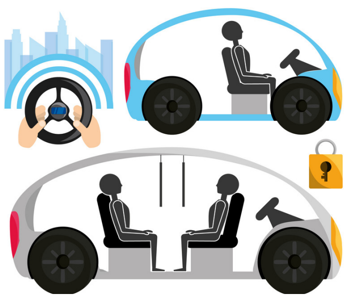
Connected & Autonomous Vehicle Technologies

Prepared by:
Farah Samouh
Master of Applied Science in Civil Engineering
Ryerson University

Email: fsamouh@ryerson.ca
Website: https://litrans.ca/team/samouh-f/



September2019

This project was funded through Mitacs and co-supervised by:

Bilal Farooq, Ph.D.
Assistant Professor, Transportation Engineering
Canada Research Chair, Disruptive Transportation Technologies and Services
Director, Laboratory of Innovations in Transportation (LiTrans)
Ryerson University

And

Lee Weissling, Ph.D.
Senior Research Officer
Ontario Society of Professional Engineers

Mitacs is a national, not-for-profit organization that has designed and delivered research and training programs in Canada for 20 years. Working with 60 universities, 4,000 companies, and both federal and provincial governments, they build partnerships that support industrial and social innovation in Canada.

Project guidance and data were provided by the Canadian Urban Transit Research and Innovation Consortium (CUTRIC).

“ Technology and innovation will enhance our transportation systems and urban environments for the future of connected automated vehicles and smart cities. ”

Rob Schebesch
Senior Vice President, Sector Leader,
Transportation at Stantec

“Car-to-X communications has the advantage that we are also able to obtain information from points far outside the drivers’ field of vision, which is not the case with conventional sensors.”

Dr. Christian Weiss
Car-to-X Communication Specialist
at Mercedes-Benz Development

“If you are in the connected vehicle industry you are in the business of saving.”

Jason Conley
Executive Director
of the OmniAir Consortium

“The key with autonomous is the whole ecosystem. One of the keys to having a truly, fully autonomous [system] is vehicles talking to each other.”

Mary Barra
CEO of General Motors Company

TABLE OF CONTENTS

I. Introduction

Two terms are often associated with smart mobility: “autonomous vehicles” and “connected vehicles”. Autonomous vehicles are equipped with a system that allows hardware and software to take over the act of driving and reduce human interactions. Connected vehicles are equipped with internet access, and usually have a wireless local area network. This allows them to communicate with other vehicles and infrastructure depending on the level of connectivity. Connected vehicles can share internet access, and hence data, with other devices both inside as well as outside the vehicle.

Currently there has been an ongoing discussion on the effect of autonomous vehicles without connectivity, which is where the term “connected vehicles” came into place. It is essential to acknowledge the fact that autonomous vehicles alone, without connectivity, will not show a prominent improvement in current networks, because autonomy only focuses on the environment surrounding the vehicle based on the lidars, radars, sonars, cameras, etc. creating an imaginary bubble around the vehicle. But the technology to help a vehicle identify congested points further along its path or detect accidents that occur in real time and change routes, does not exist in autonomous vehicles alone. Here is where connectivity plays a key role into providing the smart mobility system required for the future.

There are five ways a vehicle can be connected to its surroundings and communicate with them:

1. Vehicle to Infrastructure (V2I): This type allows the vehicle to communicate with the infrastructure to obtain information about traffic conditions, as well as safety conditions and environment-related conditions.
2. Vehicle to Vehicle (V2V): This technology allows vehicles to talk to each other. In other words, vehicles are able to communicate information about their location and surroundings through a wireless exchange of information, which provides more accuracy than relying solely on sensors onboard of the vehicle.
3. Vehicle to Cloud (V2C): This technology exchanges information for applications of the vehicle with a cloud system.
4. Vehicle to Pedestrian (V2P): This technology enables the vehicle to communicate with pedestrians by sensing information from the infrastructure and personal mobile devices, for the purpose of improving safety and mobility on the road.
5. Vehicle to Everything (V2X): This technology connects all sorts of vehicles and infrastructure systems with each other, including cars, highways, ships, trains and airplanes.

The main motivation for connecting autonomous vehicles and equipping them through special technologies with very low latencies is safety and eliminating the excessive costs associated with traffic collisions.

Part of adapting an intelligent transportation system is creating an efficient vehicular communication system that can provide the proper tools of communication required for a connected autonomous vehicle to operate accurately.

Currently, there are two types of communication systems that are competing to provide autonomous vehicles with the proper software and hardware to form connected autonomous vehicles. The first is the Dedicated Short-Range Communication Technology (DSRC) which is discussed in detail in section 2. The second is the 5^{th} Generation Technology (5G) which is discussed in detail in section 3. Advantages and challenges of both systems are also outlined.

2. Directed Short-Range Communications (DSRC)

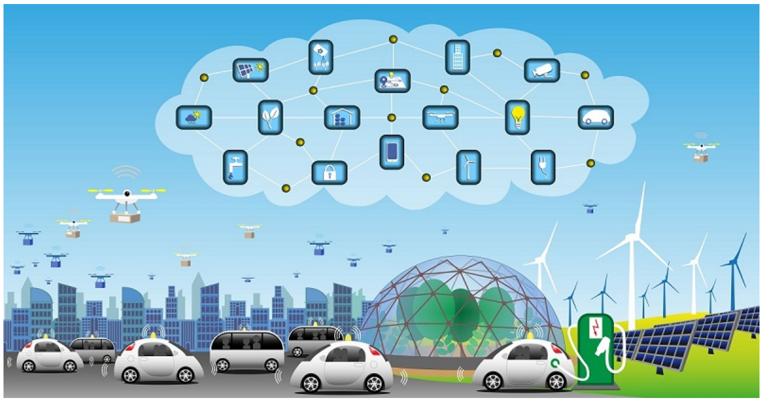


Figure 1: Future of Connectivity[1]

Dedicated Short-Range Communications (DSRC) is a wireless communication technology that enables vehicles to communicate with each other and other road users directly, without involving the cloud nor cellular infrastructure (Figure 1). DSRC works in 5.9 GHz band with bandwidth of 75 MHz and approximate range of 300 m. [2].

Vehicle to Vehicle V2V communication using DSRC (Figure 2) operates by having each vehicle send its location, heading and speed in a secure and anonymous manner. All surrounding vehicles receive the message, and each estimates the risk imposed by the transmitting vehicle. Risks are defined as “safety applications” such as Left Turn Assistance (LTA), Intersection Movement Assistance (IMA) and many others.

DSRC was designed for maximal cybersecurity, which means that the receiving vehicle validates the authenticity of the received messages without linking the message to the vehicle and exposing its identity, therefore not violating the driver’s privacy [3].

Figure 2: DSRC Communication Technology[4]

2.1 Current state of DSRC technology

DSRC protocol was released in 2002 by the American Society for Testing and Materials (ASTM). In 2003, the standardization moved to IEEE Forum[1], which changed the name from DSRC to WAVE Wireless Access in Vehicular Environments[2] (WAVE), which was also known as 802.11p [5].

IEEE 802.11p is the basis for DSRC. IEEE 802.11p is an official amendment to the IEEE 802.11 standard to add wireless access in vehicular environments (WAVE), a vehicular communication system. It outlines improvements to IEEE 802.11 (the basis of products marketed as Wi-Fi) allowing laptops, printers, and smartphones to talk to each other and access the Internet without connecting wires, which is essential to support Intelligent Transportation Systems (ITS) applications in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz) [6].

[1] IEEE forum is a nonprofit research forum that works primarily in the knowledge domain where the Industrial Electronics and Electrical Engineers community can tackle key research challenges
[2] Institute of Electrical and Electronics Engineers (IEEE) series of standards for Wireless Access in Vehicular Environment (WAVE) is currently considered as the most promising technology for vehicular networks

Any Network protocol is a layered protocol. DSRC WAVE stack protocol is divided into three major layers: Physical Layer, Network Layer & Application Facility Layer. All these three layers contain congestion control, security and management protocols.

In addition to improving safety, WAVE networks can play major roles in travel planning, traffic management, navigation, fleet and asset management, environment monitoring, logistics, congestion, emission reduction, toll collection, smart parking, emergency services, and a wide range of other location-based services.

Usually DSRC and WAVE term are used interchangeably. The primary differences are that DSRC includes IEEE 802.11p, an amendment of 802.11a MAC and PHY while WAVE standard focused on the upper layers. Furthermore, DSRC can use the WAVE Short Message Protocol (WSMP) to support V2V and V2I safety applications. [7]

Wireless vehicular networks operating on the DSRC frequency bands are currently the key enabling technologies for the evolving market of Intelligent Transport System (ITS).

There are two types of devices in a WAVE system [8] :

1- On-Board Unit (OBU).
2- Roadside Unit (RSU)

Vehicle to Vehicle (V2V) and vehicle to infrastructure (V2I) are two categories of communications enabled by the OBUs and RSUs. The OBU in a vehicle directly communicates with other OBUs within the radio coverage distance (i.e. a range less than 1000m). This V2V direct communication decreases the message latency since low latency is a critical requirement for safety applications such as collision avoidance [9]. Furthermore, RSUs can use existing roadway infrastructure, including traffic lights, traffic signal controllers and traffic signs, and be co-located with these devices in order to enable V2I communications.

2.2 Advantages and challenges in DSRC

Despite decades of safety efforts and safety advances, road accidents annually cause approximately 1.2 million deaths worldwide. Moreover, about 50 million persons are injured in traffic accidents according to the World Health Organization (WHO).

Ever since DSRC technology was introduced more than 10 years ago, industry engineers have been trying to tailor this technology for safety – critical for advanced driver-assistance systems (ADAS) applications, as well as to position it to support emerging autonomous driving systems. Over the course of developing this technology, it has been found to possess characteristics that are beneficial and can provide an important new capability for enhancing the performance and safety of automated vehicles—allowing automation to reach its full potential by connectivity.

DSRC is an appropriate technology solution for enabling communication-based safety applications precisely suitable for the dynamic traffic environment. It supports the close-range communication requirements to send vehicle Basic Safety Message (BSM) to other vehicles or the infrastructure, and with V2V applications it will directly reduce the number and severity of motor vehicle crashes and minimize the societal costs resulting from these crashes [10].

Furthermore, DSRC technology is currently the only low-latency technology available today for commercial use for connected autonomous vehicles. DSRC operates on the 5.9 GHz band which possesses low latency, high reliability characteristics and has a 300-metre transmitting range. Because of the short range that it spans, it receives very little interference even in extreme weather conditions.

Additionally, DSRC extends vehicle situational awareness to a 360-degree unobtrusive detection angle – beyond what is currently provided and surpassing the sensing capability of sensors, cameras, and radars currently used in vehicles with onboard sensor systems, which are limited by their line of sight [11].

Moreover, DSRC supports interoperability, which means it can ensure a common communication platform which all vehicles can communicate between, regardless of the vehicles size, make or model [3].

However, with all the benefits of DSRC technology come challenges that need to be addressed from a governmental, a manufacturing and previous vehicle owner's standpoint.

From a governmental standpoint, regulations need to be issued to ensure that new vehicles being manufactured are equipped with OBUs that allow V2V communication. Indeed, one of the factors that can ensure the success of DSRC technology is the number of vehicles that are connected and can communicate when encountering each other. Therefore, a low adoption rate for a long period of time would significantly impact the V2V benefits. Thus, using DSRC in V2V communications will be deemed successful when a significant level of adoption is reached.

From a manufacturing and previous vehicle owner's standpoint, in order to reach a significant number of participants, a substantial portion of the existing vehicle fleet will need replacement or modifications. However, without government intervention, a sustained, coordinated commitment on the part of manufacturers would be very hard to ensure. Therefore, regulations are a must to get manufacturers to cooperate with this evolution.

Furthermore, communication is not exclusive to V2V. V2I communication is also an essential part of the connectivity system. Hence, governments need to provide funding to upgrade the infrastructure and add RSUs to obtain the full benefits of DSRC technology due to the fact that DSRC is deployed exclusively for transportation usage while 5G technology is multi-purposeful.

Lastly, communication interoperability is critical, and while DSRC supports interoperability, measures are needed to ensure that vehicles travel over large geographical areas, cutting across local and international boundaries, can still communicate with each other without interruptions, even when they cross borders.

2.3 Expected DSRC technology advancements

A decade of research and development advancements on DSRC technologies, channel testing, applications, and standards offer a near comprehensive set of outcomes as a foundation for deployment. Hence, DSRC based technologies and Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) applications are advancing across the world in the US, Europe, Japan, South Korea, Australia, and Canada.

Government agencies across the world, along with various stakeholders and universities, have conducted analyses and prototyped and tested applications, technologies, security solutions, and new institutional arrangements. Information has been gathered and incorporated into final versions of performance specifications, guidelines and standards. In parallel, many test beds and pilot deployments have put DSRC into use for research purposes and are preparing plans to transition to operational uses which will be discussed in Section 2.4.

In North America, Canada has reserved a spectrum of 5.9 GHz for V2X and is watching its development in the US. On January 12, 2017 the US's National Highway Traffic Safety Administration (NHTSA) and Department of Transportation (DOT) released a proposed mandate titled *Federal Motor Vehicle Safety Standard (FMVSS), No. 150*. This mandate would necessitate passenger cars, multipurpose passenger vehicles (MPVs), trucks, and buses having a gross vehicle weight rating (GVWR) of 4,536 kilograms or less to be equipped with V2V communication technology after the year 2023, as well as the standardization of the message and format of transmissions [12].

Currently, the US DOT is working to synchronize operational policies and voluntary industry standards to attain worldwide compatibility and to ease national entree into international marketplaces[13].

While the US is mandating DSRC for V2V communications, they are also allowing supplies for alternate technologies that are interoperable with DSRC to allow innovation from other wireless communication technologies.

2.4 List of projects currently using DSRC technology

2.4.1 Pilot Projects around the world

Existing international efforts and significant V2V research and development activities have been completed to test autonomous vehicles, connected vehicles or autonomous connected vehicles to guarantee their safe deployment on the roads. Furthermore, efforts are being conducted to harmonize communication bands to reduce costs and facilitate cross-border traffic.

In Europe and Asia real-world deployments concentrates on V2I communication systems that can aid drivers and improve traffic flow.

Japan, Korea and Australia in the Asia-Pacific region are most involved in DSRC-based V2X communications. In Japan, the Ministry of Land, Infrastructure, Transportation and Tourism's current V2X program is the adaptation of the Electronic Tolling system operating at 5.8 GHz. Furthermore, message sets in Japan are still under development and appear to be moving to those coherent between Europe and the US. Also, Korea currently uses the 5.835– 5.855 GHz band for

Electronic Toll Collection and DSRC experimentation. Korea has conducted field tests for V2V communication in this band however industry sources indicate that Korea may move DSRC for Intelligent Transportation Systems (ITS) to 5.9 GHz to be more united globally. Moreover, the Australian vehicle market is mainly reliant on imports from the US, Europe, and Asia. Therefore, Australian agencies joined the international harmonization efforts to ensure that all vehicles transported into the country are interoperable with each other and with the infrastructure.

Listed below are some of the pilot projects in the US using DSRC technology:

2.4.1.1 - Colorado DOT (CDOT) Pilot[14] [15]

Panasonic in collaboration with Colorado's Department of Transportation (CDOT), will test new communication processes for next-generation vehicles. This includes vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) protocols. This program aims to leverage DSRC to facilitate communication between cars and traffic lights or other smart objects on the road. It is anticipated that the protocol will manage data in real-time and may also be used to send timely information to moving vehicles. This type of communications and reporting could provide early warning notifications related to icy roads, obstructions and car accidents. Furthermore, this pilot project will equip first responders with the hands-on training needed outside the classrooms to safely clear incidents from the roadway.

The program will equip over 700 CDOT first responder, ski shuttle and commercial vehicles with DSRC devices. The devices will also be installed on roadside infrastructure to gather data on vehicle speeds and incidents. Vehicles installed with DSRC will function as "data collectors" for the pilot program, sending information to CDOT that can be sent out to drivers along the corridor in a timely fashion. Additionally, CDOT vehicles, such as snowplows installed with friction sensors, could send information on icy or snow packed road conditions to this database. Sensors installed on highway infrastructure tracking traffic volume, travel speeds and accidents could also feed this data into the system for real-time traffic updates.

2.4.1.2 - Palo Alto Test Bed [16]

The Test Bed consists of 11 consecutive intersections and exchanges live data with a California Department of Transportation (Caltrans) 2070 traffic controller at each intersection for populating the Signal Phase and Timing (traffic control) (SPaT) messages and commanding adaptive signal and priority timing. The Test Bed is maintained and managed by the California PATH program and is expected to add 20 more intersections. The expanded Test Bed consists of 31 consecutive intersections between Medical Foundation Dr. in Palo Alto and Grant Rd. in Mountain View.

PATH and Caltrans are upgrading the Palo Alto Test Bed and are supported by the US DOT. The DOT is encouraging the development of DSRC by supporting up-to-date test beds on public roadways, which are essential to further testing and developing the technology. This upgrade will assist the test bed in becoming a key element in the national network of DSRC test beds. This location is especially crucial as several major international vehicle manufacturers have built research facilities in the area.

2.4.2.3 - New York City DOT (NYCDOT) CV Pilot [17] [18]

The NYCDOT CV Pilot Deployment project is one of three US DOT-funded Pilot Deployments initiated in 2016. The primary goal of this project is to eliminate traffic related deaths and reduce crash related injuries and damage to both the vehicles and infrastructure. The NYC deployment is mainly focused on safety applications – which rely on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-pedestrian (IVP) communications.

The deployment area encompasses three distinct areas in the boroughs of Manhattan and Brooklyn. Approximately 5,800 cabs, 1,250 MTA buses, 400 commercial fleet delivery trucks, and 500 City vehicles that frequent these areas will be fitted with CV technology to enable V2V communications. Furthermore, the deployment will include approximately 310 signalized intersections for V2I technology. The pilot will also focus on reducing vehicle-pedestrian conflicts through in-vehicle pedestrian warnings and an additional V2I/I2V project component that will equip approximately 100 pedestrians with personal devices that assist them in safely crossing the street.

2.4.2 Pilot Projects in Canada

Transport Canada developed guidelines for trial organizations to test autonomous connected vehicles called "*Testing Highly Automated Vehicles in Canada – Guidelines for Trial Organizations*" which is a series of guidelines to direct the safe conduct of Highly Automated Vehicle (HAV) trials in Canada, agreed upon by federal, provincial and territorial representatives of the Canadian Council of Motor Transport Administrators (CCMTA). Organizations in Canada are expected to follow these regulations[19]. Furthermore, Program to Advance Connectivity and Automation in the Transportation System (ACATS) helps Canadian jurisdictions prepare for the array of technical, regulatory and policy issues that will emerge as a result of the introduction of AV/CVs. Canada's

Safety Framework for AV/CVs and the Safety Assessment for Automated Driving Vehicles: Guidance materials for industry to support the safe development, testing and deployment of AV/CVs in Canada [20].

2.4.2.1 – Canada's ACTIVE-AURORA CV Testbed [21]

The Centre for Smart Transportation at University of Alberta has been actively preparing for the future of innovation in the transportation industry. "ACTIVE-AURORA" is a network of on-road test beds that is specifically designed to provide harsh climatic conditions such as winter climate to test Connected Vehicle Systems, technologies, applications, and services for transit, goods movement, traffic, and other active transportation. ACTIVE is based in Edmonton, Alberta, and AURORA is Vancouver, British Columbia based.

The program provides real-world test zones in three various congested corridors, such as a rural freeway, an urban expressway, and an urban arterial, which is also combined with the laboratory settings, where conditions are customizable in order to simulate various scenarios. These facilities provide transportation experts cutting-edge learning opportunities and coaching for the coming generation. Stantec provides Project Management and Construction administrative services, and the company is a leader in developing and implementing testing of this groundbreaking technology.

Currently, the test bed is at its first stage: "Improving Safety" which involves fully connected corridors using DSRC V2I technology. Later stages include "Driver Behaviour" which is then followed by "Congestion Reduction."

In the initial stage, the project is focused on bringing connected vehicle technology to minimize pedestrian collisions at signalized intersections. Results have provided a proof of concept for pedestrian detection alert on the oncoming connected vehicle using DSRC message. This allows researchers at Stantec to decide how the technology will behave in terms of performance with mixed vehicles in the arterial road as well as local streets in various weather conditions.

2.5 Gaps in research

DSRC technology has been around for over a decade, giving it sufficient time to progress and be used in real life testing. According to the US DOT, there are no significant gaps in DSRC technologies or applications. However, the following issues have emerged lately and have formed some ambiguity. Solicitation for coexistence with widespread use of Unlicensed-National Information Infrastructure (U-NII) devices[3], and a desire for spectrum management that can provide an active response to problems as they arise.

Two problems that are providing uncertainty for various stakeholders making investments have risen [13]. The first issue is from a technical viewpoint, which is the request to consider coexistence with unlicensed devices. Implementers require a certain guarantee that probable sharing of the band of radio-frequency spectrum used for V2V and V2I communications will not jeopardize their crash avoidance abilities. Since these unlicensed Wi-Fi devices (U-NII) are anticipated to become widespread in use in the foreseeable future, it is important to ensure that changes to the 5.9 GHz DSRC band do not jeopardize crash avoidance capabilities. These U-NII devices have yet to be tested to determine if they will interfere with crash-avoidance applications or result in unacceptable risks to traveler safety.

A second issue is that even as DSRC technology has advanced and the rules controlling its use have been set, a stronger form of frequency coordination needs to be applied. Active frequency coordination is required to mitigate these concerns, and technical spectrum coordination techniques and organizational management roles need to be discussed to prevent the negative impact to the delivery of communications that form the foundation for safety-critical warnings to drivers.

The US DOT is working with industry partners and in cooperation with the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) to define and assess the potential for destructive intrusion from unlicensed broadband devices in the DSRC band, since spectrum sharing was not intended. It will be important to allow enough time to meticulously test possible sharing solutions—including field testing under real-world conditions [13].

---

[3] U-NII devices provide short-range, high-speed unlicensed wireless connections in the 5 GHz band for, among other applications, Wi-Fi-enabled radio local networks, cordless telephones, and fixed outdoor broadband transceivers used by wireless internet providers.[22]

With all that is stated above, DSRC technology remains an adequately developed technology with gaps having been proactively addressed. What is remaining is the effort to deliver better specifications on matters like spectrum usage, performance requirements, or final standards.

Various advancements occurred in the field of wireless network communication over the years, in terms of overall advancements and transformations in central functionality. This has been vital for human progress. Each generation is characterized by new frequency bands, higher data rates and non–backward-compatible transmission technology.

3. Fifth Generation Technology (5G)

5G is the fifth generation of mobile networks. It follows previous mobile generations 1G, 2G, 3G and 4G (Figure 3). 1G refers to the first generation of wireless cellular technology (mobile telecommunications). 1G was a network with only voice call abilities and got the name 1G after 2G was introduced. After that came the 2G era which lasted from 1980's to 2003, allowing the various networks to carry out services such as text messages, picture messages, and multimedia messages (MMS).

Later, came 3G which was introduced in 1998 and was considered a great revolution in terms of technological development for network and data transmission. 3G had speed capabilities of up to 2 Megabits per second (Mbps) and enabled smartphones to provide faster communication, send/receive large emails and texts, provide fast web browsing, video streaming and more security amongst others. 4G networks were introduced in 2008 with a latency rate is around 50 milliseconds. The 4G standard sets numerous requirements for mobile networks including mandating the use of Internet Protocol (IP) for data traffic and minimum data rates of 100 Mbps. Soon after 4G, 4G LTE (Long Term Evolution) was introduced. This was not a brand-new technology, but rather can be thought of as the path used to achieve 4G speeds. It was a complete redesign and simplification of 3G network architecture, resulting in a substantial reduction in transmission latency, hence, increasing efficiency and speeds on the network [23].

As more users come online 4G networks get ever closer to the limit of what they are capable of, because users want more data for their smartphones and devices (Table 1). Therefore, 5G networks are being introduced by accessing a new frequency in the spectrum in order to use shorter millimetre waves. The next generation of wireless networks – 5G – will possess high resolution capabilities for cell phone usage and bi-directional large bandwidth sharing. 5G will be the foundation of virtual reality (VR), autonomous and connected driving, and the Internet of Things [24].

Figure 3: The evolution of G networks.

Table 1 : Characteristics of G networks

Parameters	1G	2G	3G	4G	5G
Speed (data rates)	2 Kbps	14.6 - 64 Kbps	2 Mbps	200 Mbps – 1 Gbps	1 Gbps and higher
Location of first commercialization	Japan	Finland	Japan	South Korea	South Korea
Applications	Voice calls	Voice calls, short messaging, browsing (partial)	Video conferencing, mobile TV, GPS	High speed applications and wearable devices connection	IoT (Internet of Things) and connected vehicle applications
Cell towers range	-	*From 35,000 up to 70,000m*	*From 35,000 up to 70,000m*	*Up to 35Km apart*	*Approximately spaced 150m apart*

3.1 Current state of 5G technology

5G is considered a new technology, however, five new technologies have emerged recently as the foundation of 5G; Millimetre Waves, Small Cells, Massive MIMO (Multiple Input Multiple Output), Beamforming and Full Duplex (Figure 4).

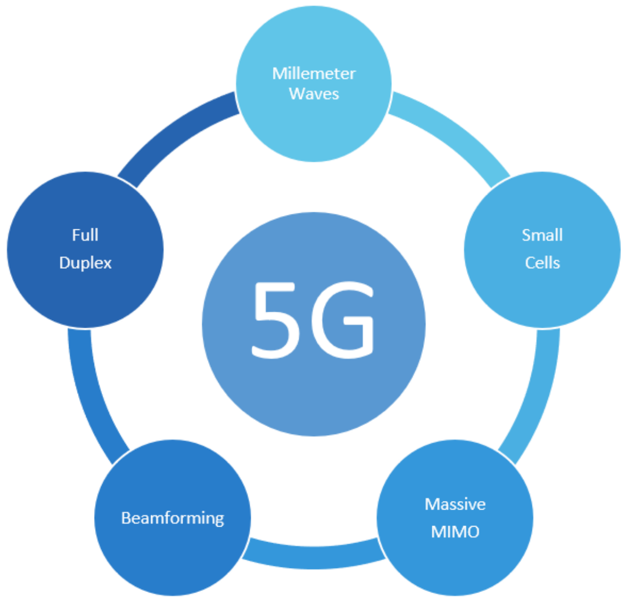


Figure 4: Foundation of 5G Technology

- Millimetre Waves

Very specific frequencies were used in the frequency spectrum - typically under 6GHz. However, unused bands at the top of the radio spectrum have recently been unlocked by regulators for licensing. These high bands are known as millimetre waves and are being introduced to provide more bandwidth for various applications, including those found in connected vehicles. 5G can use higher frequencies than 4G, and as a result, some 5G signals are not capable of traveling large distances (over a few hundred metres). Also millimetre waves cannot travel properly through buildings and obstacles, and tend to be absorbed by plants and rain. To resolve this, 5G base stations must be placed every few hundred metres to utilize higher frequency bands. This is where small cells come to place [25].

- Small Cells

Small cells are low-powered cellular radio access nodes that operate in the licensed and unlicensed spectrum, that have a range of 10 metres to a few kilometres. Small cells are not a new technology and have been deployed in both 3G and 4G networks however, they are a crucial component to 5G networks. Small cells are also able to significantly increase network capacity and provide ultra-dense networks and coverage, especially indoors [26] [27].

- Massive MIMO (Multiple Input Multiple Output)

Today's 4G base stations have about a dozen ports or antennas that handle all cellular traffic, but massive MIMO base stations can support large numbers of antennas to increase sector throughput and capacity density. Of over 562 separate 5G technology demonstrations, tests or trials globally, at least 94 of them have involved testing massive MIMO in the context of 5G [28] [29].

- Beamforming

Beamforming is like a traffic signaling system for cellular signals. Instead of broadcasting in every direction, it directs a focused stream of radio waves to its target. This means stations can handle more incoming and outgoing data streams at once. A massive MIMO base station receives all of the signals and keeps track of the timing and direction of their arrival. It then uses signal processing algorithms to triangulate exactly where each signal is coming from and plots the best transmission route back through the air to each device. Signals at particular angles experience constructive interference while others experience destructive interference and the result is a coherent data stream sent only to the specific device [30].

- Full Duplex

Today's cellular base stations basic antennas can do one job at a time - either transmitting or receiving. However, full duplex communication in 5G small cells is capable of improving the performance over conventional half duplex communication by allowing a node to transmit and receive at the same time and in the same frequency band. This theoretically doubles the system throughput over conventional half-duplex systems [31].

3.2 Advantages and challenges in 5G

The Internet has now become a necessity for people across the globe. As of March 2019, 56.8 per cent of the world's population has internet access with a 1,114 per cent growth rate since 2000.When it comes to technology, humans are on a constant path of evolution. Technology has progressed in a manner that wipes away every obstacle in its path in the attempt to make human life as easy and safe as possible. Cellular technology started from 1G and now is leaping towards 5G. This technology promises various advantages, however every technology carries its pros and cons – especially with relatively new technology such as 5G [32] [33].

The benefits of 5G are ultra-fast, highly reliable, scalable and very low latency networks with the flexibility to meet users' needs across all sectors. One of the biggest benefits of 5G technology that will aid in forming smart cities, is it provides higher speeds than ever. Data rates in 5G devices can be more than 10 Gigabits per second (Gbps) - almost a thousand times faster than 4G/4G LTE networks. This means downloading a HD movie that used to take minutes to download on a stable 4G connection will take 10 seconds or less. Furthermore, the significantly higher throughput rates, which are around 10 times more than 4G, will also make online gaming and general 4K video streaming possible at blazing speeds. In short, no more frustrating waits for a web page to load, just imagine what this technology can do when applied to different applications [34]!

5G will usher in a huge number of new applications for cases that were not even close to being possible in the 3G/4G regime. 5G will help in the formation of smart cities especially in smart mobility applications. Due to the characteristics of this technology, 5G can be used as connected vehicle technology to allow communication between vehicles, the infrastructure and all its surroundings. This is a vital pre-requisite for self-driving cars. Also, 5G will be right at the heart of the Internet of Things (IOT) revolution along with artificial intelligence (AI).

Unlike 4G and older generations, which are determined by modulation and frequency (i.e., interface-defined), 5G may likely turn out to be the final incremental update in wireless connectivity. 5G will be the first-ever software-defined wireless standard. New frequency bands/waves can be rapidly included in 5G networks, and since everything becomes programmable, newer wireless protocols will become available through software updates. In other words, all improvements will be continuously integrated, and there may not be a need for 6G as the architecture-focused 5G can be called a 'continuous G.' This would become the standard that marks the end of 'generational improvements' in wireless networking technology [35].

But with the rise of 5G comes several challenges arising from it being a relatively new technology. Carriers are willing to invest in building the infrastructure currently needed for 5G networks to operate. In the US the four major domestic carriers - AT&T Mobility, Verizon Wireless, T-Mobile US, and Sprint Corporation - are in a strongly competitive market, and to obtain new customers and retain their current ones they have collectively invested $300 billion in the last decade to construct and maintain their networks. Also, they have spent over $60 billion purchasing spectrum from the US government in the last decade. They estimate that they may need to spend another $300 billion to get their 5G networks fully up and running. However, all these investments by carrier companies will come with a cost. Over the long run the subscription of 5G prices might gradually come down but initially subscription plans are expected to be more expensive than the ones currently available [36].

Furthermore, security is always a concern when we talk about technology and in order to make 5G a viable and safe technology, the burden will lie on the carriers to incorporate vigorous endpoint security standards (behaviour-based instead of the regular signature-based) for identifying/removing malware[4], create pre-tested firewalls, monitor domain name structure[5] (DNS) activities and establish strong data integrity assurances. Better identity management systems will be required as well, along with smart sandboxing[6] solutions. If the security guarantees are not up to standards, people will be hesitant of adopting the new wireless generation [34].

[4] Software that is specifically designed to disrupt, damage, or gain unauthorized access to a computer system
[5] Protocols, services and methods for storing, updating, and retrieving IP addresses for hosts computers.
[6] A virtual space in which new or untested software can be run securely

Finally, to be able to have an operational 5G network, highly trained software and data network engineers need to be involved. Every phase of 5G will require expertise from installation to deployment, maintenance and fault-detection/repairs/debugging, therefore, providing training to the existing manpower will be paramount.

3.3 Expected 5G technology advancements

In the future, when applying 5G technology in transportation sectors it is expected to ensure connected autonomous cars reduce emissions by up to 90 per cent, cut travel time by 40 per cent, and save 22,000 lives annually in the United States. It is also estimated that 5G will save $450 billion annually in transportation costs [37].

Though 5G is being heavily researched, it is still being tested for its feasibility. A crowd of telecommunications equipment providers are supporting the efforts. Qualcomm and Intel are leading the way with 5G modems, while Ericsson and Nokia are creating tower and backhaul gear that will be used in the US China's ZTE. Meanwhile, Huawei will play a larger role in 5G networks deployed across Asia and Europe. Gadget makers are preparing their devices for 5G, as well. For example, LG hopes to launch the first 5G-enabled phone in early 2020, while Motorola has developed a 5G modem that can be attached to its modular Moto Z3 smartphone [38].

Huawei has deployed 70,000 5G base stations around the world for operators including Chinese carriers as well as LG Uplus in South Korea and British Telecom. Despite only naming 5G deployments with a few operators, Huawei says it has signed 40 commercial contracts for 5G with leading global carriers [39].

Analysys Mason ranked ten countries with developed wireless markets across key factors to compare current 5G readiness efforts. Countries were assessed based on spectrum and infrastructure policies, industry investment, and overall government support. The top 10 countries are shown in Figure 5.

According to Analysys Mason, the reason Canada ranked in the lower tier was because wireless providers have not shown a commitment, to date, at 5G deployment and policymakers have not made progress in developing a 5G strategy or identifying the spectrum bands necessary for 5G services - unlike other countries [40].

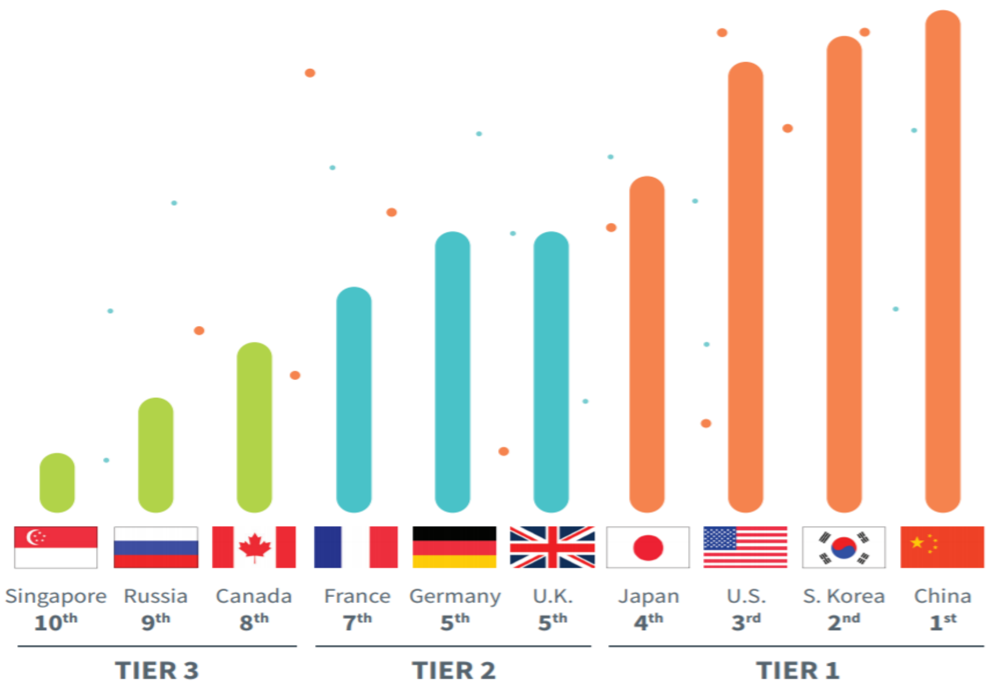


Figure 5: 5G readiness country comparison[40]

3.4 List of projects currently using 5G technology

3.4.1 Pilot Projects around the world

3.4.1.1 - Connected Vehicle to Everything of Tomorrow (ConVeX) [41]

To assist in demonstrating the viability of C-V2X, field trials in Germany started in 2017 under the ConVeX consortium. The ConVeX consortium members are comprised of Audi, Ericsson, Qualcomm Technologies, SWARCO Traffic Systems and the University of Kaiserslautern. The field trials hope to demonstrate the benefits of using C-V2X platform as well as demonstrate range, reliability, and latency advantages for real-time V2X communications using 4G/5G LTE-based V2N technology.

3.4.1.2 - Towards 5G [42]

The Towards 5G initiative aims to demonstrate how C-V2X technology can support safety and other advanced connected vehicle applications. The initiative members are comprised of Ericsson, Orange, PSA Group, and Qualcomm. The initial phase of Towards 5G developed and tested an experimental network in France to demonstrate C-V2X capabilities in real environments using two cases:

1. "See Through" between two connected vehicles on a road.

2. "Emergency vehicle approaching" which notifies drivers when an emergency vehicle is nearby in real-time.

The next steps of the Towards 5G initiative will focus on:

1. Implementing a dedicated network slice to prioritize intelligent transportation system (ITS) vehicular traffic and show improved isolation while experiencing other mobile broadband traffic in the vehicle.

2. Using direct communication features of C-V2X to V2V, V2I and V2P capabilities, while assessing the enhanced performance brought by C-V2X Release 14 with regards to direct communication range, latency and reliability.

3. The "Towards 5G" initiative members will help to develop new use cases to assess how C-V2X with 5G NR features will be designed to support advanced applications, including traffic flow optimization, improved safety and automated driving.

3.4.1.3 - UK Connected Intelligent Transport Environment (UK CITE) [43][44]

UK CITE was created for testing connected and autonomous vehicles in which combinations of V2X technologies (LTE, ITS-G5, WIFI, and LTE-V) are tested on over 40 miles of various types of roads. UK CITE is a 30-month project and is jointly led by Visteon Engineering Services Limited and Jaguar and includes Coventry City Council, Coventry University, Highways England company Ltd, HORIBA MIRA, Huawei Technologies (UK) Ltd, Siemens, VodaFone Group Services Ltd, and WMG at University of Warwick. This project will examine how V2X technologies can improve journeys, reduce congestion, and provide entertainment and safety services. Initially, testing was performed on HORIBA MIRA's City circuit followed by public road travels.

3.4.2 Pilot Projects in Canada

3.4.2.1 – ENCQOR Project [45]

ENCQOR is a transformational $400 million partnership that brings together five global digital technology leaders -Ericsson, Ciena Canada Inc., Thales Canada Inc., IBM Canada, and CGI - and provincial coordinators – Prompt, CEFRIO, Innovation ENCQOR, and Ontario Centres of Excellence (OCE). This partnership is made possible in part by funding from the Canadian government and the provincial governments of Québec and Ontario.

ENCQOR establishes the first Canadian pre-commercial corridor of 5G digital infrastructure. ENCQOR's five-year plan and focus is on providing access to 5G networks to SMEs[7], researchers, and academia means it is purpose-built not just for realizing the technological promise of 5G in the near term, but for driving long-term economic growth in Québec and Ontario and in the broader Canadian innovation ecosystem

3.4.2.2 – Rogers/University of British Columbia (UBC) Campus Project [46] [47]

Rogers announced a multi-year network plan that includes densifying its network with small cells and macro sites across the country and working on 5G trials with Ericsson in Toronto and Ottawa. Furthermore, Rogers arranged a contract with the University of British Columbia (UBC) in Vancouver to build a 5G hub on the campus that will serve as a test bed and blueprint for 5G in Canada. In the three-year, multimillion-dollar deal, Rogers will deploy 5G-ready network equipment and infrastructure at UBC starting in early 2020.

---

[7] SME is defined as a legally independent company with no more than 500 employees.

3.4.2.3 – TechCity 5G Living Lab [47]

TELUS[8] in collaboration with Huawei[9] declared that they have effectively deployed a pioneering small-cell solution to deliver ultra-fast speeds exceeding 1 Gbps in both indoor and outdoor networks in downtown-Vancouver. This effort comes as an initiative to test and deploy pioneering innovative technologies, on the path of developing next-generation 5G telecommunications networks.

3.5 Gaps in research

Connected vehicle projects using 5G technology are scarce and while 5G isn't a completely new technology, since it has 4 predecessors (1G/2G/3G & 4G), it is still considered a technology in its early stages of development, which means it hasn't been perfected yet and comes bearing its own set of challenges that need to be addressed.

5G promises to be faster than previous generations and while there is no doubt it will be, there is still speculation around the exact speed and reduction in latency it may offer, due to the fact that it has mostly been tested in a controlled environment and not as much in real life applications. Moreover, ongoing research is being conducted to assess the cost of upgrading our infrastructure to 5G and 5G subscriptions. However, since 5G does not exist yet we can only assume that initial subscriptions will be costlier than those being currently used. The introduction of 5G will also require major capital costs to be allocated for the inevitable upgrade to infrastructure.

Furthermore, security and privacy are always major concerns when it comes to technology. A group of academics from Purdue University and the University of Iowa discovered multiple vulnerabilities in cellular networks that affect both 4G and 5G protocols. The primary attack, named ToRPEDO (TRacking via Paging mEssage DistributiOn), can be conducted by hackers to locate a target device.

"ToRPEDO" adversaries can use this paging message to track a victim's location and then inject fake paging messages and stop calls and texts from coming in. Furthermore, ToRPEDO allows attackers to obtain a device's international mobile subscriber identity (IMSI) which will allow attackers to snoop

[8] Canada's fastest growing national telecommunications company
[9] one of the world's largest telecommunications and information and communications technology (ICT) provider

on victim’s calls and track its location using IMSI catchers. It also allows hackers to obtain a victim's "soft identities," such as phone numbers or Twitter handles on 4G and 5G networks.[49] [50].

Experts verified ToRPEDO against 3 Canadian service providers and all the major US service providers. This shows the need to bridge this huge gap in the technology and make it more secure before allowing consumers to use it[51].

4. Conclusion

According to the World Health Organization, in 2013 there had been 1.25 million road traffic deaths across the globe. [52] While seat belts and airbags have helped reduce the death toll caused by car accidents, much more can be done. Approximately 94 percent of fatal crashes in the US are attributable, or caused by, human error [53]. Connected vehicle technology is becoming more advanced and far more common in the hopes of decreasing car accidents and increasing safety on our roads. There are currently two competing connected vehicle technologies on the rise, hoping to make cars and roads safer.

On one hand, Dedicated Short Range Communications (DSRC) technology supports interoperability and is currently the only low-latency technology available for commercial use in connected vehicles. It offers an extended situational awareness and 360-degree detection angle beyond sensors, cameras, radars and lidars. On the other hand, 5G technology offers ultra-fast and low-latency networks with the flexibility to meet users' needs across all sectors— especially in the formation of smart cities and smart mobility applications.

After conducting this report, the conclusion is that these technologies are competing to increase road safety. Therefore, whether we use DSRC, 5G, or find a way for both to work simultaneously, all three scenarios are a win for the people. That being said, 5G is most likely to become more widely adopted due to its wide range of applications – both in connected vehicles and in other aspects of smart city development. However, DSRC is currently being deployed, and is an accessible technology, so before investing, a clear decision should be made on which technology would be used to allocate the resources properly to achieve long term success and increase the level of safety on our roads.

References

[1] “5G for a Better Planet | Keysight Blogs.” [Online]. Available: https://blogs.keysight.com/blogs/inds.entry.html/2019/04/18/5g_for_a_better_plan-bzcK.html. [Accessed: 10-May-2019].
[2] “Wayback Machine,” 19-Nov-2012. [Online]. Available: https://web.archive.org/web/20121119140100/http://www.leearmstrong.com/Dsrc/DSRCHomeset.htm. [Accessed: 08-Apr-2019].
[3] “DSRC Technology | 802.11p standard | ITS-G5 and ETSI ITS-G5, IEEE802.11p,” *Autotalks*. .
[4] “Intelligent Transportation Systems - Image Gallery.” [Online]. Available: https://www.its.dot.gov/communications/image_gallery/image38.htm. [Accessed: 10-May-2019].
[5] [Online]. Available: http://www.cas.mcmaster.ca/~rzheng/course/CAS765fa13/WSN_WVN.pdf. [Accessed: 20-Jun-2019].
[6] “IEEE 802.11p,” *Wikipedia*. 22-Mar-2019.
[7] eInfochips, “VEHICLE TO VEHICLE COMMUNICATION FOR CRASH AVOIDANCE SYSTEMS.” [Online]. Available: http://sandhill.com/wp-content/files_mf/whitepapervehicle_to_vehicle_communicationeinfochips.pdf. [Accessed: 09-Sep-2019].
[8] Y. L. Morgan, “Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics,” *IEEE Commun. Surv. Tutor.*, vol. 12, no. 4, pp. 504–518, 2010.
[9] S. E. Shladover and S.-K. Tan, “Analysis of Vehicle Positioning Accuracy Requirements for Communication-Based Cooperative Collision Warning,” *J. Intell. Transp. Syst.*, vol. 10, no. 3, pp. 131–140, Sep. 2006.
[10] “Federal Motor Vehicle Safety Standards No.150; V2V Communications (Final Standards),” *SciPol.org*, 24-Jan-2019. [Online]. Available: https://scipol.org/track/federal-motor-vehicle-safety-standards-no150-v2v-communications-final-standards/federal-motor. [Accessed: 27-Apr-2019].
[11] “What is dedicated short-range communication (DSRC)? - Definition from WhatIs.com.” [Online]. Available: https://whatis.techtarget.com/definition/dedicated-short-range-communication-DSRC. [Accessed: 28-Apr-2019].
[12] jean.yoder.ctr@dot.gov, “Vehicle-to-Vehicle Communication,” *NHTSA*, 26-Oct-2016. [Online]. Available: https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication. [Accessed: 08-Apr-2019].
[13] “DSRCReportCongress_FINAL_23NOV2015.pdf.” .
[14] “Hands-On Training Center Opened, Dedicated to Highway First Responders —.”
[15] “Panasonic Collaborates with CDOT to Pilot Vehicle Communication Protocols on I-70.” [Online]. Available: http://www.futurecar.com/606/Panasonic-Collaborates-with-CDOT-to-Pilot-Vehicle-Communication-Protocols-on-I-70.html. [Accessed: 28-Apr-2019].
[16] “California Connected Vehicle Testbed - About.” [Online]. Available: http://caconnectedvehicletestbed.org/index.php/about.php. [Accessed: 28-Apr-2019].
[17] “Intelligent Transportation Systems - Connected Vehicle Pilot Deployment Program.” [Online]. Available: https://www.its.dot.gov/pilots/pilots_nycdot.htm. [Accessed: 28-Apr-2019].

[18] "Connected Vehicle technology is coming to the streets of New York City!. | NYC Connected Vehicle Project." [Online]. Available: https://cvp.nyc/. [Accessed: 20-Jun-2019].

[19] T. Canada, "Testing Highly Automated Vehicles in Canada," 27-Jun-2018. [Online]. Available: https://www.tc.gc.ca/en/services/road/safety-standards-vehicles-tires-child-car-seats/testing-highly-automated-vehicles-canada.html. [Accessed: 28-Apr-2019].

[20] T. Canada, "Program to Advance Connectivity and Automation in the Transportation System," 05-Jan-2018. [Online]. Available: http://www.tc.gc.ca/en/programs-policies/programs/program-advance-connectivity-automation-transporation-system.html. [Accessed: 28-Apr-2019].

[21] "ACTIVE-AURORA Connected Vehicle Testbed Network - Stantec." [Online]. Available: http://www.stantec.com/en/projects/canada-projects/a/active-aurora-cv-testbed-network.html. [Accessed: 10-May-2019].

[22] "DSRC and U-NII-4 Prototype Device Testing," *Federal Communications Commission*, 07-Oct-2016. [Online]. Available: https://www.fcc.gov/oet/unii-4banddevice. [Accessed: 20-Jun-2019].

[23] "1G, 2G,…& 5G: The evolution of the G's | MS&E 238 Blog." [Online]. Available: https://mse238blog.stanford.edu/2017/07/ssound/1g-2g-5g-the-evolution-of-the-gs/. [Accessed: 08-May-2019].

[24] "List of mobile phone generations," *Wikipedia*. 14-Mar-2019.

[25] "How 5G makes use of millimeter waves," *Engadget*. [Online]. Available: https://www.engadget.com/2018/07/23/how-5g-makes-use-of-millimeter-waves/. [Accessed: 09-May-2019].

[26] "Small cell," *Wikipedia*. 06-May-2019.

[27] "Guide to Small Cells, HetNets and 5G." [Online]. Available: https://5g.co.uk/guides/small-cells-hetnets-5g/. [Accessed: 09-May-2019].

[28] "ZTE, SoftBank achieve 956 Mbps in Massive MIMO test," *FierceWireless*. [Online]. Available: https://www.fiercewireless.com/wireless/zte-softbank-achieve-956-mbps-massive-mimo-test. [Accessed: 08-May-2019].

[29] "5G Investments: Trials, Deployments, Launches - Updated March 2019," *GSA*. [Online]. Available: https://gsacom.com/paper/5g-investments-global-progress-feb19/. [Accessed: 09-May-2019].

[30] "Beamforming," *Wikipedia*. 24-Apr-2019.

[31] M. G. Sarret, G. Berardinelli, N. H. Mahmood, M. Fleischer, P. Mogensen, and H. Heinz, "Analyzing the potential of full duplex in 5G ultra-dense small cell networks," *EURASIP J. Wirel. Commun. Netw.*, vol. 2016, no. 1, p. 284, Dec. 2016.

[32] "World Internet Users Statistics and 2019 World Population Stats." [Online]. Available: https://www.internetworldstats.com/stats.htm. [Accessed: 09-May-2019].

[33] L. Sims, "These Are The Advantages & Challenges Of The 5G Network," *StartUs Magazine*, 08-Jun-2018. [Online]. Available: https://magazine.startus.cc/advantages-and-challenges-of-5g-network/. [Accessed: 09-May-2019].

[34] “5G Is Coming: An Overview Of The Advantages & Challenges.” [Online]. Available: https://teks.co.in/site/blog/5g-is-coming-an-overview-of-the-advantages-challenges/. [Accessed: 09-May-2019].
[35] “5G Is Coming: An Overview of the Advantages and Challenges - DZone Mobile,” *dzone.com*. [Online]. Available: https://dzone.com/articles/5g-is-coming-an-overview-of-the-advantages-amp-cha. [Accessed: 09-May-2019].
[36] I. Brannon, “The Folly of Having The U.S. Government Build A 5G Network,” *Forbes*. [Online]. Available: https://www.forbes.com/sites/ikebrannon/2019/03/18/the-folly-of-having-the-u-s-government-build-a-5g-network/. [Accessed: 09-May-2019].
[37] [Online]. Available: https://api.ctia.org/docs/default-source/default-document-library/deloitte_2017011987f8479664c467a6bc70ff0000ed09a9.pdf. [Accessed: 09-May-2019].
[38] “What is 5G? A Guide to the Transformative Wireless Tech That’s Being Hyped to Change Everything,” *Fortune*. [Online]. Available: http://fortune.com/2018/10/08/what-is-5g/. [Accessed: 09-May-2019].
[39] “Huawei takes its crisis PR roadshow to the Big 5G Event | FierceWireless.” [Online]. Available: https://www.fiercewireless.com/wireless/huawei-takes-its-crisis-pr-road-show-to-big-5g-event. [Accessed: 09-May-2019].
[40] “The Race to 5G is On.” [Online]. Available: https://www.ctia.org/the-wireless-industry/the-race-to-5g#section-4. [Accessed: 09-May-2019].
[41] “Consortium of Leading Automotive and Telecom Companies Host 3GPP Release 14 Cellular-V2X Technology Field Trial in Germany,” *Qualcomm*, 03-Jan-2017. [Online]. Available: https://www.qualcomm.com/news/releases/2017/01/03/consortium-leading-automotive-and-telecom-companies-host-3gpp-release-14. [Accessed: 10-May-2019].
[42] “Towards 5G Initiative welcomes Qualcomm, shows Fast results,” *Ericsson.com*, 24-Feb-2017. [Online]. Available: https://www.ericsson.com/en/news/2017/2/towards-5g-initiative-welcomes-qualcomm-shows-fast-results. [Accessed: 09-May-2019].
[43] “UK CITE – UK Connected Intelligent Transport Environment.” [Online]. Available: https://ukcite.co.uk/. [Accessed: 09-May-2019].
[44] [Online]. Available: http://connectedautomateddriving.eu/wp-content/uploads/2017/03/4_Day2_BO07_Banks.pdf. [Accessed: 10-May-2019].
[45] “5G Technology,” *ENCQOR*. .
[46] “Rogers and Ericsson partner to bring 5G to Canadians,” *About Rogers*, 16-Apr-2018. [Online]. Available: https://about.rogers.com/2018/04/16/rogers-ericsson-partner-bring-5g-canadians/. [Accessed: 09-May-2019].
[47] “Canada’s Rogers hooks up with UBC on 5G test bed,” *FierceWireless*. [Online]. Available: https://www.fiercewireless.com/wireless/canada-s-rogers-hooks-up-ubc-5g-testbed. [Accessed: 09-May-2019].
[48] Huawei, “Huawei and TELUS to create 5G ‘Living Lab’ in Downtown Vancouver.” [Online]. Available: https://www.newswire.ca/news-releases/huawei-and-telus-to-create-5g-living-lab-in-downtown-vancouver-541762271.html. [Accessed: 10-May-2019].

[49] "ToRPEDO attack allows intercepting calls and track locations on 4G/5G," *Security Affairs*, 26-Feb-2019. [Online]. Available: https://securityaffairs.co/wordpress/81648/hacking/torpedo-attacks-4g-5g.html. [Accessed: 10-May-2019].

[50] "Privacy Attacks to the 4G and 5G Cellular Paging Protocols Using Side Channel Information – NDSS Symposium." .

[51] [Online]. Available: https://www.ndss-symposium.org/wp-content/uploads/2019/02/ndss2019_05B-5_Hussain_paper.pdf. [Accessed: 10-May-2019].

[52] "WHO | Number of road traffic deaths," *WHO*. [Online]. Available: http://www.who.int/gho/road_safety/mortality/traffic_deaths_number/en/. [Accessed: 11-Sep-2019].

[53] T. Maddox, "How autonomous vehicles could save over 350K lives in the US and millions worldwide," *ZDNet*. [Online]. Available: https://www.zdnet.com/article/how-autonomous-vehicles-could-save-over-350k-lives-in-the-us-and-millions-worldwide/. [Accessed: 11-Sep-2019].

Acknowledgment

Ontario Society of Professional Engineers (OSPE)

OSPE is the voice of the engineering profession in Ontario. They represent the entire engineering community, including professional engineers, engineering graduates and students who work or will work in several of the most strategic sectors of Ontario's economy. OSPE elevates the profile of the profession by advocating with governments, offering valued member services and providing opportunities for ongoing learning, networking and community building.

Ryerson University Laboratory of Innovation in Transportation (LiTrans)

This lab is working towards creating a cyber-physical future of urban mobility using intelligent technologies & mathematics.

Canadian Urban Transit Research & Innovation Consortium (CUTRIC)

CUTRIC supports projects that develop the next generation of mobility and transportation technologies for Canadians. These advancements help grow the low-carbon and "smart" technology eco-system in the country, leading to job growth and economic development over the long-term.