ICTC CTIC

5G: JUMPSTARTING our DIGITAL FUTURE

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Preface:

ICTC is a national centre of expertise for the digital economy. With over 25 years of experience in research and program development related to technology, ICTC has the vision of strengthening Canada's digital advantage in the global economy. Through forward-looking research, evidence-based policy advice, and creative capacity building programs, ICTC fosters innovative and globally competitive Canadian industries, empowered by a talented and diverse workforce.

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Glossary of 5G Terms

3GPP: A standards development body uniting seven major telecommunication standards organizations. In December, 2017 the 3GPP announced the approval of the first 5G New Radio (NR) specification.

Backhaul: The infrastructure connecting mobile cell antennas to the main wired network. It can be wired or wireless technology like microwave and satellite.

HSPA(+): High Speed Packet Access is a collection of technologies that allowed 3G networks to get broadband-like speed. HSPA+ applies to 4G.

Inflation-Adjusted Dollars: Dollars that have been adjusted according to the consumer price index to be represented in the value of a particular year. This report often uses chained (2007) dollars. This allows us to see the "real" GDP impact independent of inflation.

LTE: Long Term Evolution is a high-speed wireless communication standard that improved upon the HSPA technologies. LTE was originally designed for 4G networks.

Matlab/Simulink: An engineering-focused matrix computational software package that, when paired with Simulink (simulation tool from the makers of Matlab), enables complex network/circuit simulation models that will help with the design of 5G infrastructure

Microwave: In terms of mobile networks, microwave is used as a high-speed point-to-point transmission technology. Due to line of sight requirements between the microwave transmitter and receiver, it will primarily be used in 5G networks to provide backhaul from cell antenna arrays.

mmWave: Millimeter wave is the spectrum band between 30GHz and 300GHz. It is going to be used for high speed network connectivity between cell antennas and mobile devices like phones, IOT devices and automated vehicles. It does not have much range (100-200 metres) requiring more densely placed antennas, especially in urban areas.

MIMO: Multiple-In-Multiple-Out is the concentration of many antennas in both the transmitter and receiver. Massive MIMO is the 5G iteration of MIMO, requiring many more antenna is each array, enabling the network to support many users with high-speed connectivity while using the same network resources, at the same time, without requiring addition radio spectrum.

NFV: Network Function Virtualization: Allows network functions to be decoupled from proprietary hardware and moved to software. This will enable lower capital costs, operational efficiencies, and rapid/agile upgrades through software deployment.

New Radio: A new air interface specification to support 5G ability to connect all the devices expected to be leveraging the 5G network ecosystem.

Regression: A statistical measure used to determine the relationship between two variables. At a minimum it can determine a correlation, and it best it can determine a causal relationship (changes in one variable directly cause changes in another).

RF: Radio Frequency is a general label for many aspects of radio frequency architectures. RF appeared in several job postings as a knowledge/experience requirement.

SDN: Software Domain Networking is another network abstraction like NFV but it is more focused on separating network control functions from forwarding functions.

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Foreword

It is my pleasure to contribute to the Information and Communications Technology Council's report, *5G: Jumpstarting Our Digital Future*. The report itself is timely. As early as next year, the introduction of 5G equipment to Canada promises to transform our telecommunications industry as we know it.

The convergence of fixed wireless and mobile technology, illustrated through the introduction of the 5G trials already underway in Canada, has permanently blurred the lines separating fixed and mobile broadband. The result of this convergence is one concept: wireless broadband – something that will enable Canadians' 5G connectivity in the years ahead.

As the introduction of 5G and the Internet of Things makes access to the Internet even more pervasive, the means by which it is delivered will become increasingly irrelevant to consumers. What will become more and more important is the availability of wireless broadband (from either mobile or fixed connections), all at dramatically increased capacity and speeds for Canadian consumers.

At Xplornet, our business was founded almost 15 years ago, with a simple mission: to make fast, affordable, high-speed Internet available to rural communities. Our focus is on places outside of the city centres, touching rural towns in every province and territory.

Canada is the world's second largest land mass, and one of the least densely populated countries in the world. With fewer than 4 Canadians per square kilometre, this means that our connectivity needs are different from many nations around the world. In rural Canada, this density is even less prevalent, making how you connect to the Internet different. At Xplornet we believe strongly that the introduction of 5G services can not be solely the domain of Canadians living in cities: rather, there is an opportunity to enable this technology wherever you choose to live in Canada.

Ten years ago, what mattered to most Canadians was simply access to an internet connection. For rural Canada, this looked very different, and connectivity was defined as a need to cover 100% of Canadians. In 2011, the connectivity concerns of many rural Canadians were similar to those in the city – focusing on topics like the ability to stream video from a new application called Netflix, which had just arrived in Canada.

Today, over 99% of Canadians have access to an Internet connection, and Canada is ranked fourth in the G20 for per capita for broadband connections that exceed 15 megabits per second. In the months ahead, the task for Canada and its telecommunications industry must be to refocus on the definition of connectivity held by rural communities 10 years ago: the need to ensure that all Canadians enjoy the same level of services, regardless of where they may choose to live.

At Xplornet, innovation has always been at the heart of our mission. We were the first company in North America and the second in the world to test LTE using 3500 MHz TDD spectrum and to push for improvements in the speed and quality of wireless broadband.

Building on this culture of innovation, Xplornet has recently focused relentlessly on field trials in rural communities using pre-5G and 5G-ready technology. To do this, we have embarked on an ambitious program to deploy fibre, wireless small cells, and licensed spectrum in the recognized 5G bands to meet a key objective: to establish a national 5G-ready network that can dramatically increase download speeds and capacity in rural Canada.

Much has been said about 5G, it's capabilities, and what it can enable. Some of these are incredibly exciting applications for cities, ranging from "smart" street lights to self-driving cars – and applications don't stop here. With low latency and high reliability, 5G networks can even return us to better times - enabling doctors to make digital house calls. In rural communities with more limited access to healthcare, some patients currently find themselves traveling long distances for care. Having access to a doctor using 5G-enabled high resolution imaging and diagnostic equipment would not only save time and money; it would save lives.

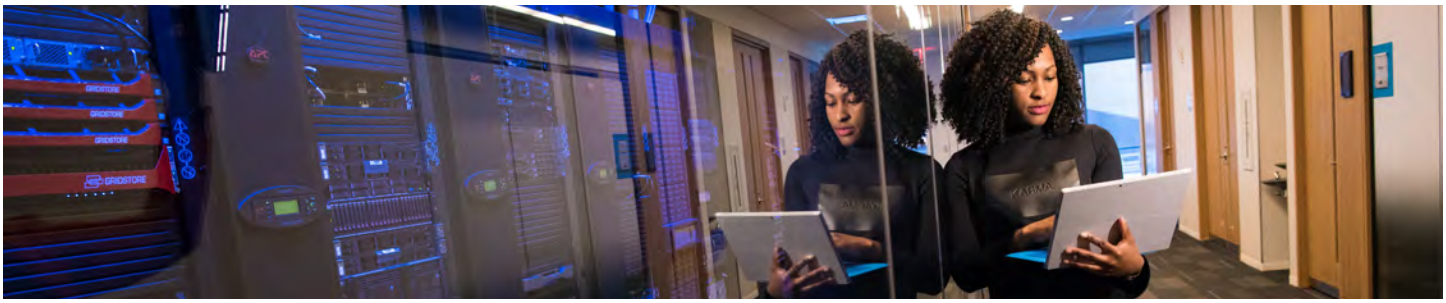
5G is not just about our cities and making them better connected or more efficient – it is about all the unique services and developments that it can enable wherever you are in Canada, at home, at work, and at play.

The applications of 5G will undoubtedly be different in rural areas but the need for robust 5G networks is the same as it is in urban centres. Regardless of where the customers are and regardless of the applications they choose to run, there will be a need for networks that can act as the backbone carrying our ever-growing IP traffic and data.

5G networks are coming to Canada quicker than many realize, and the opportunities that they can bring with them for all Canadians is unbounded. Thank you to the ICTC for its role in contributing to this exciting time for our industry.

— James Maunder, VP of Public Affairs and Communications at Xplornet

Executive Summary



5G – or 5th generation – technology is often described as the next generation of connectivity and Internet. However, 5G is much more than just that. With estimated data transmission speeds that are nearly 20 times faster than current 4G-LTE connections, 5G will allow the avid Netflixer to download a movie within a matter of seconds. However, it will also enable the development of technologies and applications that can change the provision of basic services like healthcare, and with a true capacity for Internet of Things (IoT) connectivity, it can even revamp our cities and communities altogether. This study is a deep dive into a technological revolution that is bound to play a significant role in Canada's economy over the coming decade.

While some impacts of 5G will reveal themselves more clearly once its enhanced network capabilities are fully in place, 5G is quickly becoming the new global standard of connectivity. As a result, some of its by-products are already being felt, even prior to deployment. These include an accelerated demand for skilled talent, but also the advancement of discourse on key topics that 5G's capabilities will touch and enable. Examples include the use of AR/VR for real-time healthcare solutions such as remote surgeries; or the deployment of 5G-enabled crop monitoring in the agricultural sector – something that can play a tremendous role for a sector that is extremely susceptible to even the slightest environmental shifts. 5G can even allow for the safe deployment of autonomous vehicles which will need to quickly and effectively communicate with its surroundings, and will even shape the development of solutions like a "digital twin" to help manage logistics and improve efficiencies in the manufacturing sector, in trade and many others. These are but a few of many examples of 5G-led applications that can ultimately enable a connected society that is truly run on the Internet of Things (IoT).

With this kind of potential, it is no surprise that new 5G-related jobs are already being created today in Canada, despite rollout timelines in the early 2020s. Still in the developmental phase, many of these currently revolve around research, software development and network testing. However, as we advance on this trajectory, the impact of 5G on total employment will be substantial, spreading across a variety of job types and sectors. In addition to enabling the development of technological revolutions like autonomous vehicles, 5G will bring forth employment opportunities in regulation, in infrastructure, in testing, in implementation and in accessibility, among many other verticals.

The spillovers of this next generation of connectivity will inevitably impact not only Canadians at large, but will also be a significant contributing force to Canadian gross domestic product

(GDP)[1]. This is so much so that under current economic scenarios, ICTC estimates **the impact of 5G on the Canadian economy to be around $14 billion[2], with a growth of 46,000 jobs by 2030 if spectrum auctions[3] take place in 2021.** Alternatively, if auctions (600MHz, 3.5MHz and mmWave) are **deployed *just two years earlier* in 2019, 5G's economic impact is estimated to be $23 billion by 2030, with the creation of around 73,000 jobs.** These are substantial economic gains for our country that must be supported. Moreover, should economic conditions change and allow for key advancements like foreign direct investment towards high-growth sectors, accelerated international trade and others, 5G's total economic impact may reach upwards of **$26 billion and create 82,000 jobs by 2030 if auctions take place in 2021.**

With ultra-fast speeds, high bandwidth and capacity of mass data transmission, the vast and encompassing potential of 5G is clear. It can create jobs, grow the economy and enable the development of technological revolutions that were previously only imaginable. For these reasons, there are no shortage of headlines underlining the splash that 5G is anticipated to make not just in Canada, but around the world. With the potential to jumpstart economic and job growth, 5G is poised to be one of Canada's key driving factors, adding lane after lane on the information highway of our digital future.

1 This report measures GDP using the Income Approach to GDP. This is defined as the sum of employee wages, corporate profits, proprietor's income, rental income, net interest, and net government sales tax income. Thus, the income from the additional GDP will be distributed across these many domains, including labour.

2 2007 inflation-adjusted Canadian dollars.

3 600MHz, 3.5GHz and mmWave.

Introduction

With digital technology quickly spreading across all sectors, many new innovations rely on the transfer of bits and bytes from one place to another. One example of this is cloud computing, something that is increasingly becoming the norm for data storage and transfer. Here even the most basic analysis of data requires constant uploading and downloading. This is just one instance of our progression towards a true Internet of Things (IoT) society. Under this information economy, improvements in Internet performance and data transmission have an effect similar to reductions in fuel costs to an industrial economy: that is, they are improvements that can greatly impact productivity, efficiency, and at the end of the day, revenue growth. 5G, one of the most anticipated telecom developments of recent years, is the next generation of not just mobile Internet, but of connectivity as a whole. It will not only greatly enhance our ability to transmit, store and analyse data, but ultimately, it's strength and potential rests in its ability to enable a range of new technologies that can change our lives. From autonomous vehicles, to remote surgeries, 5G has an immense potential to truly shape a connected future.

This paper will analyse and forecast the implications of this technological improvement on the Canadian economy. Section I will discuss the technologies underlying this next generation network of connectivity and the timelines of rollout; Section II will provide key examples of 5G's ability to enable a digital future, with viable use-cases across three sectors; Section III will investigate the specific labour and skill needs of this technology; and Section IV will present forecasts of 5G's impact on the Canadian economy and labour market. Specifically, these forecasts will estimate the impact of 5G on Canada's gross domestic product and total employment by 2020 according to two rollout timelines.

Section I: 5G Overview- What is it and Why is it Important?

In many ways, the term "5G telecommunications technology" is a misnomer. In truth, 5G is no single technology; rather, it is the wave of next generation technologies jointly developed by companies, academics, governments, and other stakeholders to deliver the latest leap in internet performance[4]. The specifications underlying 5G are still in the process of being developed, negotiated and released; however, global partners have been collaborating to set basic standards defining these technologies. Recently, the 3rd Generation Partnership

4 Margaret Rouse, Wireless Technologies: 5G (Tech Target: 2017), https://searchnetworking.techtarget.com/definition/5G.

Project (3GPP), a global collaborative on this subject[5] issued Release 15 (June 2018) that defined the system architecture and the set of features and functionality needed for deploying a commercially operational 5G system[6]. Following this, Release 16 (anticipated December 2019) will define specifications related to vehicle-to-everything (V2X) connectivity, satellite access, network slicing, IoT and other important topics[7] that are key to highlighting 5G's full potential. This broad consensus on what 5G will resemble and enable, and which key technologies will guide it is a crucial step on the journey.

What Changes Will 5G Bring?

At the base functionality level, 5G will enable substantial increases in bandwidth (the amount of data transmitted per second) and significantly reduce latency (the time delay in the delivery of data)[8] for commercial and consumer uses. While the International Telecommunications Union (ITU) specification calls for theoretical maximum speeds of 20 Gbps[9], actual speeds will depend on factors including geography, network congestion, and the level of implementation of next-generation infrastructure. The expectation in the engineering literature is 1 Gbps for mobile users and 10 Gbps for stationary users. This is a substantial improvement over current speeds – for example, in Q2 2017 the mean fixed broadband speed was 59.67 Mbps in Canada[10]. Meanwhile, latency is anticipated to fall to 1 millisecond – current latency ranges from 10-700 ms depending on server location, type of connection, and network congestion.[11] This is a particularly relevant consideration for highly-anticipated developments like autonomous vehicles or remote surgeries that depend on low latency. Lastly, 5G promises a variety of other improvements including mobile functionality at 500 km/hour, terminal localization within 1 meter, and high connection density (1 million devices per square kilometer).

These and other developments require 5G to transition toward underutilized, higher frequency spectra above at least 3.0 Ghz. Millimeter wave spectrum is generally considered to be between 6 GHz and 100 GHz[12], and current 5G trials are also conducted within this range. The exact range of spectra to be used by 5G will depend on availability, the timing of auctions, and the technology and business models of implementing telecommunications firms. Fundamentally, higher frequency ranges are capable of transmitting greater quantities of data, but can be constrained by shorter ranges and vulnerability to physical obstruction.

5 "About 3GPP" 3GPP: A Global Initiative, http://www.3gpp.org/about-3gpp/about-3gpp, (2018)

6 "Release 16" 3GPP: A Global Initiative, http://www.3gpp.org/release-15 (July 16, 2018).

7 Idem.

8 Brian Santano, 5G: The Road to Low Latency (EDN Network: February 23, 2018), https://www.edn.com/electronics-blogs/5g-waves/4460346/5G--The-road-to-low-latency.

9 Anthony Spadafora, ITU drafts 5G specs: 20Gbps downloads, 4ms latency per cell, (BetaNews: 2016), https://betanews.com/2017/02/28/5g-standard-specs/.

10 "Reports: Canada" Speedtest, http://www.speedtest.net/reports/canada/#fixed (September 19, 2018).

11 Imtiaz Parvez, Ali Rahmati, Ismail Guvenc, Arif Sarwat, Huaiyu Dai, A Survey on Low Latency Towards 5G: RAN, Core Network and Caching Solutions (arXiv: May 29, 2018) https://arxiv.org/pdf/1708.02562.pdf.

12 Lindsay Notwell, 5G – A Few Frequency Facts (CIO: September 21, 2017), https://www.cio.com/article/3226451/networking/5g-a-few-frequency-facts.html.

These inner workings of 5G necessitate the deployment of key technological changes to connectivity that will ultimately enable an IoT future.

Technologies of 5G

Small Cells

Small cells are one technological shift deeply linked to 5G. As opposed to the current telecommunications infrastructure involving few large or macro cells transmitting low frequency waves over long distances, 5G's small cells will be densely distributed within cities to transmit high frequency waves over short distances. Femtocells, picocells and microcells are generally considered to be subcategories of small cells, and ranges for these are typically between a few hundred meters to two kilometers[13]. Comparatively, currently used macro-cells have ranges of around 20 kilometers[14]. Operator-controlled and low-powered, small cells are anticipated to improve network capacity, density, and signal coverage, particularly indoors where most data traffic occurs.

Multiple Input Multiple Output (mMIMO) and Beamforming

Small cells will be outfitted with massive Multiple Input Multiple Output (mMIMO) antennas and beamforming signal processing software. mMIMO enables multiple data signals to be transmitted simultaneously over the same radio channel. This is particularly important for 5G rollout, as it can address potential spectrum scarcity concerns. While conventional MIMO uses 2-4 antennas, massive MIMO may use hundreds of antennas in the transmitter/receiver within a piece of hardware[15]. This is an important consideration, given that a key component of 5G research is understanding how to essentially "squeeze" more antennas into smartphones and base stations (or small cells). Meanwhile, beamforming is a signal processing technique which identifies the most efficient physical data-delivery route to a particular mobile user, while reducing interference with other users and obstructions. Beamforming then sends data directly to the receiver, which increases the probability of successful transmission, and reduces interference and energy consumption.

Network Slicing

While high bandwidth and low latency are both universally desirable, certain applications require one primarily over the other. For instance, autonomous vehicles require instantaneous communication with everything around them, including other vehicles. In this case, it is easy to imagine how even milliseconds of additional latency can affect the probability of collision. On the other hand, high definition video streaming requires high bandwidth primarily, while latency is mostly irrelevant. Network Slicing enables the layering of multiple virtual networks atop common shared physical infrastructure[16]. These virtual network partitions can be customized for the needs of the user and across functions such as bandwidth, latency, security, connectivity, capacity, and coverage. This enables users to select precisely the characteristics of the network they need, a process that ultimately improves

13 "Femtocells, Microcells, and Metrocells: The Complete Guide to Smart Cells" RepeaterStore, https://www.repeaterstore.com/pages/femtocell-and-microcell (July 16, 2018).

14 Phillip Tracy, Small cells: Backhaul difficulties and a 5G future (RCR Wireless News: July 11, 2016), https://www.rcrwireless.com/20160711/network-infrastructure/small-cells-tag31-tag99.

15 Jon Mundy, What is Massive MIMO Technology (5G.co.uk: 2017), https://5g.co.uk/guides/what-is-massive-mimo-technology/.

16 Mohammad Asif Habibi, Bin Han, Hans D. Schotten, Network Slicing in 5G Mobile Communication: Architecture, Profit Modeling, and Challenges (arXiv: July 4, 2017), https://arxiv.org/pdf/1707.00852.pdf.

efficiency.

Edge Computing

Edge computing is a trend emphasizing the decentralization of computing power towards "the edge" of the network (closer to the sources of data). This is done in place of cloud computing which centralizes computation. By moving processing power closer to the data source, latency and network congestion are significantly reduced[17] – an influencing factor in quality of coverage. Additionally, edge computing is also valuable when it is impractical or difficult to send data to the cloud (such as on an offshore drilling rig, or on remote IoT sensors).

Timeline of Rollout

The timeline of substantive 5G penetration will depend on a number of factors. These range from when spectrum auctions will occur, to regulatory frameworks for implementation, to the speed of infrastructure buildout, to the level of buy-in of consumers, among others. However, with annual 5G infrastructure investment reaching hundreds of billions of dollars across the developed world already[18], the potential value and capacity of 5G is globally evident. While some jurisdictions around the world have already begun some rollout of this technology, large scale deployment and penetration of this next generation network is set to really take shape in the early to mid 2020s. The GSM Association, for instance, predicts 5G will "scale rapidly after launch in 2020, with coverage reaching just over a third of the global population in five years"[19]. Similarly, McKinsey & Company predicts that initial rollouts of 5G may involve sub 3.5 Ghz frequencies and look more like enhanced 4G-LTE, while higher frequency (millimeter band) 5G will come later[20]. Understanding the applications of 5G today will ultimately help us make the best use of the technology once rollout takes place.

International 5G Rollout

Some movement on 5G has already taken place in parts of the world. In Korea, the 2018 PyeongChang Olympics was marketed as the first "5G Olympic Games in the world"[21] and a Korean network operator developed its own 5G specification for the games. While 5G compatible handsets were (and are) not yet available,

Bloomberg

Technology

5G Is Making Its Global Debut at Olympics, and It's Wicked Fast

By Sam Kim and Sohee Kim

February 12, 2018, 4:00 PM EST *Updated on February 13, 2018, 12:13 AM EST*

- Among the first to experience it will be Korea's wild boars
- 5G technology isn't scheduled to roll out globally till 2020

17 *"What is Edge Computing?"* GE Digital, https://www.ge.com/digital/blog/what-edge-computing, (2017).

18 *"The Full Impact of 5G on IT Industry Hardware Spending"* Moor Insights & Strategy, http://www.moorinsightsstrategy.com/research-paper-the-full-impact-of-5g-on-it-industry-hardware-spending/ (February 22, 2018).

19 Emeka Obiodu, Mark Giles, The 5G era: Age of boundless connectivity and intelligent automation (GSMA: 2018), https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download.

20 Mark Collins, Arnab Das, Alexandre Menard, Dev Patel, Are you ready for 5G? (McKinsey & Company: February 2018), https://www.mckinsey.com/industries/telecommunications/our-insights/are-you-ready-for-5g.

21 "Fans of the Olympic Winter Games 2018 to Experience World's First Broad-scale 5G Network" Olympics, https://www.olympic.org/news/fans-of-the-olympic-winter-games-2018-to-experience-world-s-first-broad-scale-5g-network (February 2018).

spectators were able to use tablets to view 360-degree video of athletes competing at speeds four times faster than 4G.

In the United States, all four major carriers have already announced timelines for their rollout of 5G[22]. While the services being tested and promised may differ in quality, there is a broad movement toward 5G implementation in the US by 2020. China, home of Hauwei, the world's largest telecom-equipment maker[23], has budgeted $800 million in 2018 on research and development for 5G, under the Chinese government's plan to roll out 5G by 2020[24]. With this kind of investment, Huawei is anticipated to be one of the world's most significant leaders in the development of 5G technology. Under accelerated plans for development and deployment of 5G technology around the word, it is crucial that Canada begin taking active steps on this front.

5G Rollout in Canada

In comparison to many international jurisdictions leading the rollout of 5G, Canada is moving at a slower pace. The Canadian government announced the auction for the low-band, 600-megahertz frequency range will take place in March 2019, followed by the first 3.5 Ghz spectrum auction in 2020, and a millimeter range auction in 2021[25]. While companies like Rogers Communications and Bell Canada already own spectrum in the 3.5 Ghz range, some major telecom providers like Telus currently do not. This has prompted calls from the company for high frequency auctions to take place earlier, starting in 2019. While many Canadian telecom providers (such as Telus for example) operate 5G testing facilities in a number of Canadian cities already, including Toronto, Ottawa, and Vancouver, an accelerated timeline of auctions would help Canada remain competitive in the global race for 5G deployment.

Section II: Potential Impact of 5G on Business

If 2G brought us SMS, 3G brought the low-bandwidth mobile internet, 4G brought high definition streaming and high-speed downloading, what will 5G bring consumers and businesses? While there are multitude of use cases that will emerge from 5G ranging from autonomous vehicles to remote surgeries, many experts predict 5G's features will facilitate the true existence of the Internet of Things (IoT)[26]. High connection densities, low latency, and high bandwidth, along with well-developed protocols for Machine to Machine (M2M) data transfer may finally enable Smart Cities and a world where unlimited devices are interconnected. This development also opens the door to the next phase of big data and the

22 Emeka Obiodu, Mark Giles, The 5G era: Age of boundless connectivity and intelligent automation (GSMA: 2018), https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download.

23 "Telecommunications equipment companies ranked by overall revenue in 2017" Statistica, https://www.statista.com/statistics/314657/top-10-telecom-equipment-companies-revenue/ (2018).

24 Dan Strumpf, China Shakes up Telecom Leadership Ahead of 5G Rollout (Wallstreet Journal: July 20, 2018), https://www.wsj.com/articles/china-shakes-up-telecom-leadership-ahead-of-5g-rollout-1532085180.

25 David Paddon, Canada to hold key 5G spectrum auction in 2020, says Innovation Minister Bains (The Canadian Press: June 6, 2018), https://www.cbc.ca/news/business/5g-wireless-spectrum-auction-1.4694214.

26 Kaya Ismail, How 5G Will Unlock The True Potential of IoT Devices, (CMS Wire: April 16, 2018), https://www.cmswire.com/information-management/how-5g-will-unlock-the-true-potential-of-iot-devices/.

associated algorithmic optimization of nearly everything. In industries typically dependent on manual labour and a physical presence – like transportation, oil & gas, manufacturing, or agriculture, for example – automation and the remote monitoring and control of equipment will eventually result in a transition in employment needs. Costs may decline, new business cases may emerge, and populations may migrate toward new employment centers as a result of developments enabled by 5G.

What Kind of Developments Will 5G Enable?

One key technology that will be impacted by 5G is augmented and virtual reality (AR/VR). Ultra-high definition video displayed within virtual reality goggles requires ultra-high bandwidth. This video must be transmitted with very low latency, as delays in updating the visual stream may induce nausea[27]. Additionally, given that this technology is often used while mobile – augmented vehicle windshields or Google Glass type products display augmented reality while the person is on the move – 5G will prove essential for AR/VR to reach its full potential.

The growth of AR/VR also extends far beyond the realm of gaming and visual effects. AR/VR can have applications across sectors, including law enforcement, construction, education, retail, healthcare and others. Equipped with AR/VR technology, a police car's windshield may automatically detect stolen license plates; a construction engineer's glasses may indicate the location of underground gas pipelines; aspiring chefs may practice their craft in a virtual kitchen; and shoppers may view a virtual furniture pieces in their living rooms before purchasing it online. These are just some examples of the potential of technologies like AR/VR when supported by 5G.

Sector Snapshot: Healthcare & AR/VR via 5G

Costs in the healthcare sector have risen significantly faster than wages over the past few decades[28]. As a result, healthcare costs are consuming an increasing share of personal and government income, especially as populations in developed countries like Canada continue to age. For this reason, innovation in the sector is often closely watched and encouraged by policy makers and industry. AR/VR is merely an example of where 5G-enabled technology can prompt substantial change for the healthcare sector.

Robotic surgery has grown in prominence since 2001, when it was first approved by the

27 Mattias Fridstrom, The bandwidth problem: 5G issues the VR industry must resolve (Venture Beat: May 6, 2017), https://venturebeat.com/2017/05/06/the-bandwidth-problem-5-issues-the-vr-industry-must-resolve/.

28 Mark J. Perry, Chart of the day (century?): Price changes 1997 to 2017 (AE Ideas: February 2, 2018), http://www.aei.org/publication/chart-of-the-day-century-price-changes-1997-to-2017/.

USFDA[29]. For example, the da Vinci Surgical System has a camera arm with precision surgical instruments attached, which the surgeon controls while seated at a console about 15 feet away[30]. The camera provides a magnified, HD video of the surgical site, and the instruments can enhance precision, flexibility, and control, while reducing invasiveness. Although this robotics technology is interesting, it becomes more so when combined with the capabilities of 5G. With high-definition video, ultra-reliable service provision, and low latency, there will be little reason why the robotic surgery could not be performed remotely.

While some common criticisms of AR/VR-enabled remote surgeries centre on surgeons not receiving sufficient training on the machines – something that can easily result in poor patient outcomes – the use of 5G in this space can actually enable a new business model for medical care. Rather than training all surgeons in robotic surgery, a select number may conduct the surgeries remotely, while on-site doctors supervise. This division of labour may result in the commodification of medical care and provision, which can increase competition and ultimately reduce costs. Furthermore, the new economics of medical care enabled by 5G may foster an enhanced level of specialization in the field, again driving down costs. Instead of asking all surgeons become experts in a variety of fields and tasks, surgeons from around the world may become experts in a particular kind of treatment or surgery.

5G can also change the nature of emergency services. With low levels of latency, coupled with reliability, the network can play a key role in the future development and use of services like ambulances. Take for example the 5G "super-ambulance"[31]: possessing high-definition video equipment, the ambulance's X-ray scans can be transmitted directly to the emergency room. This kind of data transmission would enable doctors to review and diagnose patients remotely, allowing hospitals and medical staff to treat patients more effectively and efficiently upon arrival.

Like many game-changing technologies, 5G may not merely improve the service of the healthcare sector, but it can shift the economics of the entire industry.

Sector Snapshot: Ag-tech & IoT via 5G

While the Internet of Things is often associated with the idea of Smart Cities, IoT is also highly applicable elsewhere. Oil drilling equipment, advanced manufacturing plants, logistics warehouses, or cargo ships are just as likely to benefit from interconnected devices feeding big data into analytics. Similarly, the agriculture sector is also likely to undergo changes as a result of 5G-enabled internet connected devices. Agronomy has the potential to benefit from a predictive big data approach – this is contrasted with current-day crop output, which is mainly a function of many partially-influenceable variables like weather patterns. Canadian

29 Jay Shah, Arpita Vas, Dinesh Vyas, The History of Robotics in Surgical Specialties (PMC: December 14, 2015), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4677089/.

30 "The da Vincia Surgical System" DaVinci Surgery, http://www.davincisurgery.com/da-vinci-surgery/da-vinci-surgical-system/ (2018).

31 "5G – Part 2: Why 5G Will Become Essential for Emergency Services" Lanner, https://www.lanner-america.com/blog/5g-part-2-5g-will-become-essential-emergency-services/ (July 18, 2018).

Ag-tech firms like Semios and Farmer's Edge collect data from on-farm weather stations, telematics devices, and satellite imagery on microclimates, soil conditions, insect patterns, and crop health. This data is then fed into machine learning algorithms that suggest which crops to plant and how and when to fertilize and harvest. In-field devices such as these are likely to benefit from 5G, as limited internal memory necessitates instantaneous uploading of data to the cloud.

Other ag-tech firms such as Aker rely on data collected from drones, which rely on reliable internet connections, high bandwidth for uploading data, and low latency for remote piloting. Drone use within agriculture can become more prevalent with 5G's implementation, and remote piloting may become increasingly feasible. Lastly, 5G can also drastically impact a central feature of future connectivity: the ability for in-field machines to instantaneously communicate with one another. Researchers at the John Deere Technology Innovation Center predict 5G will reduce the communication delay of combines from 30-60 seconds down to 1 second[32]. The communication of machines, collection and algorithmic analysis of big data, and remote monitoring and operation of equipment will all be enabled by 5G – with improvements in agricultural output being the result.

Sector Snapshot: Manufacturing and 5G

5G can provide significant improvements in productivity and innovation for manufacturing. The improved reliability, speed, security and continuous connectivity provides opportunities to better coordinate operations inside factories as well as the supply chain logistics of the larger production network.

As manufacturing moves from static configurations to flexible and customized production, it is increasingly important to have the ability to quickly alter the production process. 5G technology enables faster production changes in several ways. First, the improved speed and reliability of the wireless connections allows a move away from wired connections, which physically allows for greater flexibility in moving equipment. Furthermore, when a large number of machines have to be updated the total amount of data can be significant; therefore, increased bandwidth and reliable speeds allows machines to be re-programmed with individual software updates faster to reduce downtime. With reliable wireless connections, machines can even be reconfigured as they are being moved.[33]

5G's speed improvements will boost data collection and enable constant monitoring of the work process to reduce operational and management costs. 5G network connectivity can support platforms for explorative analytics related to predictive and preventative maintenance. This will allow companies to better identify potential breakdowns and bottlenecks on equipment before they occur to reduce disruption and downtime.[34] In

32 Michal Lev-Ram, John Deere is Paying $305 Million for this Silicon Valley Company (Fortune: September 6, 2017), http://fortune.com/2017/09/06/john-deere-blue-river-acquisition/.

33 "Applications for 5G in Production Communication Networks", Salzburg Research, https://www.salzburgresearch.at/blog/applications-for-5g-in-production-communication-networks/, (May 2016).

34 Andrew Allock, Is Manufacturing Ready for 5G? (Machinery: July 12, 2018), http://www.machinery.co.uk/machinery-features/is-manufacturing-ready-for-5g.

addition, improved monitoring and data collection can enable advanced life-cycle engineering where diagnostic data is used to study potential operation designs and deployment for long-term planning.[35] Combined, the application of 5G can help produce efficiencies in the manufacturing sector which will ultimately enable higher productivity at lower cost, and drive revenue growth.

Section III: Labour Implications of 5G

Canada and the Rise of 5G Jobs

With Canada currently lagging behind some global leaders when it comes to 5G rollout (China, US, the European Union, for example), Canadian companies are still in the early phases of hiring. As a result, identifying early stage jobs in architecture/design or deployment with a certain level of accuracy, is challenging at this point. However, despite slow movement in rollout, 5G is already playing a role in our economy, creating jobs and the acceleration of key skills. What can be currently identified are occupations that are on the rise as Canada builds out its software capacity and infrastructure, in preparation for spectrum auctions.

Software Defined Networks (SDNs) and Network Function Virtualization (NFV) are technologies moving to the heart of future 5G infrastructures. These are essential to manage the complexity of 5G's requirements, including the heterogeneous nature of the anticipated connected devices (autonomous vehicles, next gen mobile, IOT sensors, and others). Additionally, these technologies are key to wireless interference complexity due to small-cell densification demands. This complex software and the software applications that these platforms enable require a substantial development and significant testing cycle before market readiness.

There are currently a number of software design and engineering jobs that have been posted on Canadian job boards like Indeed.ca or Monster.ca. As 5G will rely heavily on software defined networking and network management software, the presence of these jobs is to be expected within a "preparation" for rollout phase. Moreover, although actual deployment may not take place for a number of years in Canada, given the time it will take to

35 Martti Mantyla, Industrial Use Cases of 5G (Aalto University) http://www.5gsummit.org/helsinki/docs/session%201/Session1-Martti-Aalto.pdf.

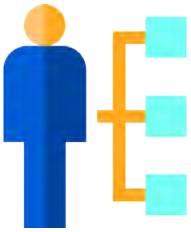
adequately develop, test, and deploy 5G network software (roughly 18-24 months), finding the talent with relevant skills and competencies today is essential.

Examining 5G Jobs and Skills

A number of Canadian job sites were searched in an attempt to identify relevant 5G jobs in Canada. In total, approximately 340,000 jobs were searched across the country, under parameters relevant to 5G and telecommunication. What is of particular interest is that currently, many 5G-related jobs do not actually identify as "5G" – instead, these postings tend to reference technologies and concepts that are important or relevant to 5G networks. Additionally, many jobs in Canada are labelled as "advanced LTE" jobs – a title that has connotations to our current telecommunication network, rather than a future development. However, upon more detailed examination of these roles, it becomes evident that the skills and eventually the positions themselves will transition into 5G jobs when Canadian 5G networks are deployed and operational. Noting this, the job board search criteria was defined to find the 5G jobs in Canada according to the specialized skills and context of the job postings.

The below represents the search parameters used to find 5G jobs:

Example: FIND ALL JOB POSTINGS THAT CONTAIN:



- (nr AND lte) OR
- lte OR mimo OR mmwave OR
- ((sdn OR nfv) AND network) OR
- (backhaul AND (mobile OR wireless))

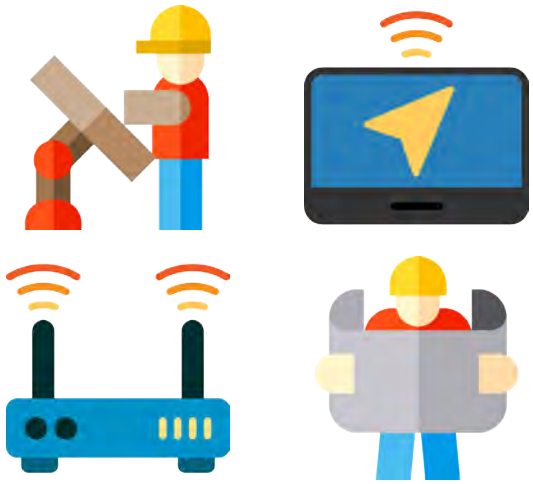
[nr=New Radio, lte=Long-Term Evolution, mimo=Multiple In Multiple Out, mmwave=Millemetre Wave, sdn= software defined networking, nfv=Network Function Virtualization]

Two job board searches were conducted: the first in August 2018, and in the second in September 2018. Between the two searches, a higher number of jobs were found in the September search; therefore, it was chosen as the snapshot for analysis. Interesting to note, however, was that the August 2018 search yielded several postings for co-op students and/or internships. The prevalence of these more "junior" level jobs is an interesting indicator of an emerging nature of this technology job market in Canada and the opportunity that lays ahead for new graduates. These postings were less prominent in the September search, potentially due to the positions being filled for the beginning of university/college academic years.

Findings: Jobs & Skills

The job board searches (Indeed.ca - as of Sept. 19th, 2018) yielded a total of 322 5G job postings across Canada. If compared to other jurisdictions that are farther ahead on 5G deployment like the US for example, the same search yields a total of 5459 jobs – more than 10 times the volume of 5G jobs currently available in Canada. The 5G jobs in Canada that were found include the following:

- Senior Director, Research and Development
- Protocol Lab Test Engineer
- 5G System Architect
- RF Design Engineer
- Microwave/mmWave Radio Expert
- Microwave Algorithm Engineer
- Senior RF Engineer
- Wireless Systems Engineer
- Senior Network Architect
- Senior Software Engineer



Further to the above, it is clear that the majority of 5G jobs found in Canada were software or engineering-related, rather than related to rollout, implementation or even testing – the latter of which exist in searches for other jurisdictions like the US. The following represents occupational snapshots of some of the most frequently posted 5G jobs, and their requisite skills needs.

Top 5G Job Snapshots

5G System Architect

The 5G System Architect helps set strategic roadmaps for 5G product portfolios, and works with product managers to shape product plans. The ideal candidate for this role must possess practical experience designing and delivering architectural solutions, particularly for telecommunication purposes. Additionally, he or she would have real-world experience on a broad range of technologies, including: 3GPP, large-scale technology design and deployments, diverse hardware environments, and software development and deployment.

In terms of must-have technical competencies, the ideal candidate would have experience and a high skillset related to:

- Cloud System Competencies
- Radio Access Configurations

- LTE 3GPP specifications
- 5G NR

Microwave/mmWave Radio Expert

This role conducts research into radio architecture, particularly microwave and mmWave components, and works with the product team to increase the competitive reach of microwave and mmWave technologies. The purpose of this research is to ensure that these components are market-ready.

For technical competencies, the ideal candidate would have a combination of the following skills and experience:

- 10 years experience designing and developing microwave and mmWave communication systems
- Experience simulating RF circuits
- Experience participating in industry associations and standards bodies
- PhD preferred in microwave, electrical engineering or related fields

Senior Software Engineer, IOT

This role requires leading a software development team, with the eventual goal of transforming them into a modern software development house. The ideal candidate must implement and mentor team members in Agile software engineering practices such as SCRUM and Continuous Integration/Deployment.

The must-have technical and skill competencies of this role include the following:

- Experience with object-Oriented Programming
- Experience with test automation
- Experience with cloud computing
- Knowledge of microservice architecture
- Knowledge of API architecture (RESTful APIs especially)
- Proficiency in Javascript (Node.js)
- Proficiency with NoSQL and SQL databases
- Strong understanding of message queuing tools
- Proficiency with DevOPS tools
- Experience in Telecom Cellular Networking

In-demand Programming Languages & 5G Skills

While the popularity of programming languages can shift and vary over time or depending on the specific requirements of a given business, using text mining and natural language processing of extracted 5G jobs, a few programming languages appeared frequently. It was found that the programming languages most identified with network software development were system-level languages like C/C++ and CISC/RISC assembler. These languages are more applicable to the development of technologies like 5G, versus higher-level languages like Python and JavaScript, because 5G programming network hardware and circuits require low-level, small footprint languages.

Additionally, while most 5G jobs found were related to software development and research, where wireless network design/architecture jobs were identified, an in-depth analysis of those postings revealed the following key skills:

- RF (radio frequency) engineering knowledge and experience
- Experience with HSPA/HSPA+ (High Speed Packet Access)
- Experience with SDN (software defined networking)/NFV (network function virtualization)
- Knowledge of 3GPP (3G Partnership Project) standards
- Knowledge of MIMO (multiple-input, multiple-output) methods and practices
- Proficiency with Matlab/Simulink (for simulations)

"Word clusters" Frequently Found in 5G Jobs

Word clusters are groups of words grouped together based on a common theme. Compiling word clusters are useful when yielding insights into the type of jobs posted under certain parameters. For the 5G industry, word clouds can provide useful insights into the most in-demand occupations, from which their associated skillsets can be extracted. Given the high level of investment that will need to take place in the development of the technology and relevant software applications of 5G, it is no surprise that "software developer" was the most common 2-word phrase found in job titles. "Hardware testers" were also prevalent, along with "senior/principal network architects". When it comes to skills for these occupations, a significant consideration must be placed on talent with strong logic and algorithm skills. The complexity of the network and communication software for 5G will create a significant demand for these skills going forward.

The following represents the top 10 2-word phrases found in relevant 5G job titles:

1. Software developer
2. Contractor tester

3. Microwave algorithm
4. Senior network
5. Device tester
6. Developpeur données
7. Développeur application
8. Agorithm communication
9. Architecte principal
10. 5G baseband

Additionally, using clustering algorithms on job descriptions can also identify patterns in the job postings, themselves. The algorithm examines the words in each job posting and groups them into a chosen number of clusters (in this case 3) based on common words. The clustering algorithm found the following basic themes for grouping job descriptions into 3 categories:

1. Software and testing jobs
2. Microwave and algorithm jobs
3. Networking jobs

Under Cluster 1 (189 job descriptions), we examine common words and job titles found for Software and Testing roles.

> **Key Words:** testing, software, networking, requirements, wireless, protocols, technologies.
>
> **Example Job Titles:** Sr. Specialist- Network Quality, LTE 4G/5G Test Developer, Wireless Test Engineer, Software Developer – Network Communications & C/C++, Radio Performance Verification, Experienced Wireless Layer 1 Software Developer, Network Quality Analyst

Under Cluster 2 (83 job descriptions) the most common words and job titles were identified for Microwave and Algorithm roles.

> **Key Words:** technologies, communications, code, solutions, fibre, lte, hspa+, architecture
>
> **Example Job Titles:** Microwave/mmWave Radio Expert, Microwave Algorithm Engineer, Algorithm Engineer, Microwave Algorithm Expert, Architecte Télécoms, Ingenieur radiofrequences.

Lastly, under Cluster 3 (50 job descriptions), the following were the most common words and job titles found for Networking roles.

Key Words: networking, customer, solutions, wireless, technologies, data, software, architecture, cloud.

Example Job Titles: Wireless Networking Technologist, Cellular Network Deployment Designer (LTE 4G), Wireless System Designer - Intermediate, 2018 Graduate Engineering and Leadership Development Program, Senior Manager- Wireless Network Performance, Resident SDN/Network Engineer

It is clear that currently, employment demands related to 5G in Canada are focused on research, software development and network architecture. These are key occupations that must lead progress in any revolutionary technology such as 5G. However, as we draw nearer to spectrum auctions and deployment, the impact that 5G can have on jobs becomes exponential. Impacting a variety of sectors, 5G can enable never-before attempted changes to sectors like healthcare, trade, manufacturing, transportation and many others. At the same time, 5G will create employment opportunities across a number of vectors including regulation, testing, infrastructure development and many others. The pathway for opportunities of 5G across our society is only in beginning phases at the current time – as we draw nearer to rollout, the potential of this this game-changing connectivity technology becomes unbounded.

Section IV: 5G Economic & Labour Forecasts

Despite being in very early phases in Canada, 5G is already creating employment opportunities for Canadians. Currently focused in the space of R&D and software development, opportunities will extend and expand ana 5G auctions draw nearer. Naturally, as time progresses and a clear path is chartered for this next wave of connectivity, we will likely see a range of occupations emerge, from deployment to testing, to application across all sectors of the economy. These applications will be the crux of 5G's true potential: from its ability to bring autonomous vehicles to our streets in a safe and effective way, to revamping the health sector with practices like remote surgery, ultimately, this next generation of connectivity has the potential to reshape our connected future, bringing us closer to a true IoT-based "smart" reality. The impacts on employment and economic growth under such a circumstance are significant. Understanding this, we have forecasted the potential impact of

5G on our economy and on talent needs in Canada. Given that the full and various impacts of 5G's applications across all our sectors are also tied to when spectrum auctions take place, we have created two (2) forecasts: identifying labour and economic growth prospects if auctions take place in 2019, vs. labour and economic growth prospects if auctions take place two years later in 2021. While this gap in timeline may seem small, given 5G's immense potential across the economy, even a two-year difference is considerable.

Basis for GDP and Employment Forecasts

The net GDP and employment forecasts are derived first according to a basis of historical, country-level panel data obtained from the Organization for Economic Cooperation and Development (OECD). The key explanatory variable used in the analyses of GDP and employment is the number of mobile subscriptions per capita, which serves as a proxy for telecommunications penetration across the country. The benefit of using a panel across many countries is that a larger sample of data is obtained which enables a more accurate determination of the mean effect across many countries. The larger sample size also enables identification of statistically significant relationships – something that would be a challenge to determine with accuracy if considering only a single country.

Accessing 20 years of data across 38 countries, ICTC has chosen a number of cariables used as controls in the developmetn of the forecasts. These include: national research and development spending as a percent of GDP, tertiary education levels for various age groups, debt to GDP ratio, and annual deficit as a percent of GDP, among others.

Using this methodology, we see that Canada possesses an average number of total telecommunications access paths (about 160), but a low number of mobile telecommunications access paths (under 100) relative to other nations.

Figure 1: Mobile Access Paths

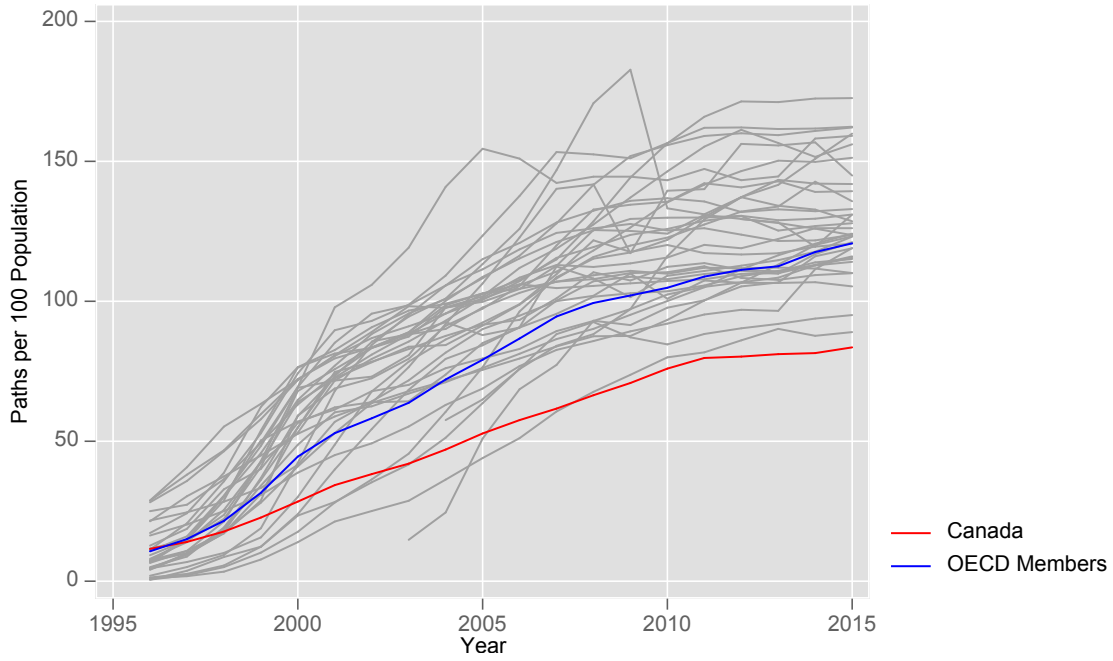
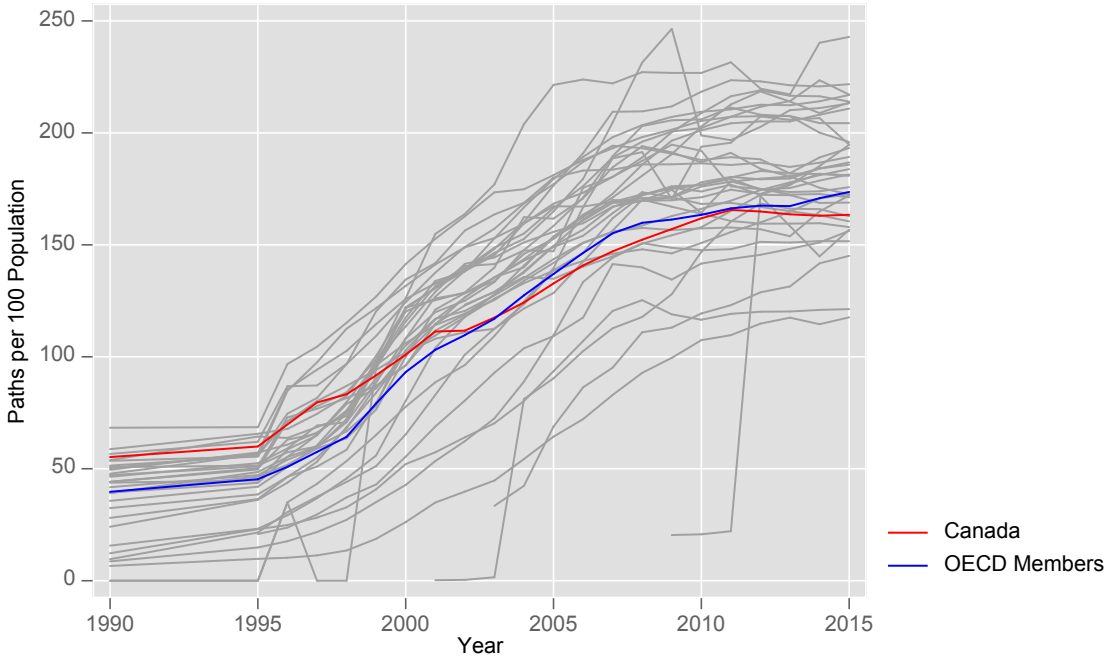


Figure 2: Total Telecom Paths by Country

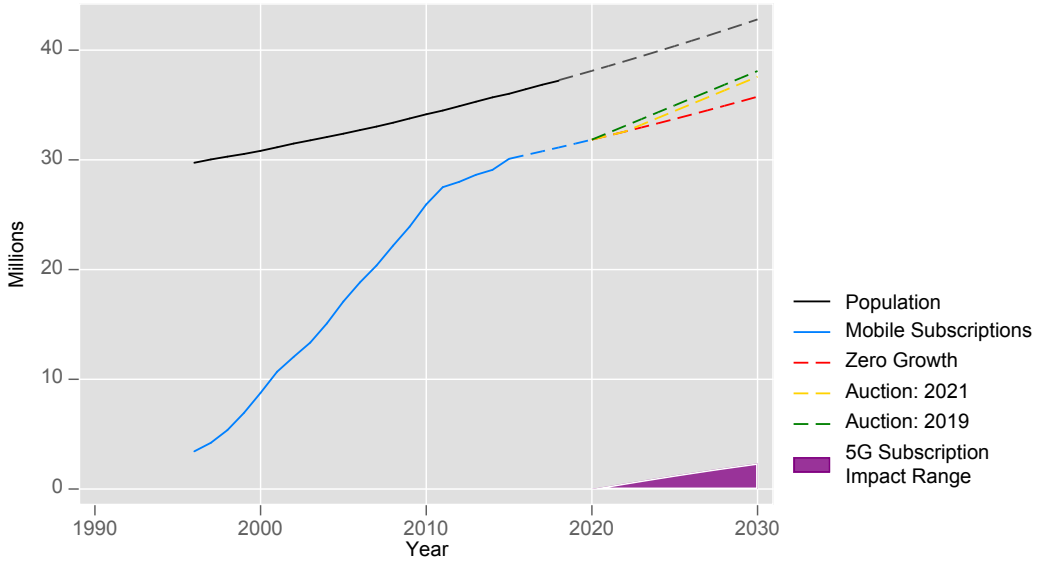


Using a series of assumptions that ICTC has chosen based on key informant interviews and expert testimony, the historical relationship between mobile telecommunication access paths (or subscriptions) and GDP or employment has been established. This relationship is crucial in forecasting future growth in mobile subscriptions that is solely attributable to 5G. In other words, it is necessary to understand the incremental impact of 5G on mobile subscriptions, or how many more mobile subscriptions will be anticipated to be in the presence of 5G.

Mobile Growth Subscriptions Under 5G

Figure 3 shows three scenarios for growth in mobile subscriptions attributable to 5G. Whereas the "zero growth" scenario (red dashed line) represents a hypothetical situation where 5G does not exist and 4G-LTE remains in place, the green and yellow lines indicate scenarios where spectrum auctions take in 2019 and 2021 respectively. This enables impacts on subscriber growth as of 2020 and 2022, respectively. Under the **2021 auction scenario, we estimate that Canada will see 37.6 million mobile subscriptions by 2030** as a result of 5G. Similarly, **a 2019 auction scenario estimates 38.1 million subscriptions at the same timepoint –** that's 500,000 more mobile subscriptions as a result slightly accelerating the auction period.

Figure 3: Mobile Telecom Access PathForecast



Obtained from OECD, Finance Canada, and US Conference Board Data.
Dashed line indicates forecast.

While a 2021 auction scenario has already been declared, some – such as Telus for example – are calling for high-frequency spectrum auctions to take place much sooner, as of 2019. These two scenarios are meant to capture the potential difference in impacts based on these two timelines. Other factors which will determine the mobile subscriber growth include factors such as: the development of relevant regulation and standards; the price of service provision; and other changes to economic policy and circumstances like fluctuating interest rates, attraction of foreign direct investment and industry competition, among others. This forecast is designed to provide an estimate of how moving key auctions earlier could impact economic outcomes.

GDP Impact Forecast

5G and the Growth of the Total Canadian Economy (GDP) by 2030

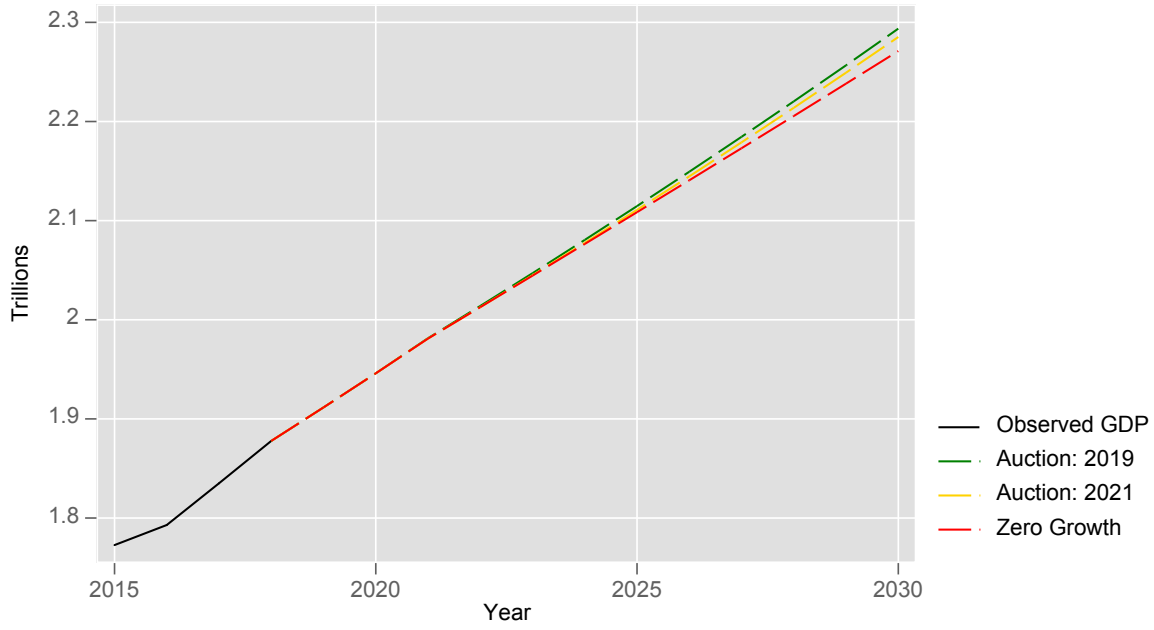
The GDP forecast model uses the mobile subscription growth scenarios under 5G to predict gross domestic product growth. This report uses the Income Approach to GDP, which defines GDP as the sum of employee wages, corporate profits, proprietor's income, rental income, net interest, and net government sales tax income.

In our research, we determine that for each additional mobile subscription per 100 population, the GDP growth rate increases by 0.0311%. Additionally, Finance Canada forecasts a GDP growth rate of 1.8% from 2016-2021 and 1.6% from 2022 to 2030 according to current economic conditions. It should be noted that the estimated GDP growth rate can also increase or decrease as a result of other economic levers such as foreign direct investment, interest rate change and others stated above. Figure 4 uses this growth forecast

and corresponds it to the 2021 auction timeline (as the Finance Canada estimate already has the future impact of 5G implicitly "priced in").

According to this methodology, the 2019 auction timeline (green) scenario represents significantly higher rate of mobile subscriptions as a result of 5G. Under the 2021 auction timeline, Canada's total GDP will reach approximately $2.285 trillion including 5G impact by 2030. However, if the auction is moved up two years to 2019, Canada's total GDP will total around $2.294 trillion by 2030. The difference between the 2021 auction timeline and the 2019 auction timeline is approximately $9 billion. This figure is more than the value of Canadian exports to India and Korea combined – totaling slightly more than $8.6 billion that year[36].

Figure 4: GDP Impact of 5G (Total Canadian GDP)



GDP Impact of 5G

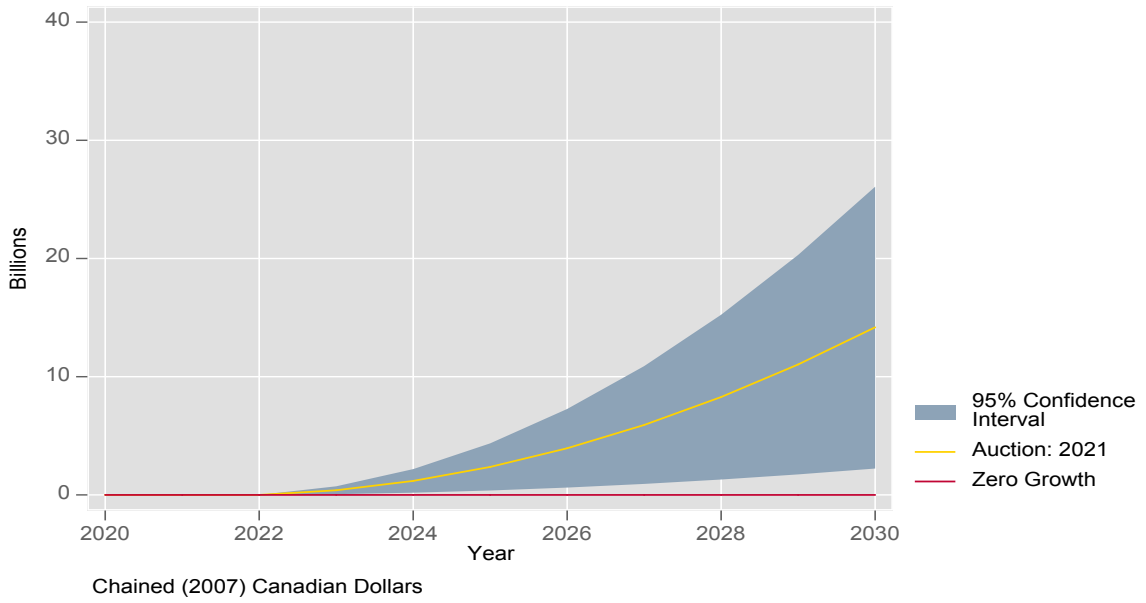
Similar to the cumulative GDP growth of the Canadian economy of 5G under 2019 and 2021 auction timelines, the figures below display the potential GDP impact of 5G itself.

We have estimated the growth of 5G in terms of GDP impact, relative to GDP impact under current and potential future conditions. Figure 5 indicates that under **2021 auction timeline, 5G's cumulative impact on Canada's GDP by 2030 will be around $14.2 billion**[37] under current economic conditions. However, impact may scale **as high as $26.1 billion** depending on the acceleration of other economic factors that can act as catalysts to economic growth. These include things like increase in foreign direct investment, interest rate changes, increase in international trade and others.

36 "Canada's State of Trade: Trade and Investment Update – 2017: Table 4-2 Goods Exports 2016" Global Affairs Canada, http://www.international.gc.ca/economist-economiste/performance/state-point/state_2017_point/index.aspx?lang=eng (July 19, 2017).

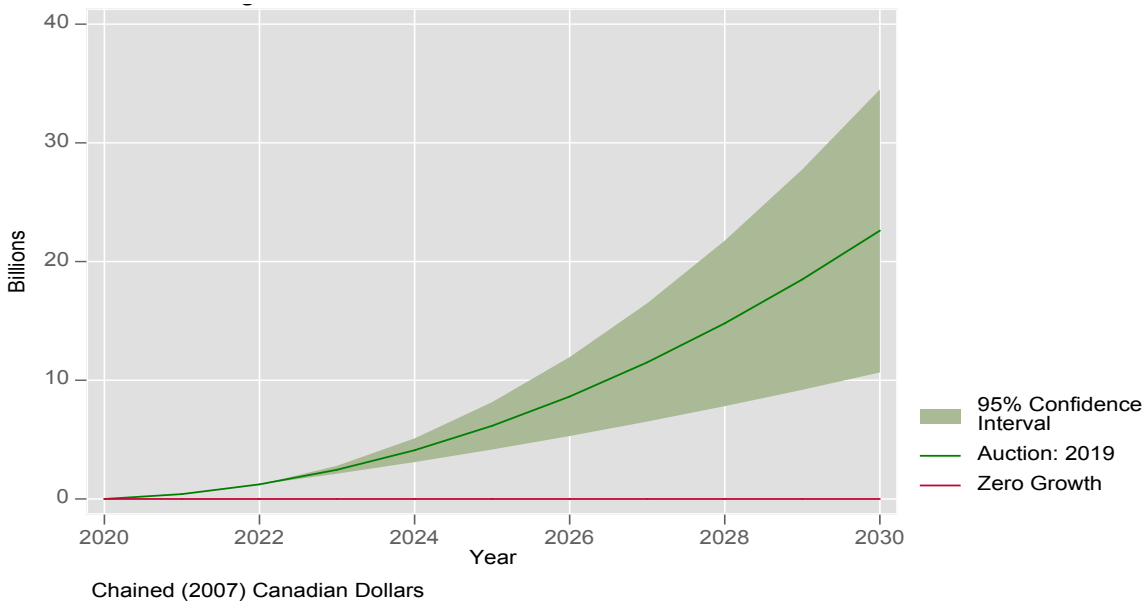
37 in 2007 inflation adjusted Canadian dollars.

Figure 5: Auction 2021 Cumulative GDP Impact Confidence Interval



By contrast, Figure 6 below showcases the cumulative impact of 5G on Canada's GDP in the event that auctions take place in 2019. Here, according to current economic conditions, the **impact of 5G on Canada's GDP will total approximately $22.6 billion** by 2030. This impact may range **as high as $34.5 billion** depending on other economic factors noted above.

Figure 6: Auction 2019 Cumulative GDP Impact Confidence Interval



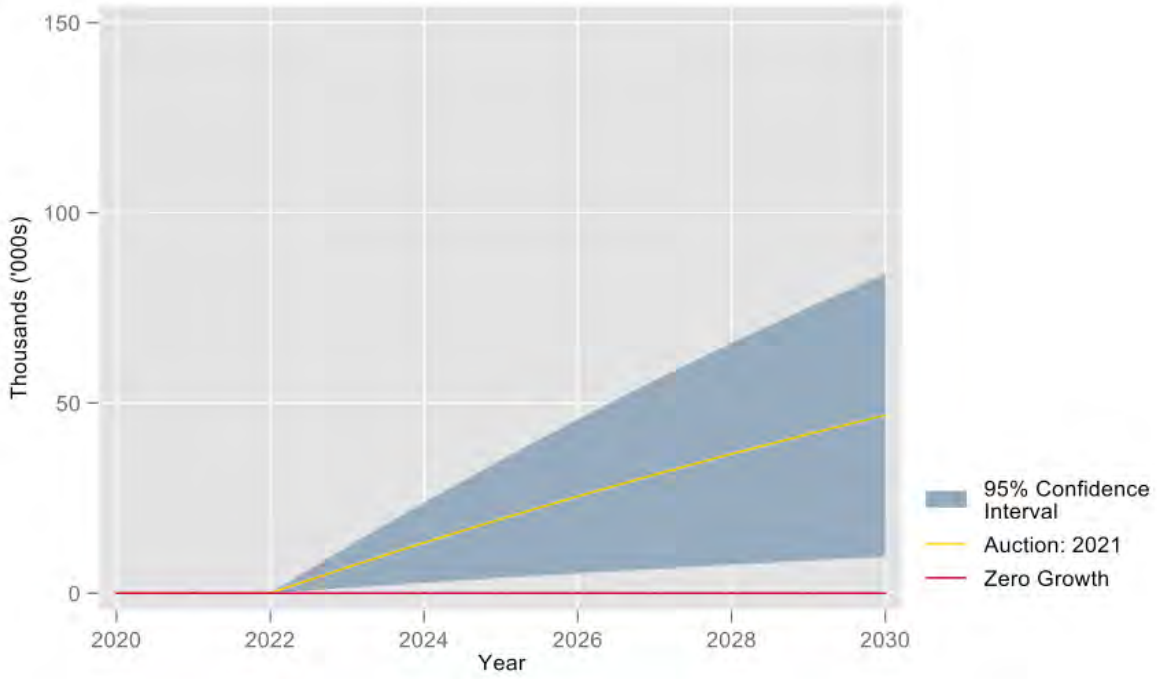
5G Employment Impact Forecast

The net employment impact forecast uses a similar approach to the GDP impact forecast. Using the *Income Approach to GDP* it should be noted that income from the additional GDP will be distributed across many domains, including labour output. Additionally, it must also be recognised that the productivity enhancements of 5G will not merely create new jobs, but likely raise the wages of existing jobs. Therefore, it is misleading to calculate the average wage per newly created job by taking the incremental GDP created and dividing it by the incremental jobs created. Instead, the *Income Approach to GDP* includes sum of employee wages, corporate profits, proprietor's income, rental income, net interest, and net government sales tax income.

Based in the historical relationship identified between the percent of the working age population that is employed and the number of mobile subscriptions per capita, this relationship is supplemented with trends identified in primary research on current and potential future employment needs associated with 5G.

Figure 7 and 8 show the incremental impact of 5G relative to current connectivity capability. Figure 7 shows the cumulative employment impact of 5G under a 2021 auction timeline. In the instance that **auctions take place in 2021, 5G will have created roughly 46,800 jobs by 2030.** However, again, in the event that other relevant changes to current economic conditions take place impacting things like investment, infrastructure development and trade, **job creation may reach 84,000** by this period.

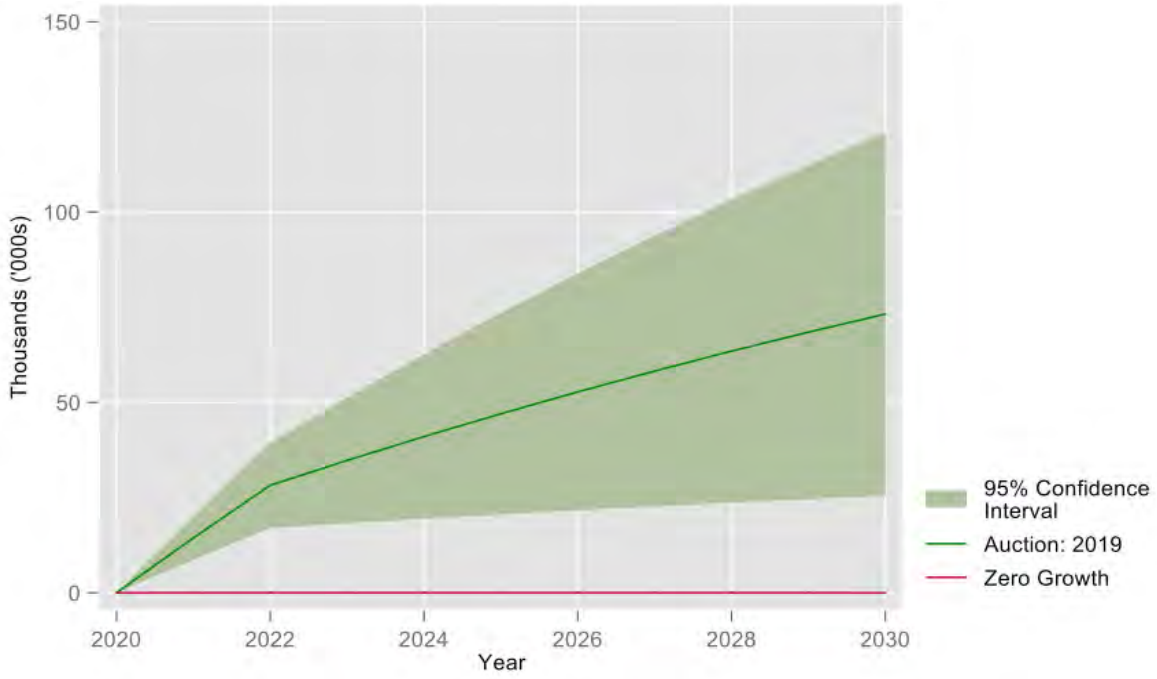
Figure 7: Auction 2021 Cumulative Employment Impact Confidence Interval



Similarly, Figure 8 shows the same forecast assuming a 2019 auction timeline. The employment impact by 2030 under current economic conditions are substantial. **According to the**

2019 auction timeline, approximately 73,200 job will be created by 2030. However, under accelerated economic conditions in a 2019 auction timeline, **job growth can reach 121,000 by 2030.**

Figure 8: Auction 2019 Cumulative Employment Impact Confidence Interval



Conclusion

5G is expected to affect Canada's economy and society in ways that outpace that of recent technological developments. While some impacts – including on labour and economic growth prospects – can be predicted today, others will be seen and elaborated upon in the coming years as the technology develops, and is deployed on a large scale. Given that in many cases even identifying the impact of current transformative technologies is no simple task, predicting the future – particularly when related to technological progress – can always be a challenge.

However, despite some uncertainties and external factors that may surface along the way, there is significant reason to be not only optimistic, but confident about the future of 5G in Canada. Employing a variety of methods to understand the potential economic and labour impact of 5G, this report underlines in-demand jobs and skills that have and will continue to surface as a result of 5G, and charts a course for the future in terms of economic impact and talent needs. Underlining 5G-enabled technological developments like augmented and virtual reality and the Internet of Things as important outcomes, this report explores specific 5G-related skill needs and the impacts of 5G on GDP and employment in Canada according to two auction timelines.

Estimating a total economic impact ranging between $14 billion to $26 billion depending on external economic influencers, a 2021 auction timeline will bring significant prospects for

economic growth to Canada. At the same time, a 2021 auction timeline will yield anywhere between 46,000 to 82,000 new jobs for Canadians – this is no small feat. However, understanding that many global players are making key advancements in this space at a more accelerated rate, holding auctions just two years earlier in 2019 will yield immense benefits for Canada. Under a 2019 spectrum action timeline, the economic impact of 5G will total between $22 billion to $35 billion, creating between 73,000 to 121,000 new jobs for Canadians.

5G is so much more than just the next generation of mobile Internet. It will make the economy larger, more accessible, generate more jobs for Canadians and contribute towards solutions to real-life societal challenges. The timing or rollout is a key factor on this journey, and our collective success in harnessing 5G's capabilities and benefits means preparing for them today.

Appendices

I. Research Methodology

This report was created using a variety of primary and secondary research tools. Primary research tools included an advisory committee, a select number of key informant interviews, and a survey distributed to employers across a variety of sectors in Canada, gaging: a) their understanding of 5G, b) employment needs for telecom roles; c) expectations of growth related to 5G; d) expectations on improvement of productivity related to 5G; and d) estimated skill needs for 5G-related workers, among others.

The Advisory Group was set up in February 2018, and is comprised of 9 members from research bodies and regulatory institutions, companies developing 5G technologies, and major Telecom providers including Rogers, Telus and Ericsson, among others. The advisory group met three times during the course of this project to evaluate research progress, to validate findings and to provide additional resources where necessary. The advisory group was key in validating the final outputs of this report.

The key informant interviews were completed with a number of players in the 5G space, including national service providers like Telus and Rogers, regional providers like Xplornet and national consortiums on telecommunication networks and development like the Ontario-Quebec partnership, ENCQOR.

Lastly, a survey was distributed to companies across Canada, operating under 7 high-growth industries (ICT, digital media, agri-foods, health/biotech, clean tech, clean resources, advanced manufacturing). While this survey was not specifically designed for the sole purpose of extracting solely 5G insights, it contained six (6) 5G questions, related to the understanding of 5G, the usefulness of 5G to business, the anticipated impact of 5G on sales and growth, past and future hiring trends, and the telecom-related jobs and skills relevant to those companies. At the time the survey responses were analyzed for this report, a total of 63 respondents provided feedback on these 5G questions. The 5G survey questions

were reviewed and validated by the Advisory Committee prior to release.

The secondary research component of this study included a thorough literature review of 5G reports and relevant research to date – both from Canadian and international sources including the US and the European Union. This research was conducted to identify the key technologies behind 5G, estimated timelines for rollout, and job and skill needs related to development of 5G technology. Once a robust set of parameters were identified relevant to 5G jobs based on secondary research, advanced analytics were employed to build a web scraper that extracted jobs in Canada related to 5G. More than 340,00 jobs were searched, with more than 300 relevant roles extracted on a 2-month basis for comparison (for August 2018, and September 2018). Once extracted, the roles were analyzed via text mining and natural language processing to identify relevant skills and competencies.

Other data sources used include data sets from Finance Canada, Statistics Canada, the US Conference Board and the OEDC. These were utilized to determine statistically significant relationships between a number of variables in the interest of identifying indicators to use in the forecast methodology. The forecast was used primarily to estimate the impact of 5G on the Canadian GDP and employment in Canada by 2030. The forecast methodology is described in greater detail below.

II. Forecast Methodology

While some existing research on the impacts of 5G appear to have used a basic Input-Output (IO) model, ICTC has chosen an alternative technique in the attempt to more accurately forecast the economic (GDP) and labour (jobs) impacts of 5G on the Canadian economy. The reasons for choosing this alternative model are several. Firstly, IO models indicate how spending in some sectors of the economy may trickle into other sectors of the economy. They then provide an estimate of how much economic activity and jobs are "supported" (not created) by the assumed-to-be exogenous spending in the original sectors. While the model is highly tractable, its interpretation in this case is somewhat constrained considering that the 5G infrastructure spending is simply not exogenous (an external modelling assumption not influenced by factors within the model). Thus, while the IO model can inform the modeller how much total economic activity and jobs are associated with some spending, it is unlikely to accurately determine the causal (or incremental) effect of something like 5G relative to current conditions (4G-LTE status quo, in this case). Understanding this, it is then even more difficult to truly understand the direct impact of developments like 5G on economic outcomes or job creation/development using this model.

In contrast, the forecast in this report uses a panel data regression methodology. Panel data refers to time-series data across some other variable (in this case country). This methodology enables us to determine the historical relationship between some proxy for mobile internet technology and economic outcomes of interest, after controlling for changes in a variety of other relevant variables (including time and country). Once this relationship is determined and found to be statistically significant, the future increase in the proxy variable attributable to 5G is estimated. This is where various mobile subscription growth scenarios are assumed

according to the different auction timelines. Finally, the historical relationship between the proxy and economic outcomes is assumed to hold into the future, and the future incremental impact of 5G on the economic outcome is estimated.

III. Limitations of Research

As with all research, certain limitations can occur that may influence findings. While ICTC has attempted to mitigate these as much as possible, the following limitations exist in relation to this project.

Survey: Responses to the survey were limited at the time that results were collected at analyzed. With only 63 companies providing input at that time, these survey responses are not necessarily indicative of the entire Canadian business population in reference to 5G. Furthermore, considering that 5G is still in very much an exploratory phase – particularly in Canada – some respondents found it difficult to clearly articulate what impact they believed 5G may have on their businesses. This included what type of hiring would be necessary to support 5G operations in their companies. While we received some interesting responses to these questions, given the relatively low number of responses, survey results were used more to shape scraping activities and forecast methodology, rather than as direct indicators of future trends.

5G Rollout Timelines in Canada: Given the arguably slow progress made in Canada when it comes to 5G development and rollout, oftentimes those we contacted for key informant interviews were not able to provide extensive details on job and skill needs, particularly beyond somewhat generic roles like "Network Engineers" or "Software Developers". This problem was even more acute at the deployment level, where even telecom providers were unable to determine which jobs would be relevant to the deployment of the networks – for example, would tower technicians require different skills and competencies to network tower technicians today? Would this work be completed by Canadian companies (employing Canadian workers) or outsourced? As a result, given the lack of reliability for job needs outside of research and software development, we have limited our analysis skills to those occupations.

Web extraction: Using the parameters identified for 5G jobs as agreed upon via secondary research and consultations with industry experts, 5G-relevant jobs were extracted from a number of Canadian job boards like Indeed.ca and Monster.ca. Extracted jobs were then further analyzed using natural language processing and text mining to identify relevant skills for those jobs. That said, while this exercise was completed for two (2) different months (August and September 2018), more time series data via extraction over a longer period (3+ months) would have been useful to more accurately highlight trends over time.

Uncertain nature of technology and few current tangible examples of impact: Given the very rudimentary nature of 5G technology currently in most cases, it becomes difficult to accurately and specifically estimate its potential impact as an enabler of various other technological developments. For example, while 5G may eventually be a key enabler of autonomous vehicles, remote surgeries, precision agriculture, and even connected or

"smart" cities, the nascent nature of 5G at this time makes it challenging to quantify the impact (economic and labour) of all potential applications of 5G across the economy. As a result, our employment job and skill analysis is limited to in-demand jobs in research and development of 5G in Canada. Alternatively, our forecast is limited to estimating the economic and employment impact of 5G across the economy generally – rather than according to applications in various sectors or industries. Additionally, while some jurisdictions around the world are accelerating at a faster pace than Canada when it comes to 5G development and deployment, there are still relatively few cases of actual 5G "success stories" around the world that can be used for comparison purposes. One example of a 5G-enabled city is that of Berlin under Deutsche Telekom. ICTC had reached out to a representative from the company for a consultation, but was not successful in securing one.

Forecast: The GDP and employment forecasts rely on a number of assumptions which can be difficult to validate in cases like these, where the given subject of interest (5G) is still largely conceptual. In such cases, firstly, the historical relationship determined by the regressions are considered to be causal. This is false to the extent that the regressions suffer from endogeneity as a result of reverse causality or omitted variable bias. If this is the case, the regressions have determined a mere historical correlation, not a necessarily a causal relationship. In this case, it is possible that reverse causality may be partially true, as while mobile internet affects GDP, GDP also affects mobile infrastructure. This is something that may act to bias the estimated impact upwards. Second, the proxy is assumed to fully capture the effects of mobile internet infrastructure on economic outcomes. If mobile internet improvements affect economic outcomes independent of or uncorrelated to changes in the proxy variable, the forecast may underestimate the impact of 5G. Conversely, if the proxy variable affects economic outcomes independent of or uncorrelated to changes in mobile internet improvements, the forecast may be an overestimate. Lastly, the three growth scenarios for the proxy variable in the future have a transparent exposition with the red, yellow, and green lines. This is because the forecast is sensitive to changes in the forecast for the proxy variable.

The GDP and employment forecasts contain multiple independent sources of uncertainty. The first is the result of the estimated effect range in the regression (or the confidence interval). The second is the forecast mobile subscriptions per capita. These overlapping sources of uncertainty with regard to the proxy growth scenario and the regression confidence interval results in a wide range of potential outcomes. This outcome range is presented with graphs indicating the confidence interval under different mobile subscriber growth assumptions.

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