.[7]

5.2 Adoption and Barriers

Connected cars will continue to improve and develop, however dramatic innovation uptake will be slow, most likely following an S-shaped curve of adoption. Whilst over the next 5 years, cars will most likely maintain partial automation at level 1 and 2**, nearly 45% of all global car sales could have level 3 automation** or above by 2030.[8] These cars will have environmental detection

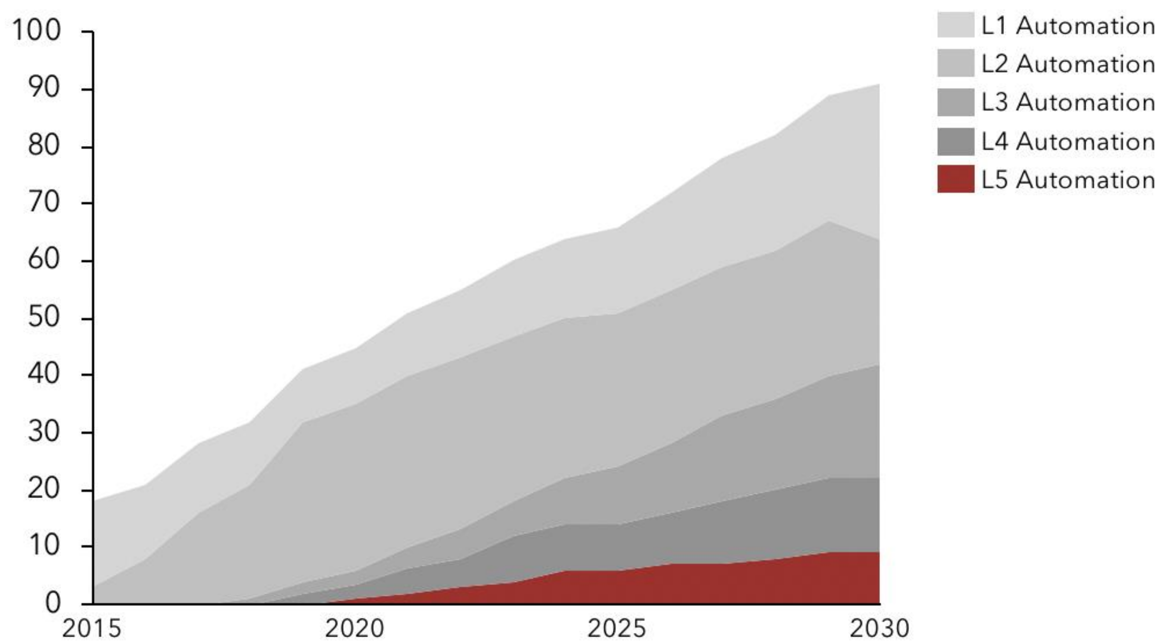
[6] Clements and Kockelman

[7] IHS Markit

[8] McKinsey & Company

capabilities that can perform nearly all tasks but require some human intervention. Complete automation will not be achieved until well into the future, due to the numerous barriers slowing down the process.

Exhibit 7: Global penetration of connected cars, percent of new vehicle sales by automation level[9]



Lack of Effective Infrastructure

Autonomous vehicles require good conditions for driving in order to be effective. However, only 41% of US roads meet the requirements for a "good ride".[10] Poor conditions like potholes and unclear striping mean that autonomous vehicles cannot operate and prevent AV pilot testing. Furthermore, the **lack of widespread 5G coverage** prevents the widespread adoption of autonomous vehicles. This will continue to be a problem, as the 5G network is reliant upon base stations with a much shorter range than today's 3G and 4G equipment. This means that autonomous vehicles require the construction of 5G cell towers near roads to ensure that there is widespread coverage.

Software Expertise

Many automotive companies may lack the expertise internally to integrate innovation and technology into their current business models. The traditional **automotive industry lacks sufficient knowledge in software**, which will become crucial as autonomous vehicles gain prominence. This marks a potential disruption to the automotive industry, as strategic partnering between technology and telecom businesses comes to prominence.

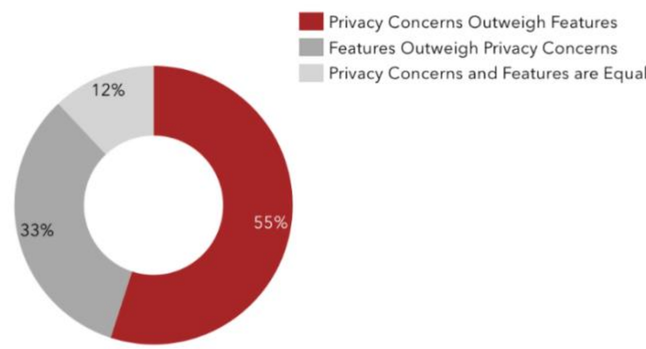
[9] McKinsey & Company

[10] International Roughness Index

Privacy Concerns

Furthermore, the prevalence of connected cars creates privacy concerns for both automotive manufacturers and their partners such as network operators. Since cars will now be holding multitudes of a driver's personal information, **data security becomes a highly contentious issue** that will need to be addressed before connected autonomous cars achieve widespread popularity. Manufacturers will have to implement strong digital security features in order to assuage such concerns. This is especially complex because there is data associated with people using the vehicle as well as outside pedestrians, so ownership of data becomes a serious concern.[11]

Exhibit 8: A majority of consumers believe that security and privacy dangers outweigh the potential positive features of connected vehicles that store large amounts of information concerning the driver[12]



Government Regulation

Underdevelopment of government regulation is another important barrier to consider. Governments, regulatory agencies and manufacturers around the world will need to develop **robust legal and regulatory frameworks** in order to respond to the introduction of autonomous vehicles. These regulations will **differ from country to country**, meaning that manufacturers must be extremely flexible and receptive to changes in the regulatory sphere in order to effectively respond to this barrier.

Public Buy-In

Public buy-in to the technology is extremely vulnerable**.** For example, a death caused by an AV vehicle would be a significant psychological setback for the entire industry.[12] **Without the attainment of a critical mass** in terms of actively used commercial terminals, the use of 5G will no longer become commercially or economically viable. However, public support for autonomous vehicles seems to be growing as innovation and technology generally become more and more prominent in society.

> "Death caused by an autonomous vehicle would be psychologically, **a real setback for the industry**.
>
> – Professor Mark Fagan, Harvard Kennedy School"

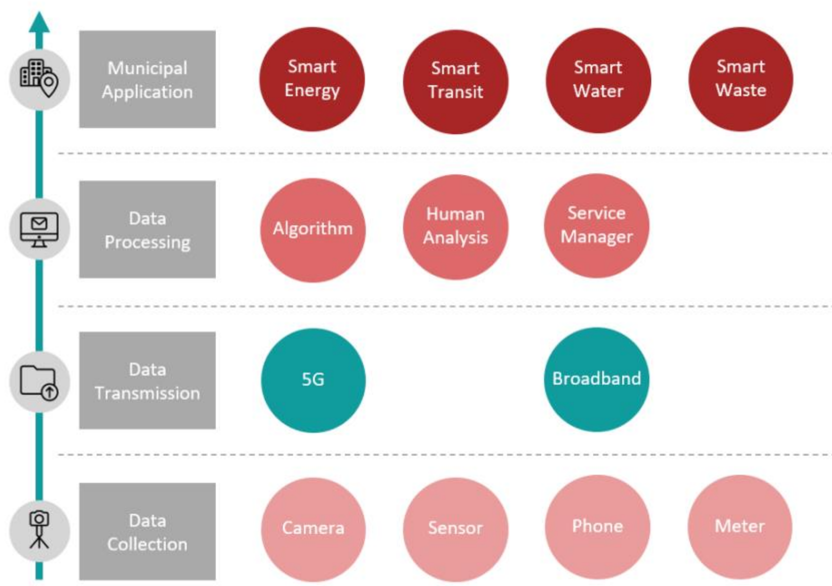
[11] Interview with Professor Mark Fagan, Harvard Kennedy School

[12] HCCG's January 2021 5G Applications Survey

6. Smart Cities

Smart cities can be generally understood as **cities which apply cutting-edge technology and innovative problem-solving to improve the efficiency of their operations**.[13] As the level of urbanization has continued to increase worldwide, effective resource management and sustainable development have become crucial to mitigating the unprecedented strain placed on urban infrastructure. One of the key functionalities of the smart city is **leveraging information and communications technologies (ICT) for robust data collection** that can then be applied to generate improvements.[14]

Exhibit 9: Smart City Service Layers[15]



6.1 Applications

Smart Transit

One area which has high potential for smart city improvement is transportation infrastructure. Road congestion is a growing issue that costs cities billions of dollars in wasted time, pollution, and accidents every year.[16] In addition to the potential for autonomous vehicles that communicate with each other, 5G technology creates the **possibility of vehicle-to-infrastructure communication**, where cameras and sensors installed on roadside structures like street lamps and barriers can record traffic flow information, consolidate it in a central processing hub, and use it to more effectively manage congestion and redirect traffic.[17] These monitoring devices

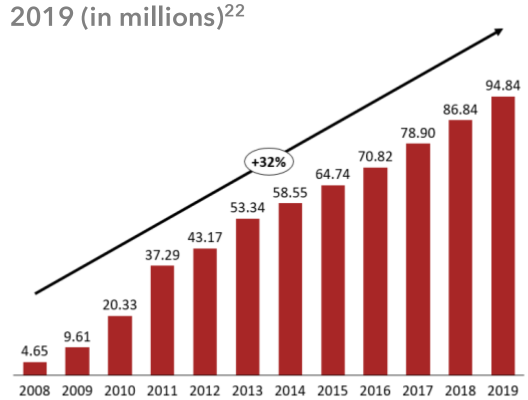
[13] Personal Wireless Communications
[14] Journal of Urban Technology
[15] Deloitte
[16] Statista
[17] Personal Wireless Communications

can also better **track fluctuating demand on public transit, collecting the data necessary to better plan the timing and quantity** of bus and train deployments during rush hour and off-peak times.[18] An even more promising fine-grain capability would be tracking specific vehicles, on a large scale, in order to **record specific commuting patterns and produce more accurate predictions for road space demand** and optimal re-routing plans.[19] Moreover, the close monitoring of roadways through cameras and sensors installed on streetlamps and roadside barriers will provide **valuable data on road quality and areas in need of repair**, which has largely relied on fragmented and incomplete data reported by concerned citizens.[20]

Smart Energy

A second important use for smart city technology is resource management, from the provision of utilities to monitoring the quality of the environment. Devices connected through 5G can provide **near-instantaneous, location-specific energy consumption data, creating a "smart" electrical grid** that records exactly how much energy is used by different services in every neighborhood.[21] Smart meters and other advanced metering infrastructure capture individual consumers' electricity usage within precise time frames, providing the data necessary to help manage home energy consumption and incentivize more sustainable off-peak energy usage.[22] This real-time reporting will also provide the data needed to **effectively forecast power surges and quickly detect outages, enabling better service and faster repairs**. This type of predictive maintenance for critical infrastructure is forecasted to reach an accumulated revenue of over $5.7 billion between 2016 and 2025, making it the sixth most profitable AI use case.[23]

Exhibit 10: Number of advanced electricity meters installed in the US from 2008 to 2019 (in millions)[22]



Smart Water

The State of New York has found a very similar application for 5G and smart city technology in water management systems. In Nassau County, service provider New York American Water is embarking upon a $40.8 million plan to replace all of its water meters with new smart water meters.[24] The previous automated meter reading (AMR) system that was used needed employees to drive within range to capture signals from each meter, requiring a significant number of field workers. The new **smart water meters** will record usage data every 15 minutes and automatically report it four times a day via cellular technology, producing **estimated savings**

18 Mass Transit
19 Interview with Mason Kortz, Clinical Instructor at Harvard Law School
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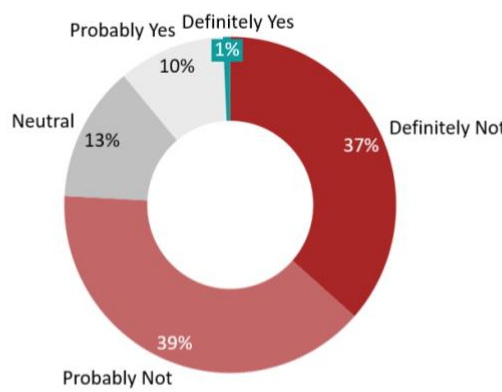
22 Applied Energy
23 Tractica
24 New York State Senate

of $5 million for Nassau County alone.[24] These meters will also allow water companies to bill their customers with greater accuracy—New York City's Department of Environmental Protection previously had to use proximate data to estimate bills for up to 17% of its customers, an amount which has been **reduced to 3% with the introduction of smart meters**. [25] Finally, smart meters can also be connected to end-users' cellular phones, a feature that has been successfully **used in water leak warning systems to prevent $73 million in damages**.

6.2 Adoption and Barriers

Privacy

Exhibit 11: Opinions on whether telecom companies should be able to sell user data[26]



One of the most common concerns cited with the increased capabilities of a 5G-enabled smart city is privacy. With everything from critical infrastructure to smart home devices linked to an incredibly high-speed network, **unprecedented amounts of data will be produced, collected, and processed**.[26] Telecommunications companies with access to this data will inevitably want to profit from this data, especially considering the high upfront costs they face with establishing the new infrastructure needed to build out a city-wide 5G network. Due to the public-private partnership model of 5G initiatives in the US, **"so many of these efforts necessarily involved real tight connections between government and private companies, but the companies that want to get in bed with cities want boatloads of data in return."**[27] However, when asked whether they believed private telecom companies should be able to profit from user data, a combined 76% of consumers replied negatively, with 37% "definitely" opposed.[28] This presents a hurdle that private corporations, local government, and concerned citizens will have to work together to build a lasting and mutually-beneficial partnership.

Social Inequality

Another concern associated with the development of smart cities is the **likelihood of the technologies involved reinforcing existing social inequalities**. A growing body of research shows that algorithms trained on datasets produced by discriminatory institutions will continue

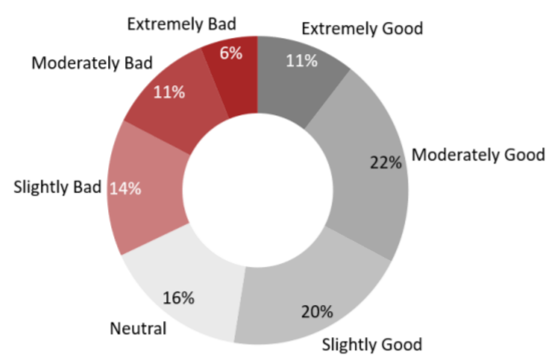
[25] US Energy Information Administration
[26] HCCG's January 2021 5G Applications Survey
[27] Interview with Christopher Bavitz, Clinical Professor at Harvard Law Scool
[28] HCCG's January 2021 5G Applications Survey

> It might seem like more efficient provisioning, and is a perfectly logical call to make, but it will nonetheless **reinforce bias and inequality.**
>
> – Mason Kortz, Harvard Law School Cyberlaw Clinic

to perpetrate such inequalities;[29] examples include racially biased court sentencing algorithms and Amazon's infamous gender-discriminating recruiting tool.[30] The additional problem presented by **this form of discrimination is that it can be harder to detect, since many algorithms used are proprietary** and companies are not compelled to demonstrate how they function.

When applied in the context of a smart city, something as simple as electricity can take on a discriminatory dimension. If a smart power grid were to become overloaded, an algorithm would likely be in place to decide what to prioritize for electrical provision. This would include essential services like hospitals, which "might seem like more efficient provision, and is a perfectly logical call to make, but it will nonetheless **reinforce bias and inequality"** because **hospitals and other essential services tend to be located in wealthier neighborhoods** that would also benefit from the continued power while poorer neighborhoods get reduced service.[31]

Exhibit 12: Opinions on municipalities using technology to increase surveillance for public safety[32]



Smart cities also come with **the promise of increased surveillance, which 53% of consumers were overall in favor of if applied to improve public safety**,[32] but increased surveillance tends to produce over-surveillance of vulnerable populations which will further compound social inequality.[33]

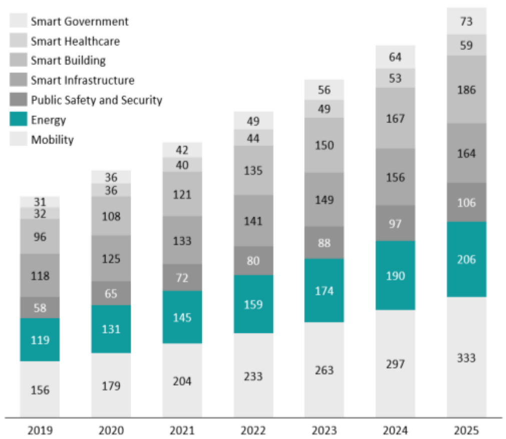
Adoption

Another consideration is how rural areas will be affected. The term "smart city" would appear not to apply to suburban and rural areas
, and there is a very real risk that these already **under-served areas will be left behind as large cities rush forward into the high-speed hyper-connected future.** Rural areas could stand to benefit the most from 5G technology, with the chance for technological leapfrogging in areas still lacking broadband Internet, but **there is still a lack of incentive for private companies to undertake these projects**.[34] The other option would be for governments to step in and fill the

29 New Scientist
30 Reuters
31 Interview with Mason Kortz, Clinical Instructor at Harvard Law School
32 HCCG's January 2021 5G Applications Survey
33 Interview with Katya Abazajian, Affiliate at Harvard's Berkman Klein Center
34 Interview with Mason Kortz, Clinical Instructor at Harvard Law School

gaps where private companies are unwilling to provide service, but **there are 22 states with regulations that effectively block municipalities from exploring a public broadband service option**.[35] With more and more research demonstrating the positive relationship between Internet access and economic health, rural communities are another group that may experience exacerbated social inequality in the face of 5G and smart cities.

Exhibit 13: Worldwide spending on smart city projects, by segment (in billion US dollars)[36]

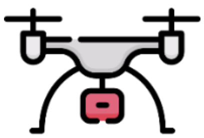


Despite these important concerns, smart city projects worldwide continue to forge ahead. **Spending on smart city projects is projected to continue growing and reach over $1 trillion by 2025.[36]** Current US government regulations place **very few limitations** on the ability of telecommunications companies to roll out 5G technology within municipalities, with current FCC rules actually limiting the ability of local governments to regulate 5G instead of restricting private companies. However, this may change as the US transitions to **the Biden-Harris administration, which may produce a more regulation-heavy FCC**.[37] Nonetheless, telecommunications regulation in the US has always been relatively patchwork, suffering in recent years from ambiguities between “communications” and “information” services that have helped telecom companies avoid strict regulation when it comes to users’ privacy and data. It is possible that this will change under a new, more interventionist administration, but it is unlikely to take top priority.

[35] Broadband Now
[36] Statista
[37] Interview with Katya Abazajian, Affiliate at Harvard’s Berkman Klein Center

7. National Defense

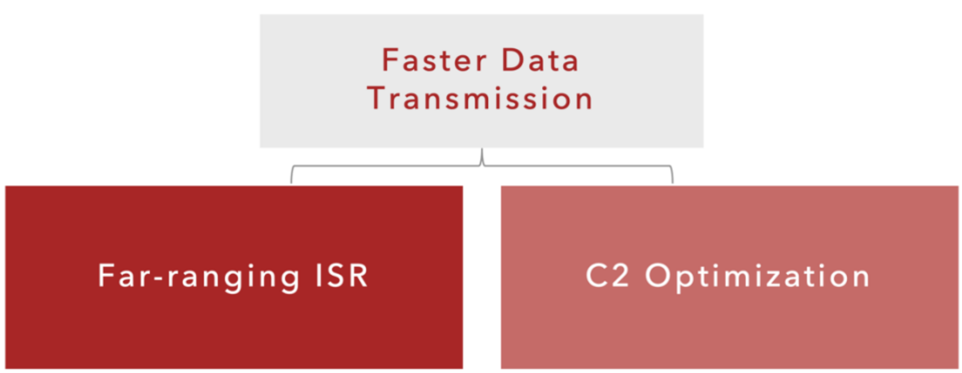
As 5G uptake increases across different industries, the novel technology offers the potential to **revolutionize how public, not just private, actors operate**. As an institution, the military relies on some of the highest data transmission rates of any United States institution, both during battlefield operations and peacetime management. Therefore, the military constitutes one of the arenas where next generation technology could potentially return the highest gains and the most change.[38] Of course, increased military **information flows are not without risks**, as the more information that transverses this new network, the more data that are susceptible to theft or exposure.



The added capacity of 5G, as compared to 4G systems, will accelerate the increasing reliance on unmanned devices by lowering the risks of outsourcing operations to a machine. The limiting factor to wider usage of remotely-operated drones or tanks has been the inability to access the same level of control as a stationed human, a barrier that is increasingly eroded by new generation communications technology. **Military operations in the future will be defined more so by outsourced information gathering rather than terrestrial deployments.**[39]

The trend towards autonomous systems is part of a larger movement that locates the future of warfighting not in material capabilities but rather in the realm of information networks. As the speed of warfare increases both in the literal reaction times and faster rates of communications, **the fight will be located on the network rather than the battlefield** itself. Although massive benefits will certainly accrue to the winners who choose to utilize 5G to its highest potential, the advantages of operating in the realm of this novel technology are not without risks or roadblocks.

7.1 Applications



[38] Department of Defense

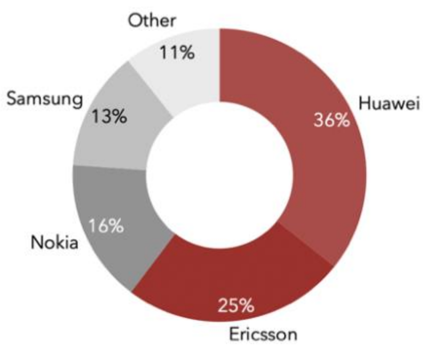
[39] Li et al.

ISR

Much of the military's global data flows comes from its network of sensors that conduct intelligence, surveillance, and reconnaissance (ISR) across the globe. These information flows represent the lifeblood of military communications, providing officials with global feedback upon which important geopolitical decisions hinge.

5G networks will operate as an upgrade of this communications architecture, allowing the network to be thickened in ways that support higher levels of communications.[40] As increasingly lower latency allows huge amounts of data to be moved across territories at faster rates, **the battlefield environment will be able to support much larger amounts of sensor-inputs**. Whereas military network systems could only support intake flows from a limited number of sensors at any given time period, next generation technology will allow multiple sources of information to operate simultaneously, and even in real-time.[41]

Exhibit 14: 5G equipment company market share in 2020[41]



At a high level, this upgrade in information flows will make nations more responsive, as reaction times increase to everything ranging from natural disasters to surprise attacks. Moreover, **the barriers between nations will harden**, as border surveillance becomes much more accurate and reflexive. Stationing millimeter wave (mmW) cell towers throughout one's perimeter, for example, would provide instant knowledge of enemy combatants who are attempting to trespass.

On a smaller scale, these new information flows could revolutionize how wartime operations themselves operate. A platoon of troops, for example, who all share live biometric data with each other would instantly have knowledge of the whereabouts or vital signs of the others, alerting them when a fellow combatant goes down.[42] The advent of **5G allows these types of instantaneous alerts** such that the constellation of actors within a military network is incredibly flexible and responsive.

This technology offers not only better communication with existing sensors but also the potential for novel forms of military operations to begin with. The ability to quickly onboard large amounts of information granted by 5G allows **machine-to-machine transmission without the need of a data intermediary** such as a satellite or relay aircraft. Freed from the shackles of a data go-between, 5G communications allow vehicles to be integrated within the network environment without the attendant delays that previously characterized autonomous infrastructure.

40 Congressional Research Service
41 Equal Ocean
42 Bhardwaj

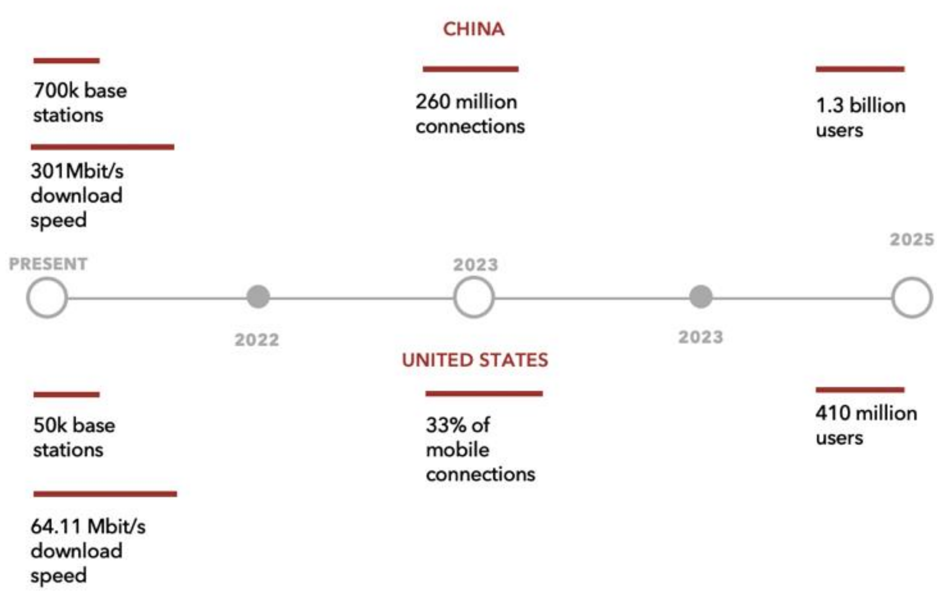
Command and Control (C2)

In addition to ISR changes, 5G will impact the central basis of operations, the command and control (C2) infrastructure of the military. The high rate of data processing that 5G allows for will open the door to several **optimization possibilities in the field of military logistics and resource distribution**. The real-time situational awareness given by 5G, for example, would allow more pinpointed and efficient resource distribution. Overall, as well, supply chains will increasingly be automated so that warehouses and storage units can communicate with each other, limiting the possibility of surprise shortages and ensuring that resources travel to where they are needed the most.[43,44]

7.2 Adoption and Barriers

The biggest security risk posed by this new technology is a problem that already dominates current information networks: cyber hacks.[45] Given the complexity of 5G networks combined with the massive amounts of necessary component parts, the likelihood of security oversights or vulnerabilities is much higher than that of former generations. Moreover, the expanded network size increases possible "attack vectors," as more components like small cells, cellular towers, etc. are now part of the network.[46] Finally, because of the superior integration of a 5G information environment, **any hack is more likely to have spillover effects** and be difficult to contain.[47]

Exhibit 15: A timeline of the 5G race between China and the United States[48,49,50]



[43] US Army
[44] Materials, Handling, and Logistics News
[45] Interview with David Simpson, Professor at Pamplin College of Business at Virginia Tech
[46] Cybersecurity and Infrastructure Security Agency
[47] Bhardwaj
[48] Wall Street Journal
[49] Light Reading
[50] Statista

> From a risk perspective…the greater risk is on the software side.
>
> – Professor David Simpson, Pamplin College of Business

All of these problems are compounded by the fact that **the United States must inevitably operate abroad on foreign networks.** So, no matter how secure the domestic communications infrastructure is, allied networks through which sensitive US information is transferred may not be as secure. Because of this inevitable uncertainty, the military will most likely adopt a "zero trust model" by building multiple levels of redundancies into their approach to 5G. [51,52]

Although much discussion has been given to the possibility of backdoor espionage occurring through the implanting of malicious hardware by China into US systems, the real threat comes in the form of software, not hardware, intrusions. As of now, **there have been zero verified instances of any planting of backdoors** into 5G systems by China or any Chinese company.[53] It is, of course, possible that China could take advantage of their overwhelming market power to plant backdoors in the future, there is still presently zero evidence that they plan to do so.

[51] Department of Defense
[52] Defense Innovation Board

[53] Interview with David Simpson, Professor at Pamplin College of Business at Virginia Tech

8. Conclusion

5G is a new wireless standard offering **faster speeds, lower latency, and more coverage** by a factor of 1000. The greatest potential of 5G lies in its unprecedented level of network reliability for millions of IoT devices. However, since 5G operates on entirely new spectrum of radio waves than previous network standards, it **requires entirely new infrastructure that will come at a high cost**. As a result, adoption of 5G in the status quo has been relatively low, but is expected to drastically accelerate within the next decade.

In automotive industry, 5G will help enable "**connected cars" that can communicate via IoT with almost any other device,** such as other cars or traffic lights. The impact of these cars is fewer pedestrian deaths, less environmental pollution, lower commuting times, and autonomous vehicles. In the short-term, uptake of these "connected cars" will be low due to issues with patchwork government regulation and privacy concerns. However, in the long-term, as many of these issues are addressed, "connected cars" are expected to completely replace conventional automobiles.

In smart cities, 5G will help facilitate **smart transit and smart resource management by collecting fine-grained data at the household and individual levels**. A number of smart cities have already begun implementing these systems. However, these applications are facing severe backlash since they come at the cost of invading citizens' privacy in order to obtain sufficient data.

Finally, within the scope of national defense, 5G will the enable much **faster data-processing and analysis, enabling the military to have real-time information on the battlefield**. Moreover, 5G will enable a shift in warfare away from terrestrial battles to information network: consequently, cybersecurity and cyber-defense will play an increasingly important role in the context of national security.

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