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**The Evolution of 5G: Delineating the Impact and Limitations across Transportation,
Education, Healthcare, Agriculture, and Manufacturing**

By

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Advisor: Dr. Molly Rapert

**An Honors Thesis in partial fulfillment of the requirements for the degree Bachelor of
Science in Business Administration in Information Systems.**

**Sam M. Walton College of Business
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May 13, 2023

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Introduction

A world previously only thought possible in science fiction is about to become a reality. A world where doctors can operate on patients thousands of miles away. A world where students can experience ancient cities and distant galaxies like they are physically there. A world of fully self-driving cars. A world where every step of the supply chain is automated. A world where factories have a handful of employees overseeing robots handling the entire manufacturing process. A world of fully autonomous farms, where one farmer can manage an entire farm from seed to harvest from their smartphone. The development, implementation, and adoption of 5G cellular networks will make this world a possibility. 5G networks will impact the world in an almost infinite number of ways. Business models will change, the way people work will change, the way students learn will change, the way patients get health care will change, the way people get their food will change, the way people drive will change. In this thesis, I examine the development, applications, benefits, and socioeconomic impacts of 5G technology, as well as current limitations facing the industry and ways to address them.

What is 5G?

5G is the fifth generation of cellular networks. It is the successor of the current fourth generation (4G) networks. 5G technology is characterized by ultra-low latency, massive data rates, near perfect reliability, extreme density of connection, and wide coverage areas. 5G is not just another “G”, it has the potential to completely disrupt the way we work and live (Binney, 2020). Some experts say that the development and implementation of 5G capable technologies could be as revolutionary as Guttenberg’s printing press (Campbell, Diffley, Flanagan, Morelli, O’Neil, Sideco, 2017). A large focus of this section will be the increasing size of data transfer possible as networks evolved, so I have included a table to illustrate different sizes of data.

Unit	Definition	Storage Size
Bit	Single binary digit (1 or 0)	A yes/no response
1 Byte	8 bits	One letter of text
1 Kilobyte (KB)	1,024 bytes	A few paragraphs of text A typical email is 1-2 KB Most word docs, excel sheets, etc.
1 Megabyte (MB)	1,024 KB 1 million bytes	MP3 audio is about 1 MB per minute High quality digital picture is 2-5 MB A typical CD stores about 700 MB
1 Gigabyte (GB)	1,024 MB 1 million KB 1 billion bytes	30 minutes of HD video DVD movie is 4-8 GB Most memory cards for cameras are 16 GB
1 Terabyte (TB)	1,024 GB 1 million MB 1 billion KB 1 trillion bytes	About 200 HD movies Computer hard drives are commonly sold in TB The entire Library of Congress can be stored in 82 TB of data

“Kilobytes, Megabytes, Gigabytes, Terabytes”.

Evolution of Cellular Networks

Each evolution of cellular networks is usually caused by advancements in technology, infrastructure organization/strategies, availability, etc. These advancements lead to improvements in latency, bandwidth, reliability, coverage, and connection density. These generations of networks are not just the little numbers shown in the corner of your iPhone—they represent massive improvements in technological infrastructure and potential.

1G

The first generation of cellular networks was established in the 1980s. This was the first attempt at stepping away from landline phone technology. This generation was marked by cellphones that resembled bricks and could only place calls, text messaging and internet use were not even considerations at this point. The max data rate this network could transfer was 2.4 KBps, only allowing for transfer of voice data (Dangi, Lalwani, Choudhary, You, Pau, 2021). This technology was very rudimentary, posing several drawbacks: sound quality and coverage was poor, also since the networks used radio frequencies and there was no encryption, anyone with a radio scanner could drop in on a call (Haverans, 2021). Even though there were several issues, this generation of mobile telephony laid the foundation for a future with great potential.

2G

The second generation of cellular networks saw some minor improvements from its predecessor. Throughout the 1990s, cellular networks were able to send and receive much more data thanks to 2G technology. This led to the first Short Message Service (SMS) and Multimedia Messages (MMS) being sent and received over cellular networks (Korzeniewska, Krawczyk, 2019). Voice *and* data could now be transferred, thus began the age of texting. The max data rate of 2G networks was 10 KBps (Dangi, Lalwani, Choudhary, You, Pau, 2021). While more than a 300% increase in data rates from 1G, this is still an infinitesimal amount of data compared to successive generations.

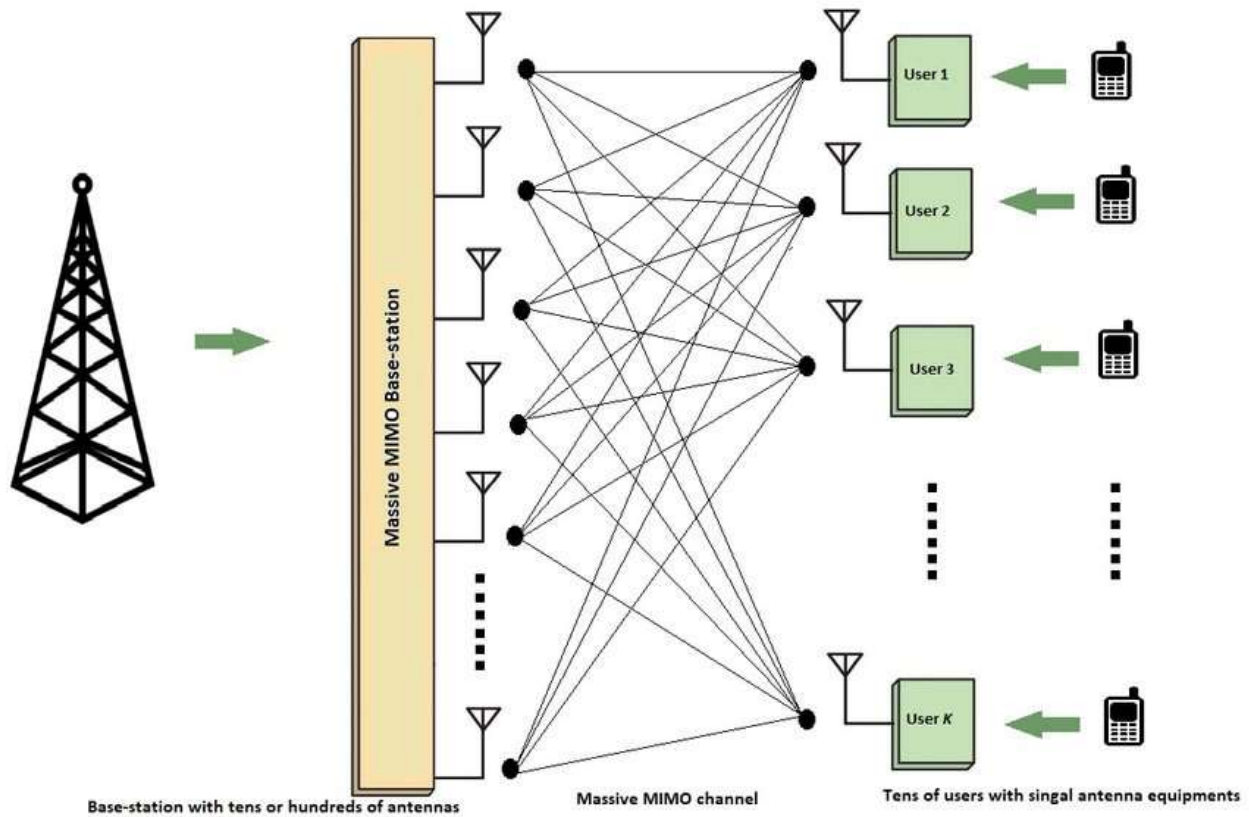
3G

The evolution to the third generation of cellular networks was characterized by one quality: speed. Rolling out in the early 2000s, 3G technology made fluent communication with the internet a possibility (Korzeniewska, Krawczyk, 2019). 3G networks could now transfer data at speeds between 384 KBps and 5 MBps, a massive increase from 2G (Dangi, Lalwani, Choudhary, You, Pau, 2021). This era was paired with the emergence and mass adoption of smartphones. The launch of the Blackberry in 2002 and iPhone in 2007 pioneered an age where mobile networks and phones could communicate using voice and video data (Haverans, 2021). Applications like Skype could now be used on mobile phones, radically changing the way people communicate.

4G

Starting in the late 2000s, the shift to the fourth generation was also marked by massive increases in speed. Speeds could now be between 100-200 MBps, making high quality video streaming a possibility (Haverans, 2021). Also, online gaming, an intensive activity regarding latency and bandwidth, was now practicable. Another advancement in 4G technology was massively improved bandwidth. This was made possible by the development of Multiple-in

Multiple- Output (MIMO) technology. MIMO technology uses multiple transmitters and receivers to transfer more data at the same time. Before, cellular antennas could only send a single data stream to a single device, but MIMO technology allows antennas to transmit multiple data streams to multiple devices simultaneously (Dangi, Lalwani, Choudhary, You, Pau, 2021). MIMO was first implemented during 3G but was not commonplace until 4G. A graphic describing MIMO and its capabilities to handle multiple devices at once is shown below.



(Riaz, Javed, Sultan, Amin, Zahid, Loo, 2020).

5G

Finally, the current generation of cellular networks: 5G. 5G brought about the biggest improvements in cellular networks to date. This generation experienced revolutionary changes in speed, reliability, bandwidth, and more. 5G networks can “support speeds from 10-50 GBps and more than 1,000,000 devices per km². This is an increase of over 100x from previous generations” (Haverans, 2021). The massive improvements are powered by 5G’s use of MIMO and millimeter wave (mmWave) technology. MmWave is an extremely high radio frequency band that 5G uses for data transmission. This is called mmWave technology because these waves have wavelengths of 1-10mm, which are very fast frequencies that provide very high-speed wireless communication (Dangi, Lalwani, Choudhary, You, Pau, 2021). Previously, this technology had only been used in radar systems and satellites. But with advancements in circuitry technology making this technology more accessible, it became available for cellular networks. Other technologies such as GPS, Wi-Fi, 3G, 4G, etc. use radio frequency bands

between 1-6GHz, this leads to a crowded frequency band, and thus, slower speeds. MmWave uses bands between 30-300GHz which are significantly less crowded and much faster (Dangi, Lalwani, Choudhary, You, Pau, 2021). This can be compared to planes using different airspaces at different altitudes. If most recreational and smaller passenger aircraft must fly at lower altitudes due to technological deficiencies, there would be more traffic in this airspace. Their flight paths, speeds, and efficiencies will be much lower than larger commercial aircraft that are able to fly at higher altitudes in uninterrupted direct paths. 5G networks allow data to “fly” at whatever altitude and as fast as it would like. Other frequency bands are shown below.

Designation	Frequencies	Wavelengths	Uses
Very Low Frequency	3 KHz – 30 KHz	100km – 10km	Submarine communications
Low Frequency	30 KHz – 300 KHz	10km – 1km	Navigational systems, AM radio broadcasting
Medium Frequency	300 KHz – 3 MHz	1km – 100m	Land and marine broadcasting, AM radio broadcasting
High Frequency	3 MHz – 30 MHz	100m – 10m	FM radio broadcasting, aeronautical broadcasting, radio navigation
Very High Frequency	30 MHz – 300 MHz	10m – 1m	FM radio broadcasting, aeronautical broadcasting, radio navigation
Ultra High Frequency	300 MHz – 3 GHz	1m – 100mm	WiFi, GPS, television, meteorological communications, space communications, 3G and 4G communications
Super High Frequency	3 GHz – 30 GHz	100mm – 10mm	Space and satellite communications
Extremely High Frequency	30 GHz – 300 GHz	10mm – 1mm	5G communications, earth and space exploration, remote sensing, astronomy
Tremendously High Frequency	300 GHz – 3 THz	>1mm	X-ray imaging, material characterization

(Awati, 2023).

The use of mmWave technology offers “three advantages: (1) mmWave is a much less used band, (2) mmWave signals carry more data than lower frequency wave, and (3) mmWave can be incorporated with MIMO antenna with the potential to offer a higher magnitude capacity compared to current communication systems” (Dangi, Lalwani, Choudhary, You, Pau, 2021). With mmWave, the frequencies are much faster and can transmit much more data.

The evolution to 5G technology is designed for on-demand real time interactions such as remote surgery, vehicle-to-vehicle communication, industry 4.0, smart grids, intelligent transport systems, etc. (Dangi, Lalwani, Choudhary, You, Pau, 2021). This will lead to unlimited internet connection, anytime, anywhere with extremely high speeds, high throughput, low latency, higher reliability, lower energy use and greater scalability. A world of “Smart cities, internet of things (IoT) connectivity, smart homes, smart health care, autonomous driving, etc.” (Korzeniewska, Krawczyk, 2019) will be a reality soon. 5G also has the potential to save lives, with applications in agriculture and healthcare. (Haverans, 2021). 5G will make a significant impact on every area where wireless transmission is available.

Summary of the differences in cellular network generations.

Generation	Data Rate (per second)	Bandwidth	Latency	Application
1G	2.4 Kbps	Analog	>500ms	Voice
2G	10 Kbps	25 MHz	500ms	Voice and data
3G	384 Kbps – 5 MBps	25 MHz	100ms	Voice, data, and video calling
4G	100 MBps – 200 MBps	100 MHz	50ms	Voice, data, video calling, HD television, and online gaming
5G	10 GBps – 50 GBps	30 – 300GHz	1ms	Voice, data, video calling, ultra-HD video, virtual reality applications, IoT

Table I created using data from Dangi, Lalwani, Choudhary, You, Pau (2021).

Why Businesses Should Implement 5G Technology

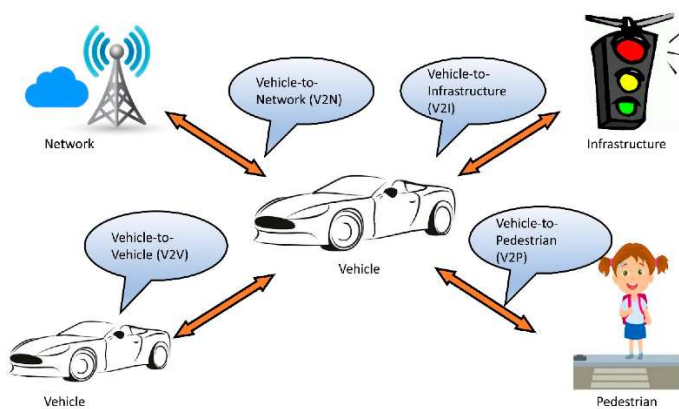
Applications of 5G by Industry

While 5G has the potential to greatly affect any industry, I have highlighted the 5 industries that 5G will have the greatest impact on. As the business world gets more digitized and automated, a more supportive network is critical to streamlined operations. 5G is critical to this because of the ultra-low latency, high data rates, high reliability, density of connection, and wide coverage area it provides. If you think of these industries as artists working on a canvas trying to produce a painting, previous generations of mobile networks provided the artists with a small canvas, limited number of colors, and a few brushes to work with. However, with 5G networks, the painter is given an essentially infinite canvas with endless colors and whatever tools they desire. The possibilities are endless.

Transportation

I will examine the impacts that 5G will have on the transportation industry regarding auto manufacturers/personal vehicles sector as well as the transportation and logistics (T&L) sector. The low latency and high data rates/bandwidth that 5G provides will be the main factor in technological advancements in the transportation industry.

The automobile industry is shifting towards automated vehicles (AV). AV sales are estimated to exceed 33 million per year by 2040 (Gohar, Nencioni, 2021). This will be powered by onboard sensors that sense the environment around the vehicle and perform all driving operations in real time. This technology requires a massive number of connections both within and outside of the car. Vehicles will need to conduct four types of communication to achieve full automation: “Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Network (V2N), which are all collectively referred to as V2X” (Gohar, Nencioni, 2021). With a substantial number of connections required for V2X to operate, 5G’s extensive connection density will make this communication possible. V2X communications are illustrated in the graphic below.



(Haque, Abdelgawad, Yanambaka, Yelamarthi, 2020)

The main application of 5G in the personal automobile sector is simple: cars that drive themselves. While this idea is certainly exciting, there are some very practical implications as well. This can grant mobility to populations that are unable to drive e.g., the youth and elderly.

This can also make possible the idea of delivering rental cars from one location to another without a driver, remote taxi services, remote public transportation, remote car-sharing services like Uber and Lyft, etc. These services will need ultra-high reliability (>99.999%) and low latencies (<5ms) between cars and V2X sensors, all which 5G networks provide (Gohar, Nencioni, 2021).

Similar requirements and use cases will be used in the T&L sector. T&L is comprised of a delicately balanced network of teams and assets. Success depends on timely, effective communication; 5G unlocks efficiency of communication among these people, vehicles, and goods (6 Ways 5G Will Accelerate Possibilities in Transportation and Supply Chain Logistics, 2021). 5G will enable this efficiency in 4 ways: improved decision-making, fleet management optimization, safety, and automation. With 5G technology, operators and managers can use information to make better decisions about routes, maintenance schedules, delivery times, etc. This is enabled by 5G because of the massive amount of data 5G networks can handle in a very short amount of time. V2X sensors and decision makers are connected instantaneously using 5G technologies. For fleet management optimization, 5G technology will ensure safe and efficient movement through routes by optimizing traffic patterns (6 Ways 5G Will Accelerate Possibilities in Transportation and Supply Chain Logistics, 2021). This will lead to accelerated delivery times. Automation—automated robots that perform repetitive tasks like drones, tools that parse data, invoicing robots, and automatically guided vehicles (AGV)—will create efficiencies and reduce costs. These efficiencies will lead to greater safety in the T&L sector. With improved sensors and delivery of data, urgent information on weather, traffic, etc. will be transmitted from sensors to driver to dispatch instantaneously. 5G enabled technologies will introduce a safer, innovative, and more efficient era in transportation.

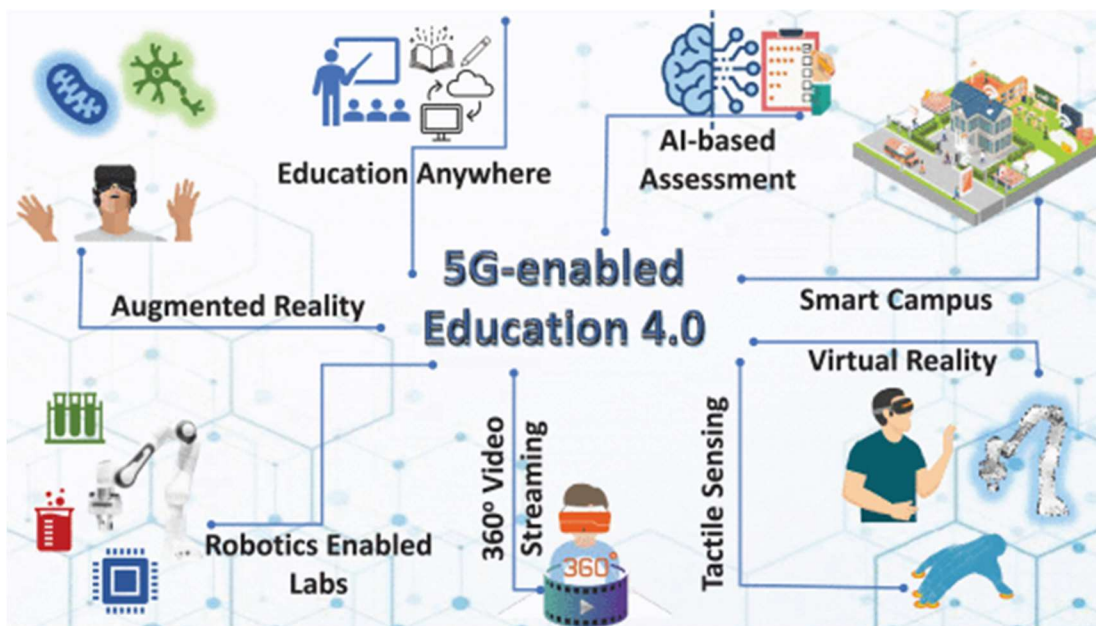
Education

In the past 100 years, almost every industry has gone through extensive changes and improvements. The one industry that looks almost identical to as it did 100 years ago is education. For the most part, education is still conducted using the lecture format. While this format is effective, there are many possibilities in the field of education for increased learning, retention, and engagement. 5G-enabled technologies can play a massive role in achieving these possibilities.

The main role 5G will play in education is enabling augmented and virtual reality (AR/VR) technologies on a massive scale. With this, students and teachers will be able to better interact in real time (Lee, Kim, 2020). AR/VR requires a *substantial* amount and rate of data transfer which 5G can make possible. AR/VR can simulate conditions and allow students to learn as if they are using a specific equipment/tool or experiencing a certain stimulus. AR/VR can have multiple applications in the classroom. For example, in a history class, students can explore generated models of ancient cities as if they were there. Or in chemistry, students can play around with 3D models of molecules or perform dangerous experiments without risk. The possibilities with AR/VR are virtually endless—other fields of application include medicine, biology, astronomy, engineering, and more. This is currently tough to implement because many school systems lack access to strong networks with high bitrates and low latencies, 5G solves

this problem (Haus, Ludovico, Pagani, 2019). Also, educational AI programs can provide students with personalized, learning experiences, tailored to each student; 5G makes this possible by collecting and analyzing large amounts of data (Lee, Kim, 2020).

Overall, “these changes will transform the tradition unidirectional, text based and assignment-based university education to remote discussion, experiential learning, and collaborative learning. In the new paradigm, professors will not merely be a messenger of knowledge but will be an essential coordinator of the education service that designs the educational service to maximize interest and creativity” (Rapoza, 2022). 5G will lead education into its long overdue next evolutionary step.



(Kizilkaya, Zhao, Sambo, Li, Imran, 2021).

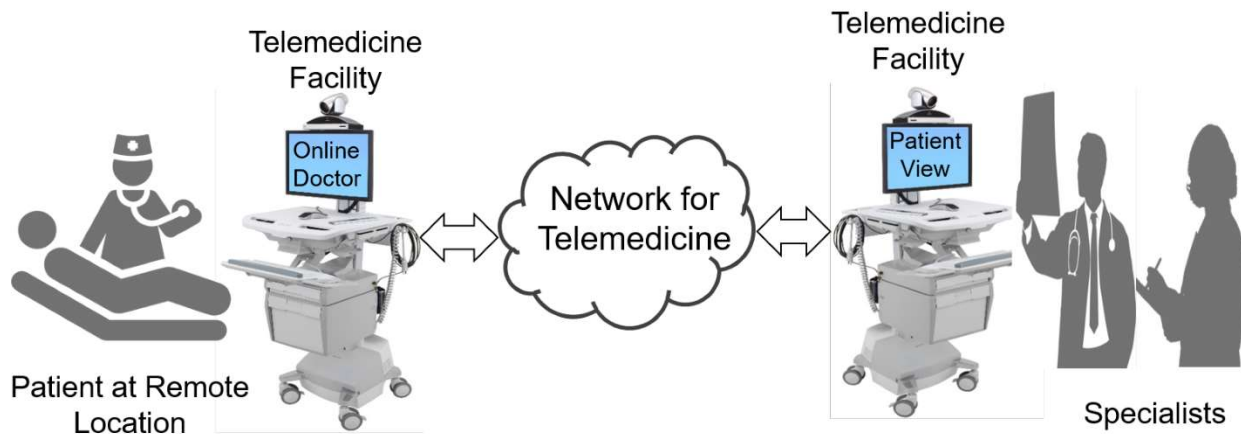
Healthcare

Some of the most exciting applications of 5G exist in healthcare. While many of these applications are in very early stages of development and have successfully been proven effective for the patient in trials, they are still impressive and hold a lot of potential. The potential applications exist in the fields of emergency medical services, telesurgery, telemonitoring, obstetrics, spinal cord stimulation, and telerehabilitation. 5G is important to this industry because it will allow urgent medical data to be transferred at an extremely low latency. The following section is sourced the paper “5G in Healthcare: From COVID-19 to Future Challenges” by Bercholli, Cuschieri, Geogiou, Gerogiou, Marinov, Moglia, Satava.

In emergency medical services, ambulances, paramedics, patients, and doctors will be more connected than ever. In a study from Madrid, 5G was used for management of heart attacks. Patients were wearing wearable devices, like smartwatches, that sent out an alarm of a possible heart attack to a central cloud server that monitors patient status via 5G. The server analyzes the patient’s medical records, builds a diagnosis, and sends an EMS team to the patient’s location. In the UK, a remote diagnosis was performed from an ambulance by a doctor

wearing a VR headset in a different location. The EMS team on the ambulance was supplying video footage and the paramedic on board was wearing haptic gloves that the remote doctor guided to perform an ultrasound scan. 5G was critical to these applications because of bandwidth and latency support.

There have also been successful cases of telesurgery performed using 5G technology. In these cases, latency is most critical. Latencies higher than 100ms but lower than 300ms have been reported as “noticeable, but still operable” by doctors. In China, there have been heart surgeries successfully completed by doctors over 300 miles away with latencies as low as 30ms. Also, in the US, cases of tele stenting have been successful. A doctor in Boston remotely inserted a stent on a patient in San Francisco with an “imperceptible” latency of 100ms. There have also been cases of laparoscopic and ophthalmic surgeries done, both in small numbers, but these still show promise. While these latencies are not as low as the 1ms that 5G promises, they still would not be possible without 5G technology. 1ms response times are strictly best-case scenarios.



A graphic describing telesurgery from Latif, Qadir, Farooq, Imran (2017).

Regarding telemonitoring, there have been successful cases in China. For example, in Gaozhou, CT scans and video data were streamed in real-time to an expert 250 miles away to assist a heart surgeon. The expert was using VR, which provided a real time view. This allowed them to give immediate guidance to the surgeon. The two connections maintained a transmission rate of 25MBps with a latency of 30ms.

In obstetrics, 5G technology could lead to a new future of in-home obstetric care. In the US, there have been cases of patients using at-home fetal heart rate monitoring and ultrasound devices that streamed real-time data medical centers at 99% reliability.

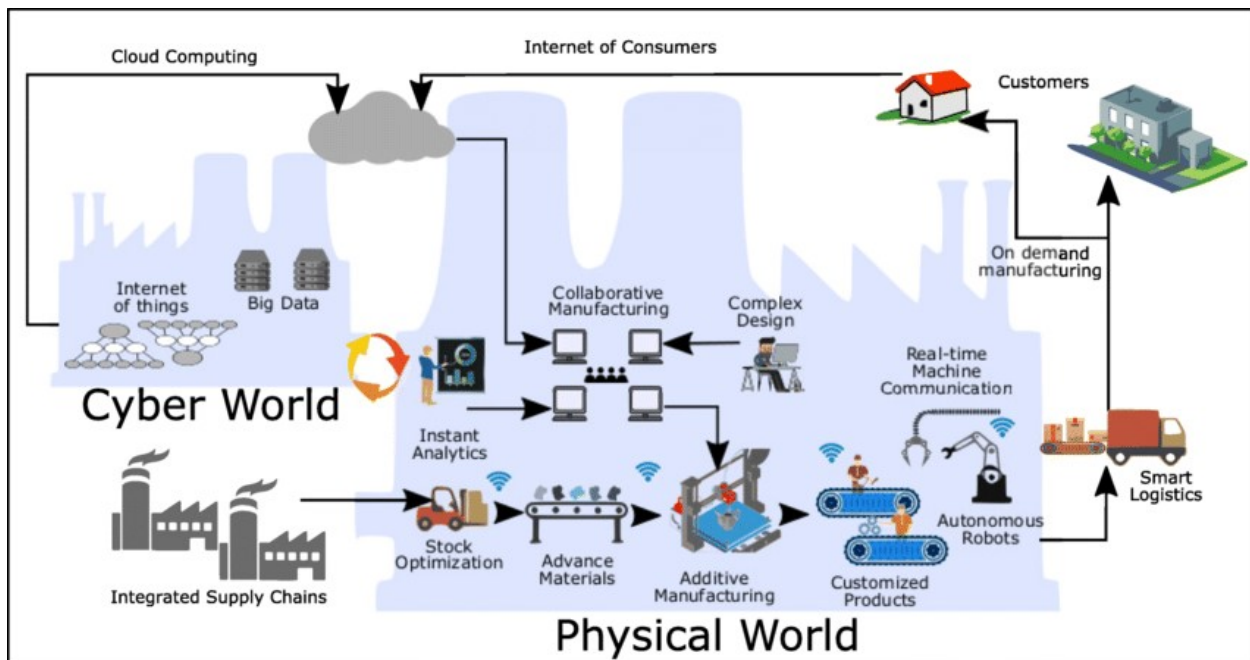
A study in Beijing with 64 patients suffering from Parkinson’s disease was done to test remote spinal cord stimulation treatment. A device in the patient’s spine is connected to a smartphone that transmits data to physicians. The doctor is then able to remotely adjust the device and check the status of the device. These devices need to be regularly replaced, so having the ability to remotely check on these devices allows patients to avoid trips to the hospital to verify their status in person.

In a study done by Gupta, Tanwar, Tyagi, and Kumar (2021), telerehabilitation methods were assessed. Neurological rehabilitation through VR simulated environments with doctor guidance and real-time feedback was proven successful. Also, there were physiotherapeutic rehabilitation methods conducted from cameras on smartphones that transmitted data in real-time to doctors and data centers. The AI technology and doctors were able to assess patients' postures and movements in real-time and correct them.

Healthcare could potentially see a large shift in care moving away from the clinic and into the home. 5G provides the healthcare industry with the reliability, speed, and bandwidth that it needs to successfully implement remote care.

Manufacturing

5G technology will be the main driver leading manufacturing into Industry 4.0. Industry 4.0 is “a name for the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things, cloud computing and cognitive computing” (Prasad, Rao, 2018). This leads to the creation of “smart factories”. The previous evolutions of industries (1.0, 2.0, 3.0) were characterized by the introduction of water and steam powered manufacturing systems, the introduction of electricity and mass production, and the introduction of electronics and IT to achieve basic automation, respectively (Prasad, Rao, 2018). This is why some experts claim that the advancement of 5G technology could be as revolutionary as the invention of the printing press or steam engine. The applications will be realized in several forms, some of which include cell automation, automatic guided vehicles (AGV), process automation, factory automation, logistics and warehousing, and monitoring and maintenance.



Graphic illustrating Industry 4.0 from Balderas, Mendez, Ortiz, Ponce (2021).

The most apparent form of automation in factories in Industry 4.0 will be cell automation. Cell automation is essentially robots on a factory line automatically performing repetitive tasks. These devices on the assembly line communicate with the control system in real-time requiring 1ms latency and high reliability (Prasad, Rao, 2018). This was possible under previous networks, but 5G will provide factories with unprecedented coverage, capacity, and speed leading to greater scalability.

Vehicles that move around the factory carrying products to different stages of production will be crucial to achieving Industry 4.0. This kind of technology requires high mobility, reliability, and capacity” (Prasad, Rao, 2018). These vehicles can achieve automation in processes such as distribution, transportation, and sorting (Han, Shen, Shi, 2019). This is how 5G will impact the logistics and warehousing of Industry 4.0 as well because this greatly impacts the flow and storage of materials.

Process automation refers to automating the processing of electricity, water, petroleum, food, and other materials. Fully autonomous systems will monitor and control various parameters such as flow rate, temperature, liquid level, pressure, etc. in these processes (Han, Shen, Shi, 2019). Fast systems and mobile robots can monitor these processes under 5G systems. Like AGV, high mobility, reliability, and capacity is required.

Factory automation is different from process automation because it refers to the automation of the *entire* factory and all aspects of the production process. This will be comprised of connected devices across functionalities communicating in real time. For example, when something “deviates from a predetermined specification, the system will alarm in real-time, locate the failure position, and solve it immediately” (Han, Shen, Shi, 2019). This is accomplished through the ultra-reliable low latency connections provided by 5G networks.

Finally, a high number of wireless sensors in factories will greatly benefit the monitoring and maintenance of factories in Industry 4.0. These sensors will be able to perform supervision on the state of machines without affecting manufacturing processes, gain insights into different environments, monitor and adjust equipment health in real time, and locate and solve errors almost instantaneously (Han, Shen, Shi, 2019).

This evolution of industry will see workers transition from roles on the factory floor to managing the devices and systems that run the factory. This will benefit businesses greatly regarding their bottom-line but will significantly impact the skill requirements and duties of the labor force, as well as the nature of work.

Agriculture

The industry that has the possibility to change the greatest number of lives is agriculture. 5G technologies will increase efficiency, crop yields, sustainability, and more. The central applications for 5G in agriculture will be seen in the implementation of Unmanned Aerial Vehicles (UAV), real-time monitoring, virtual consultation and predictive maintenance, AI robots, and data analytics (Tang, Dananjayan, Hou, Guo, Luo, He, 2021). 5G is crucial to agricultural advancement because of the large capacity, high data speed, and low latency 5G networks provide.

UAVs will support farmers by scouting land and crops, performing field analysis, crop spraying, seed planting, livestock monitoring and health assessments. This will require real-time data such as HD video that will be supplied over 5G networks. Transmission will be faster and more seamless than in previous generations.

Smart farming is the use of IoT devices that are deployed throughout fields that allow farmers to gain insight into different parameters of the soil, plants, weather, livestock, etc. using a smartphone over the internet (Tang, Dananjayan, Hou, Guo, Luo, He, 2021). This will provide farmers with the opportunity to monitor their farms in real-time, remotely. Sensors will monitor factors such as humidity, temperature, luminosity, soil moisture, etc. in real-time to ensure streamlined operations of the farm. Because of the substantial number of devices this requires, 5G networks makes this feasible because of its ability to handle more than 1,000,000 devices per km². The implementation of these sensors will lead to advancements in virtual consultation and predictive maintenance. Like medicine, farmers will be able to consult experts remotely, who can see video livestreams and data uploads, in real-time to hear their opinion on a failing crop or any other problem that might arise. Predictive maintenance refers to the early detection of disease, issues, failing parts, etc. (Tang, Dananjayan, Hou, Guo, Luo, He, 2021). Data from IoT sensors will be uploaded to cloud repositories where AI data analysis will take place predicting yields, trends, issues, generating insights and more. This will lead to a great reduction in unplanned downtime for farms by not halting operations (Tang, Dananjayan, Hou, Guo, Luo, He, 2021).

AI robots in farming show great promise. In 2017, the 5G Rural First project successfully “planted and harvested a crop using autonomous tractors to sow seeds, drones to monitor crops, and machines to apply water, fertilizer, and pesticides. The whole process was performed without any laborers stepping into the field” (Tang, Dananjayan, Hou, Guo, Luo, He, 2021). There have also been cases of AI machine learning (ML) models that detect and eliminate weeds without affecting crops, implement facial recognition of pigs to monitor their wellbeing, analyze and identify individual cows based off their movement. These ML models collect and process this data and an extremely fast rate which is made possible by 5G. In robotics, there have been developments of robots that complete repetitive greenhouse tasks such as inspecting plants and fruits using bionic hands to determine their health condition. Many devices are required for this process, which 5G handles seamlessly.

These advancements in agriculture will lead to greater efficiencies and increased yields due to less downtime and better analysis. However, this will greatly change the labor force required for the agricultural industry and will have various socioeconomic impacts. Many less laborers will be required to run farms in the future, but these farms will see increases in output.



Graphic illustrating a fully automated smart farm (Tang, Dananjayan, Hou, Guo, Luo, He, 2021).

Benefits of Implementation by Industry

In this section I will include some quick facts illustrating the benefits 5G technologies will bring to these 5 industries.

Overall Benefits

- “The 5G Economy: How 5G Technology Will Contribute to the Global Economy” (2017)
 - 5G will enable \$12.3 trillion of global economic output in 2035
 - 5G value chain will generate \$3.5 trillion in output and support 22 million jobs in 2035
 - 5G value chain will invest an average of \$200 billion annually to continually expand and strengthen the 5G technology base
 - From 2020-2035, the total contribution of 5G to real global GDP will be equivalent to an economy the size of India

Transportation

- 20% greater traffic efficiencies, 15% fewer crashes (Gohar, Nencioni, 2021)
- Currently 1.3 million road accident deaths per year, automated vehicles will greatly reduce this number (Gohar, Nencioni, 2021)
- “6 Ways 5G Will Accelerate Possibilities in Transportation and Supply Chain Logistics (2021).”
 - Connected and automated vehicles could
 - Prevent 210,000 accidents per year
 - Save the T&L industry \$3.6 billion in collision costs per year

- Reduce driver-related costs, currently account for 28-50% of revenue on average for T&L companies
- Help address the massive driver shortage in the industry (60,000 driver shortage in 2018, projected to be 160,000 in 2028)
- Data driven digital transformations could create for T&L companies:
 - 10-20% in additional value
 - 20-30% increase in productivity

Education

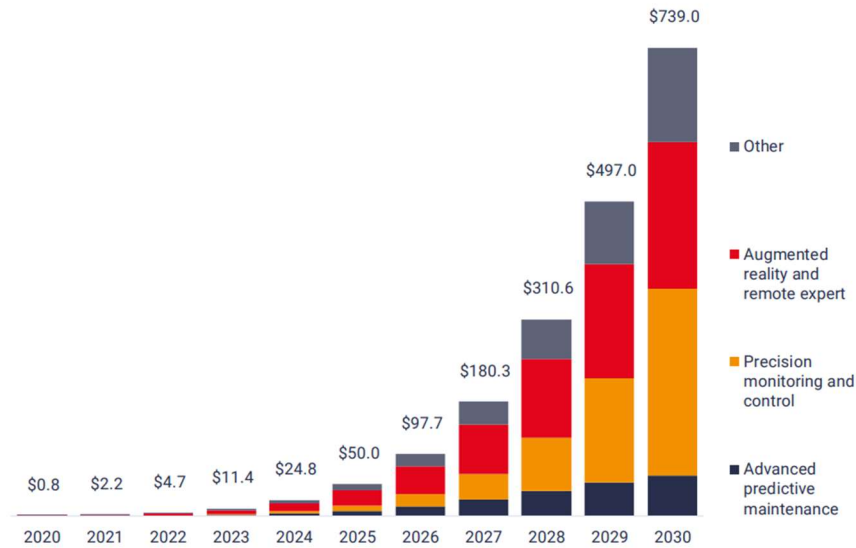
- “Pioneering with 5G: Higher Education” (2022).
 - 81% of students in a biology lab study agreed that VR helped them feel motivated to understand the material and interested in learning more about neural communication
 - Improved retention
 - Elevated course success rate
 - Increased student engagement
- “How Leading Higher Education Institutions are Modernizing Connectivity and Building Smart Cam” (Rapoza, 2021).
 - #1 planned technology to promote student success
 - 83% of universities say 5G is critical to their IT modernization plans
 - Universities that have deployed 5G are:
 - 45% more likely to be completely prepared for remote and hybrid learning
 - 2x more likely to be using AR/VR technology in learning
 - 30% more likely to have implemented smart campus IoT devices
 - 2.5x more likely to have security to prevent unauthorized network access

Healthcare

- “The Global Economic Impact of 5G. Powering Your Tomorrow” (2021).
 - 5G powered healthcare applications will add \$530 billion to global GDP by 2030
 - Productivity gain from 5G applications in healthcare by use case by 2030
 - \$161 billion—fewer and shorter hospital stays
 - \$89.5 billion—streamlined doctor-patient interactions
 - \$155 billion—drone-transported medical equipment and therapies
 - \$123 billion—improved experience and efficacy of telemedicine

Manufacturing

- “The Impact of 5G on The Manufacturing Industry” (Adib, 2019).
 - \$739 billion increase in global manufacturing GDP by 2030
 - 8.7% reduction in unplanned downtime for advanced predictive maintenance
 - 10% reduction in defect rate
 - 10% increase in machine productivity
 - 25.2% reduction in unplanned downtime for AR and remote experts



Impact of 5G on global manufacturing GDP by use case (Adib, 2019).

Agriculture

- “The Economic Benefits of Broadband and 5G in Farming” (Christenson, 2021).
 - When farms use internet speeds up to 25 MBps, corn yields increase by 3.6%, and soybean yields by 3.8%
 - Overall operating expenses decrease by 2.4%
 - \$18-23 billion per year could be realized from digital farming technologies connected by rural broadband
- “How 5G can Boost Agricultural Output” (2022).
 - Automated farming solution lowers freshwater usage and manpower costs by 40%
 - Automated farming trial in Jilin Province, China
 - Benefit of 3.3 million Yuan (\$475,000)
 - 10% increase in output
 - Unmanned tractor was 50% more efficient; unmanned harvester 60% more efficient

What Does This Mean for Businesses

Opinions from Business Leaders

Leaders across many industries believe in the potential of 5G. There is a consensus that 5G will have a massive, global impact on countless industries. (Reiss, 2020).

Name	Company/Organization (Industry)	Quote
Rob Johnson	CEO of Vertiv (Data Infrastructure)	“While still in its early ages 5G is already demonstrating the key role it will play in transforming healthcare, business operations, and more”
Suzanne Foster	President of Cardinal Health (Healthcare solutions)	“The shift we see happening now will become the big shift in health care: the ability for technology to have the speed, the reliability, the density to start providing higher acuity care in the home... 5G will be instrumental in significantly elevating the quality of health at home”
Manish Sharma	Group Chief Executive Accenture Operations (Consulting)	“5G will take us into an experience economy, enabling us to operate in more human ways... 5G and edge computing removes proximity as a barrier to getting real-time actionable insights—offering an exponential gain to a company’s operations.”
Caroline Chan	VP and GM of 5G Infrastructure at Intel (Tech)	“5G will bring job opportunities for women in telecommunications and IT, as well as a whole new era of communications for consumers and industries of all kinds.”
Dr. Christoph Grote	SVP Electronics, BMW Group (Auto Manufacturing)	“We expect 5G to become the worldwide dominating mobile communications standard of the next decade.”
Tom Wheeler	FCC Chairman (Government Agency)	“If we’ve learned anything in the generational march through wireless connectivity, it is that we have always underestimated the innovation that would result from new generations of wireless networks. The immutable law of network history will again repeat itself as the 5G network spawns transformational secondary effects.”

How 5G Will Change the Labor Force

Many jobs will be created as 5G grows. The most direct impact will be jobs created for 5G deployment. With 5G enabled technologies fostering widespread automation in every industry, there will be a significant shift in the labor force. Skill requirements will change; industries will need less workers performing repetitive tasks and more workers implementing and overseeing the technology that will perform the tasks.

Globally, many jobs stand to be created. By 2035, it is estimated that 5G will generate 22.3 million jobs (Hill, 2021). The development of 5G infrastructure will require a significant number of workers. Then, because of 5G implementation, there will be more jobs created from the multiplier effect. It is estimated that for every 1 job created by 5G development, there will be an additional 1.8 jobs created in other sectors (Hill, 2021). Accenture estimates that there will be 1.2 million direct jobs created for 5G development, plus another 1.2 million indirect jobs created as a result from household spending created from those additional jobs (Hill, 2021).

In the US, 5G deployment will contribute \$1.4-\$1.7 trillion to national GDP over the next 10 years and create 3.8 – 4.6 million jobs (Hill, 2021). This covers both direct infrastructure investment/deployment as well as indirect growth in jobs. “At first, 5G will contribute to economic activity directly through network infrastructure deployment, but as 5G networks continue to roll out and improve, an even greater wave of economic activity will occur indirectly as the networks enable new and improved use cases across industries. These will deliver significant socioeconomic benefits through higher productivity, improved cost competitiveness, and better health and safety” (Hill, 2021).

However, with millions of jobs being created, there will also be millions of jobs displaced. “More than 120 million workers globally will need retraining in the next 3 years due to artificial intelligence’s impact on jobs... the world’s most advanced cities aren’t ready for the disruptions of artificial intelligence” (Kelly, 2020). It is estimated that 50 million Chinese workers will need retraining because of AI-related deployment, and the US will be required to retool 11.5 million workers with skills needed to survive in the workforce (Kelly, 2020). There are attempts to reskill workers being taken by companies to reskill their workers, however, Amazon recently announced that it was investing \$700 million to reskill 100,000 of its employees in areas such as machine learning and robotics (Binney, 2020). Industry leaders like Amazon will pave the way for other companies to reskill their workers to adapt to this changing labor market.

What does this mean for the *way* people work? During the COVID-19 pandemic, a rapid shift to remote work was carried out. As 5G technology grows, remote work will only become more common and effective. With 5G’s enhanced speed combined with IoT, VR, etc., workers will truly be able to work from wherever they want—whether that be the home, a park, on a train, etc. (Lim, 2020).

Kelly poses the question, “what if we are unable to find jobs for the millions of Americans who no longer have ‘fourth industrial revolution’ skills? Technological innovation doesn’t have to stop, but it must be monitored and analyzed to ensure that we don’t go past the

point of no return.” This is a valid concern; however, jobs have been lost with every industrial revolution. It is only natural for markets to reassess their demands and the responsibility to meet those demands lies in the hands of workers. Evolution and adaptation are obvious in biology and ecology, but it is also what drives innovation in business. It may sound harsh, bleak, or severe, but this next evolution in business is necessary to sustain the needs of markets. Also, since this technology is so new, there are new jobs being created every day, so all hope isn’t lost. “Some of the jobs created by 5G will likely be new occupations in new industries, requiring skills that don’t yet exist” (Binney, 2020).

Problems Facing 5G and Possible Solutions

Implementation

High Costs

There are two central cost issues regarding 5G implementation: construction/infrastructure costs and energy costs.

With rising energy costs around the globe, service providers and businesses have started to consider power consumption regarding 5G deployment decisions. This is causing some operators to “tap the brakes on rollout plans” (Donegan, 2023). The cost of running the world’s mobile network is \$25 billion per year and this number is only increasing because energy costs have increased 50% in the last year (Donegan, 2023). This increase in energy prices will cause a delay in seeing the full potential of 5G monetization.

Another costly part of using 5G is building the infrastructure and acquiring the devices compatible with 5G technology. According to an Accenture survey, upfront investment was cited by 36% of respondents as the top barrier to 5G adoption (Binney, 2020). Businesses will have to purchase 5G capable systems, devices, sensors, transmitters, and more. In addition to upgrading or replacing current devices, businesses will also need to retrain workers to use newer technologies.

Finding Ways to Use 5G Technology

Since 5G is a brand-new technology with a wide range of applications, it is a struggle for some businesses to imagine ways how they can implement this technology to help their business. According to an Accenture survey, 72% of executives said they need help imagining the future possibilities and use cases of 5G (McDonagh, 2019). These executives believe there are not many things possible with 5G that they could not already accomplish with 5G technology. This can be unlocked by organizations that understand customer needs and that can overcome barriers to adoption and drive collaboration among service providers (McDonagh, 2019).

Possible Solutions for Implementation

It is hard to establish a single solution to solve implementation cost issues. Some companies may have to just invest the capital to develop 5G infrastructure with the mindset of a long-term investment horizon, because their businesses will eventually see benefits.

A similar solution should be used for addressing startup costs, “it’s better to make those investments early on than to try to catch up after 5G is widespread” (Binney, 2020). The world is moving to 5G no matter what, so businesses are better off in the long run to join the movement now, so they will have more time to reap the benefits of a fully implemented 5G-enabled business.

For finding ways to use 5G, education is the most crucial solution. Business executives need to be educated in the ways they can implement 5G technology. Whether this be through hiring consulting firms to examine their business or hiring executives proficient in 5G technologies, education on the possibilities of 5G is crucial to their success.

Public Perception

There are several unpopular opinions about 5G being expressed in the media today, ranging from claims that 5G causes cancer or COVID-19 to claims that 5G will cause planes to crash. Most of these claims are unfounded, and can be dismissed quickly, however.

It is a common theme to see on social media, or on some online news outlets, to say that 5G causes negative health benefits. Also, during the COVID-19 pandemic it was common to see the claim that 5G enhanced the spread of COVID-19. These claims are based on the fact 5G uses a higher radiofrequency than previous generations. However, this higher radio frequency makes 5G *safer* than previous generations. The World Health Organization and FDA declared 5G safe in a statement: “the electromagnetic waves have a higher frequency, which allows it to carry more information. It also has a smaller wavelength and does not penetrate the body as far as lower-frequency energy” (Laurence, 2023). Higher frequencies and smaller wavelengths have a *much* harder time penetrating objects, so 5G is completely safe. Thus, these claims are completely unfounded and can be labeled as misinformation.

Also, there have been claims that 5G technologies interfere with aircraft instruments, specifically altimeters. This claim is true. 5G hardware could “interference with altimeter systems, which were not designed to deal with a changing RF environment or terrestrial 5G operations but are crucial to the ability to gauge how far an aircraft is above the ground at low altitudes, particularly during times of low visibility” (RCR Wireless News, 2022). In worst case scenarios, this interference could lead to dangerous malfunctions. This has led to complicated discussion between the FCC, FAA, NTIA (National Telecommunications and Information Agency), and Department of Defense on how to best address this issue. The FAA has established buffer zones around many airports and introduced technology on planes to limit 5G interference and mitigate this risk (Laurence, 2023). However, limitations on this buffer zone have only been followed by AT&T and Verizon, there are many other companies that have done nothing to mitigate this risk. There have been no industry-wide restrictions placed on communication service providers (CSPs), only on AT&T and Verizon. The FAA claimed in a letter to the FCC and NTIA that “the 5G mitigation zones around airports have been agreed to entirely voluntarily by AT&T and Verizon. Nolen (FAA Acting Administrator) noted that his agency has no regulatory authority to require the 19 other spectrum holders to adopt the same restrictions agreed to by AT&T and Verizon. He wants FCC and NTIA to codify the process.” (RCR Wireless News, 2022). This means that a buffer zone was promised, but there were no plans to establish

plans for development or a mechanism for enforcement. This creates a lot of uncertainty for the direction of aviation safety management.

Possible Solutions for Public Perception

The main solution for solving public perception issues of 5G is education. The public needs to be educated on how 5G technology works and how it poses no risks. The responsibility to carry this out lies in the hands of agencies like the FCC, WHO, and FDA. Also, better communication and cooperation between agencies like the FAA, FCC, NTIA, and DoD are crucial to strengthening the effort of mitigating aviation risks posed by 5G. The letter from the FAA to the FCC and NTIA shows promise of greater cooperation across government agencies in the future concerning the management and mitigation of these risks. If industry-wide restrictions are placed on CSPs, detailing buffer zone restrictions and enforcement protocols, public perception regarding 5G and the safety of U.S. aviation will greatly improve.

Security

Because of the massive amount of information and devices 5G networks allow, there is more room for error regarding security risks. When a business has 100,000 IoT devices in a factory, there are at least 100,000 new potential network weaknesses. The following section is based on the article “Is 5G Technology Dangerous? Pros and Cons of 5G Networks” published by Kaspersky, a cybersecurity provider.

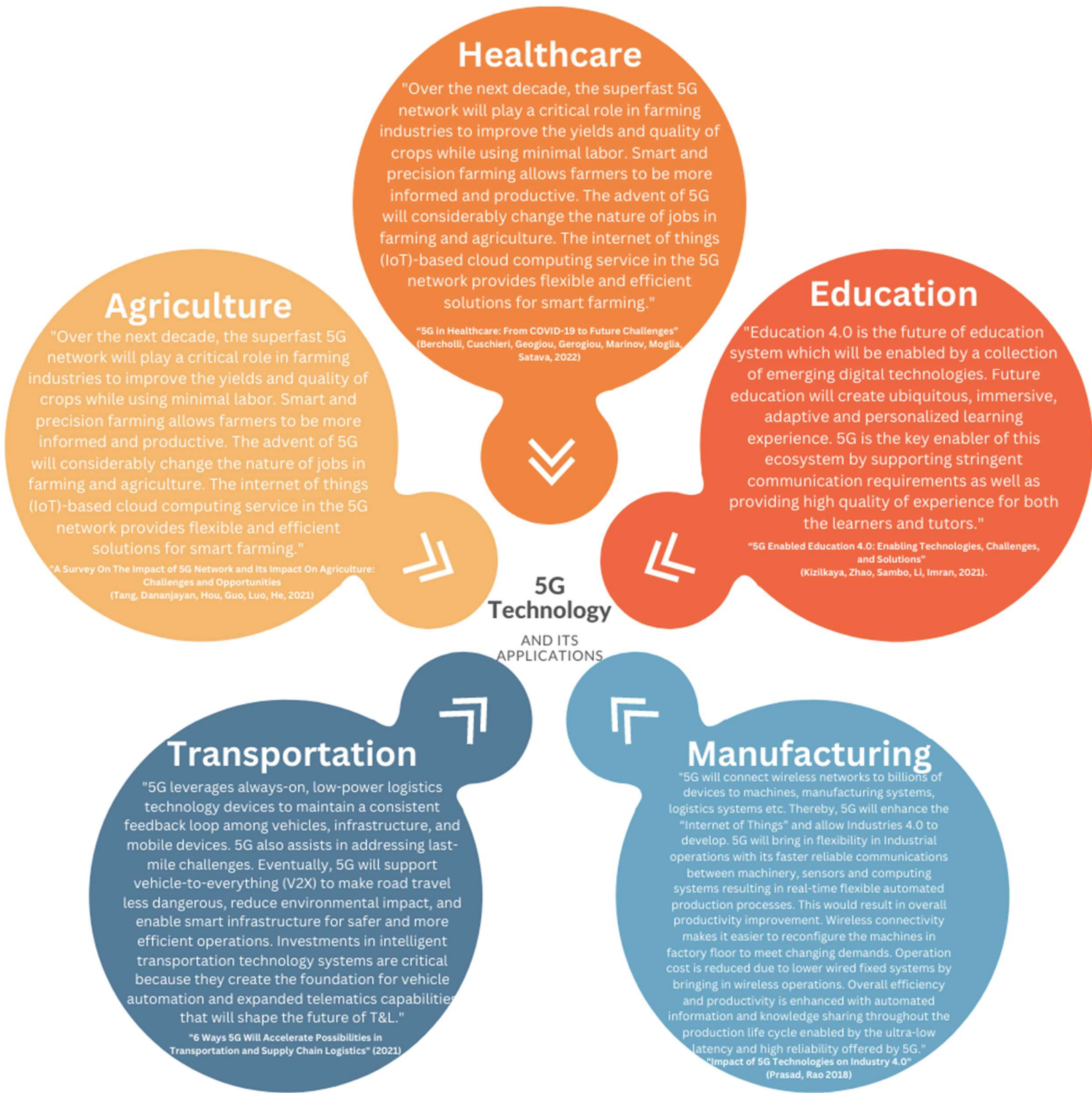
The increased bandwidth provided by 5G will strain current security monitoring. Existing networks are limited in speed and capacity, which makes it easier for providers to monitor in real-time. So, with a massive increase in data transfer, it becomes much more difficult to monitor this data. Added speed and volume will greatly challenge security teams to create methods for identifying risks.

Many IoT devices are manufactured with a lack of security. As businesses increase the number of IoT devices they use, their number of risks increase too. This is applicable for at-home users of IoT devices as well, your smart fridge can be an access point for hackers to access your network.

Possible Solutions for Security

The main solution for security issues is that IoT devices need to be manufactured with security as a priority. Also, networks need to increase the development of methods to identify and stop cyber threats. This will be seen through the development of software protections to combat the unique risks of 5G. IoT device manufacturers will need to be incentivized to create better protected devices. Finally, consumers and executives need to be better educated on cybersecurity principles and practices. If manufacturers receive benefits for creating safe products, or receive penalties for creating unsafe products, more secure IoT devices will become commonplace. Average consumers are introducing numerous IoT devices into their home and implementing 0 protections to their network. 5G is still very early in its development and security issues are very common with new technologies. As 5G becomes more widespread, so will better security protocols and practices.

Conclusion



5G and the applications it promotes can have a nearly unlimited impact and drastically change the world we live in. The 5 industries that I outlined which 5G will have a massive impact on will not only increase bottom lines but also save lives. 5G will guide the world into a time of unprecedented connectedness and technological innovation. Classrooms, hospitals, factories, farms, and cars will change in extraordinary ways due to 5G. As 5G is more fully absorbed into our society, future research should focus on whether the expressed concerns became realities and if the promises of the technology were reached. Given our past evolution of technology, 6G will be here before we know it, so it is important to detail the efficiencies and shortcomings of 5G so that the next generations of cellular communications will be more advanced, applicable, and safer than those before. As you can now see, the world of 5G is thoroughly complex but also ripe with functionalities and possibilities. The 5G market is still developing and there is rationale for both optimism and skepticism. However, the benefits 5G provides will be too great for skeptics to ignore.

Is 5G The Future of Business?

As market demands grow, businesses will have no choice but to implement 5G technology. There exist benefits both for the consumer and for the business from implementing 5G enabled technologies. Even though jobs may be lost, there are too many benefits to pass up. Especially in industries like healthcare and agriculture, where there is the possibility of saving many lives. If businesses do not implement 5G-enabled technologies, they will fall behind market leaders who are already implementing them. Whether the number of lives positively benefitting from 5G outnumbers the lives negatively impacted is hard to determine, but I believe the implementation of 5G and subsequent technologies will bring about a net positive change on business and the world as a whole for many years to come.

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