Taiwan's 6G Future: The Impact of Next-Gen Infrastructure

An Interactive Qualifying Project Report Proposal submitted to
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Abstract

This study, in collaboration with Taiwan’s Institute of Economic Research, assesses Taiwan's advancement in 5G and explores the preparatory measures for 6G. Background research highlighted Taiwan’s advantageous position to adopt and develop 6G technology. The team conducted expert interviews and surveys to evaluate the state of 5G and public perceptions of 6G in Taiwan. The analysis shows that 5G still has significant work to be done, and the public is concerned about privacy and security in 6G systems. During interviews with 5G experts, the team identified the paramount importance of using densification and satellite technology to enhance connections and bridge the digital divide. Insights from the survey lead to recommendations around public transparency.

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Executive Summary

Introduction and Background

The global communications landscape has undergone a transformative shift in recent years, driven largely by advancements in technology and the adoption of smartphones. With the evolution from 4G to 5G and now towards 6G, this sector is on the brink of ushering in unprecedented capabilities in speed, connectivity, and data handling. Taiwan stands out in this global narrative, poised to leverage its significant advancements in semiconductor fabrication and telecommunications expertise.

The strategic importance of Taiwan in the technological industry, especially with entities such as the Taiwan Institute of Economic Research (TIER), provides a unique vantage point from which to explore the potential impacts and opportunities presented by 6G technology. TIER is a independent think tank, a group of experts who provide ideas and advice for economic and political problems, as well as the sponsor of this project. This research aims to dissect the broader implications of these technological advancements on societal structures, economic growth, and the global market positioning of Taiwan.

As 5G continues to advance, the transition to 6G looms on the horizon, promising to enhance not just connectivity but also the integration of technologies like the Internet of Things (IoT) and Artificial Intelligence (AI). Taiwan's role in this transition is critical, given its technological prowess and innovative capacity. The research conducted provides insights into how Taiwan can maximize these opportunities.

This research paper explores three main areas: the impact of internet access on Taiwan's social development, the current state and challenges of 5G technology in Taiwan, and the projected advancements towards 6G. Understanding these areas helps frame the potential strategies and policies that Taiwan could adopt to solidify its position as a leader in the next technological era.

Methods

To comprehensively address the research objectives, the team used a mixed-method approach, combining both qualitative and quantitative research techniques. This approach facilitated a balanced exploration of both the technical aspects of telecommunications technology and its broader societal implications.

The team conducted five expert interviews, one from Taiwan and four from the United States. These interviews gathered qualitative data from industry leaders, technologists, and academics who are at the forefront of telecommunications research. The team These interviews aimed to provide depth and context to the technical challenges and innovations associated with the evolution from 5G to 6G.

The team distributed surveys broadly across Taiwan to capture public perception and acceptance of the current and future telecommunications technologies. These surveys were designed to quantify public opinion and gather demographic data that could inform policy and infrastructural adjustments.

Then, the team analyzed the data from these methods to identify trends, challenges, and opportunities. The qualitative data from expert interviews provided insights into the technical and strategic challenges of advancing telecommunications technologies. In contrast, the quantitative survey data offered a snapshot of public sentiment and potential consumer adoption rates.

Additionally, the team undertook a thorough review of existing literature and current technologies to supplement the primary research data, ensuring a robust framework for analysis and recommendation.

The combination of these methods provided a comprehensive understanding of the telecommunications landscape in Taiwan, particularly in the context of global advancements and local impacts.

Results

The interviews with telecommunications experts highlighted a range of technical and strategic insights, particularly concerning the infrastructure requirements and the potential applications of 6G technology. Experts expressed optimism about the enhanced capabilities of 6G, including its potential to revolutionize industries through improved IoT connectivity and AI integration.

Survey results indicated cautious optimism among the Taiwanese public regarding the transition to 6G. While there was appreciation for the potential technological advancements, concerns about privacy, security, and the pace of technological change were prevalent. These concerns underscore the need for clear communication and robust policy frameworks.

The combined findings from both primary research components suggest a strong foundation for 6G development in Taiwan but also highlight significant challenges that must be addressed. These include technological infrastructure, public trust and understanding, and regulatory environments.

The survey showed respondents a hypothetical usecase of 6G to gauge their thoughts in a number of areas. One of the major findings is what people were most concerned about with the proposed system. The results can be seen in Figure 1.

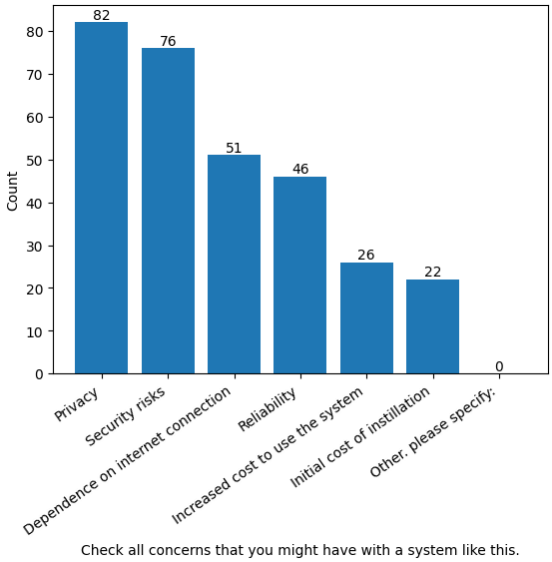

Figure 1: People's concerns with the proposed 6G system (n=103).

Importantly, the survey identified a critical gap in public knowledge and acceptance of 6G technology. This gap suggests the need for targeted educational programs and public engagement strategies to ensure a smooth transition and broad acceptance of new telecommunications technologies.

Overall, the results underscore the need for a strategic approach to 6G rollout in Taiwan, one that balances technological

advancement with public transparency and engagement.

Recommendations

Based on the research findings, the team proposes several strategic recommendations. Each of these recommendations falls under the topic of either infrastructure, policy, or public recommendations:

Infrastructure Recommendations

Build dense networks

Beginning to build out a dense network of cell towers early will spread out the burden of developing infrastructure over time. This will allow for an earlier launch of 6G in Tawian, while also benefitting the companies involved in building cell towers.

Research satellites

Taiwan should research the viability of satellite internet for its rural areas. If the research succeeds, satellites could be a valuable tool to provide internet access to historically under-served areas of Taiwan, helping to close the digital divide. This could also benefit cellular communications companies by providing a more cost efficent alternative to traditional cell towers.

Policy Recommendations

Plan for phased rollout

Taiwan should plan on a phased 6G rollout for all parties involved. This means that cellular networks should not expect to fully support the 6G specification at the initial deplomen in Taiwan. Knowing this will help set expectations for early adopters of this technology.

Prioritize businesses

Taiwan should prioritize businesses in the early stages of 6G implementation. This prioritization should include both marketing and legislation. This is recommended because the expected impact of 6G is much more significant for buisnesses than the public.

Public Transparency Recommendations

Implement digital trust lablel

Taiwan should implement a digital trust label. This would be a certification that products can go through to gain a label showing their compliance with security and privacy laws. This will aid in easing the public's fear of privacy and security in new technologies.

Transparency Towards AI in 6G

New policies should involve clear communication about data handling and safety measures. Taiwan's public has shown concerns with these issues which could be quelled if they see their government and businesses taking steps to be more transparent when addressing them.

Conclusion

This research offers a comprehensive overview of the current state of telecommunications in Taiwan, with a forward-looking perspective on the transition to 6G technology. By aligning infrastructure development, policy reform, public engagement, and international collaboration, Taiwan can effectively navigate the complexities of this next technological era. The team provided recommendations to guide stakeholders in creating an environment that not only fosters technological innovation but also addresses

societal needs and economic goals, ensuring that Taiwan remains at the forefront of the global telecommunications industry.

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Glossary

Terms	Definitions:
Artificial Intelligence (AI):	the capacity of a computer, robot, programmed device, or software application to perform operations and tasks analogous to learning and decision making in humans
Augmented Reality (AR):	an enhanced image or environment as viewed on a screen or other display, produced by overlaying computer-generated images, sounds, or other data on a real-world environment.
Bandwidth:	the transmission capacity of an electronic communications device or system; the speed of data transfer
Broadband:	of, relating to, or being a high-speed communications network and especially one in which a frequency range is divided into multiple independent channels for simultaneous transmission of signals (such as voice, data, or video)
Cell Site:	a cell site, cell phone tower, cell base tower, or cellular base station is a cellular-enabled mobile device site where antennas and electronic communications equipment are placed (typically on a radio mast, tower, or other raised structure) to create a cell, or adjacent cells, in a cellular network.
Digital Divide:	the economic, educational, and social inequalities between those who have computers and online access and those who do not

Hertz:	the standard unit of frequency in the International System of Units (SI), equal to one cycle per second.
Interactive Qualifying Project (IQP):	The IQP is an important part of WPI's curriculum that aligns with the project-based approach to learning. This paper is the result of an IQP.
Internet of Things (IoT):	a network of everyday devices, appliances, and other objects equipped with computer chips and sensors that can collect and transmit data through the internet.
Machine Learning (ML):	computer systems capable of learning and adapting by utilizing statistical models and algorithms in order to identify data patterns and draw inferences, all without following explicit instruction.
Major Qualifying Project (MQP):	WPI's Major Qualifying Project is a team-based research and design project that provides students with a professional level experience that utilizes the lessons accumulated by students through the project based focus curriculum at WPI.
Semiconductors:	a substance, as silicon or germanium, with electrical conductivity intermediate between that of an insulator and a conductor: a basic component of various kinds of electronic circuit element used in communications, control, and detection technology and in computers.
Telecommunications:	the telegraphic or telephonic communication of audio, video, or digital information over a distance by means of radio waves, optical signals, or along a transmission line
Terahertz (THz):	a unit of frequency equal to one trillion hertz

Virtual Reality (VR):	a realistic and immersive computer simulation of a three-dimensional environment, created using interactive software and hardware, and experienced or controlled by movement of the body.

1 Introduction

In the last decade and a half, the global communications landscape has undergone a profound transformation, driven by the rapid evolution of technology and the universal adoption of smartphones. This digital revolution has not only reshaped the way individuals across the globe connect, communicate, and consume information but has also set the stage for unprecedented societal and economic changes.

As 5G technology continues to mature, enhancing global connectivity and data management, the stage is set for the transition to 6G, which promises unparalleled speed, connectivity, and capacity. This promises to redefine the telecommunications industry and significantly alter today's societal and economic structures. Artificial intelligence (AI) and Internet of Things (IoT) are integral parts to this technological revolution, ushering in a new era of intelligent connectivity and seamless interactions. Amidst this innovation landscape, Taiwan, known for its technological development, manufacturing prowess, and strategic foresight will likely emerge as a major player in the development and execution of 6G technology. As a global leader in semiconductor fabrication and electronic manufacturing, Taiwan has the expertise and resources to drive the evolution of 6G technology. To support this evolution, the team's research explored the impact of internet access on social development, the current state of 5G in Taiwan, and the state of 6G research.

Taiwan's network of research institutions, industry partners, and government agencies facilitates collaborative efforts to push the boundaries of technological innovation. With a strong focus on investing in R&D, Taiwan is well-positioned to leverage its strengths in semiconductor design, wireless communication technologies, AI, and IoT applications to propel the development and adoption of 6G technology.

Amongst those institutions actively involved in 6G research is Taiwan's Institute of Economic Research (TIER). Established in 1976 by Koo Chen-fu, TIER was the first private independent think tank in Taiwan, beginning a mission to actively engage in domestic and foreign macroeconomic and industrial economic research (*Taiwan Institute of Economic Research*, 2007). The project team worked with TIER's Research Division 1 team in collaboration with the Metal Industries Research and Design Center and Auray Technologies to anticipate 6G development and deployment hurdles in Taiwan. The team satisfied this goal by ultimately providing TIER with research and recommendations outlining frameworks and policies for 6G adoption in Taiwan.

During the background research, the team delved into the impact of internet access on Taiwan's social and economic development, with the goal of answering the question, "How does internet access affect social development in Taiwan?" In addition, the team researched the historical and current developments in 5G to address the question, "What is the current state of 5G in Taiwan?" Lastly, the team explored the current state of research and development in 6G, with the hope of answering the question, "What is the current state of 6G development in Taiwan?" To support the initial findings and research the team conducted interviews and surveys to satisfy the following research objectives:

1. To determine the technical feasibility of 6G, and the historical issues of 5G.
2. Determine the public perception of 6G, IoT, and AI.

Ultimately the team was able to come up with several recommendations to provide to TIER to shape the future of 6G in Taiwan. These recommendations fall into the following categories:

1. Infrastructure
2. Policy management framework
3. Public transparency, trust, and education

The team hopes Taiwan can leverage these recommendations, and insights from the paper, to ensure a successful rollout of 6G. Ultimately, these recommendations could help Taiwan with advancement of decent work and economic growth, development in industry, innovation and infrastructure, and reduced inequalities.

2 Background

To enhance the reader's understanding and facilitate navigation through the technical terms and concepts discussed in this chapter, the team provided a glossary (see Glossary).

Exploring Taiwan’s telecommunications landscape uncovers a complex interplay between internet access, advanced telecom technologies, and socio-economic dynamics. This background chapter sets the stage for a comprehensive analysis by explaining the significance of these factors in shaping Taiwan’s future telecom technology trajectory. Beginning with a glimpse into recent telecom advancements and the influential role of semiconductor companies like Taiwan’s Semiconductor Manufacturing Company (TSMC), the narrative then unfolds toward understanding the profound impact of internet access on Taiwan’s social development and economic growth. The following section proceeds to delve into the current state and development of 5G and ends by examining the horizon of 6G research and development. The background chapter intends to provide insights and context regarding the current state and trajectory of the telecom industry in Taiwan and its global ramifications.

2.1 Foundations of 5G in Taiwan

2.1.1 Telecom in Taiwan

Taiwan's rapidly evolving telecommunications market plays a vital role in developing 5G, 6G, and future communications technology, as it fosters a competitive environment that encourages continuous technological innovation and infrastructure investment. This section aims to provide insights into Taiwan's dynamic telecommunications market.

Companies like Chunghwa Telecom, FarEasTone, and Taiwan Mobile dominate the Taiwan telecommunications market with 38.91%, 25.9%, and 24.02% market shares,

respectively, and lead in 5G and 6G developments (*Communications Market Report*, 2022). They provide advanced mobile communication services and, more importantly, direct the deployment and development of 5G technology. The release of 5G broadband licenses in 2020 by the National Communications Commission (NCC) marked a significant milestone for Taiwan, as it demonstrated the government's commitment to enhancing the nation's digital infrastructure and reducing the digital divide. This release allowed for fair competition and ensured multiple providers could access the necessary resources to provide broadband services (*Communications Market Report*, 2022). Furthermore, this move catalyzed the recent developments and adoptions of 5G across the island, enabling faster internet speeds, lower latency, and higher bandwidth - thereby assisting innovative IoT applications such as smart manufacturing, transportation, and urban living.

Additionally, following the introduction of 5G, the mobile communications segment in Taiwan exhibited healthy performance in recent years, with revenue rebounding to NT$155 billion in 2021 after declining by NT$71.7 billion from 2012 to 2020 (*Communications Market Report*, 2022). Intensified competition, market saturation, and the lack of new subscribers, especially in 4G, contributed to the decline in revenue in past years. The number of subscriptions remained relatively unchanged at around 29 million subscribers from 2012 to 2020 (see Figure 1) (*Communications Market Report*, 2022).

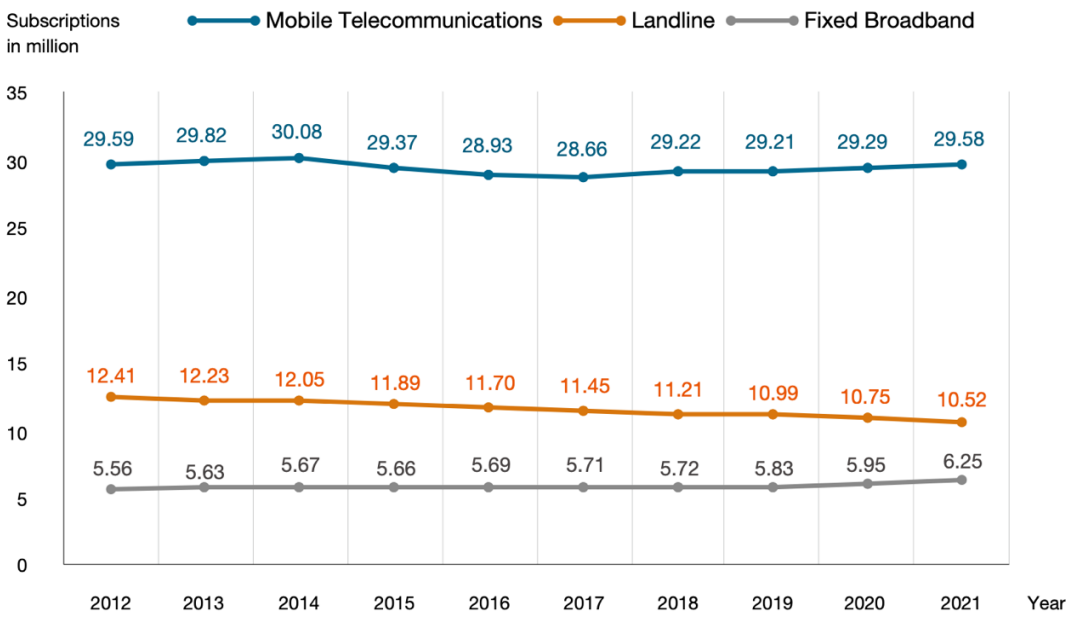

Figure 2: Number of Telecom Users in Taiwan (Communications Market Report, 2022)

The impact of 5G on the market suggests significant growth potential as more people continue to adopt and turn to 5G despite the increases in the plans' pricing (*Communications Market Report*, 2022). After fluctuations in past years, the average revenue per user (ARPU) for mobile telecom companies is beginning to stabilize and is showing further signs of growth, from NT$438 in 2020 to NT$444 in 2021 due to the number of 5G users increasing as well as the average cost of their plans (*Communications Market Report*, 2022).

The growth in the industry highlights the viability of, and demand for, advanced telecommunications technologies, encouraging further investment in research and infrastructure to enhance the capabilities and reach of 5G networks. Additionally, the stabilization and growth of ARPU indicate that consumers are willing to pay for the improved services and features offered by 5G, which is still not fully complete, providing a strong incentive for continuous improvement and expansion of the technology. This positive trajectory sets the position of 5G as a cornerstone of modern telecommunications. Moreover, in a survey conducted by the National Communications Commission, more than a third of users listed "[dissatisfaction] with 4G Mobile Internet Speeds" as their reason for switching to 5G (see Figure 3). Other reasons for users

switching plans ranged from incentives and promotional upgrades to excitement for the new technology (*Communications Market Report*, 2022). The growing acceptance of this new technology lays a foundation for developing and adopting future generations of wireless technology, such as 6G, which will build upon the advancements and lessons learned from 5G deployment.

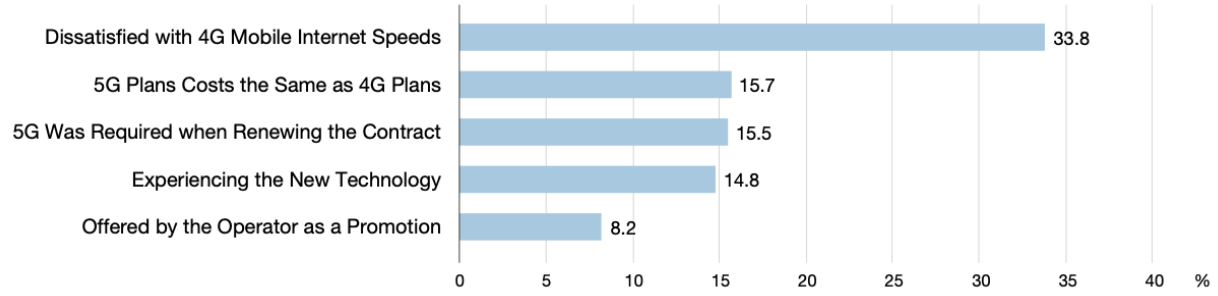

Figure 3: Top 5 Reasons for Switching to 5G in Taiwan (Communications Market Report, 2023)

Taiwan's prominence in 5G aligns with its goal of developing its position as one of the leaders in global Information and Communication Technology (ICT). The nation's ICT industry is widely recognized for its contributions to the global market. In 2019, Taiwan's ICT industry played a vital role in the launch of Rakuten Mobile's Open Radio Access Network (O-RAN) in Japan. This O-RAN service aims to improve mobile network connections and increase flexibility and innovation in network technology (*Taiwan - NextGen Telecom Services*, 2024). Furthermore, their exploration of Low Earth Orbit (LEO) satellite communications, led by the National Science and Technology Council and the Ministry of Digital Affairs, shows the country's commitment to the development, research, and resilience of its communication infrastructure (*Taiwan - NextGen Telecom Services*, 2024). As Taiwan continues to innovate and expand its telecommunications capabilities, the potential for 6G technology looms on the horizon, potentially further transforming the landscape with even greater speeds, efficiency, security, and support that could redefine the future of connectivity on the island.

2.1.2 Taiwan's Semiconductor Manufacturing Company

One of the most critical components of any modern technology is semiconductors. Semiconductors are materials that can conduct electricity under specific conditions, making them essential for various technological components. They are the backbone of modern electronics and have driven technological advancements across industries, dating back to the mid to late 1800s (Lukasiak & Jakubowski, 2010). From the evolution of 5G to the impending arrival of 6G, semiconductors continue to be at the forefront of innovation. This section provides understanding into Taiwan's largest semiconductor producer, TSMC.

TSMC is not only the biggest semiconductor manufacturer in Taiwan but also one of the leading semiconductor manufacturers in the world and is instrumental in developing 5G technology on the island. Taiwan has four of the nine largest foundries in the world by market share with companies like TSMC, United Microelectronics Corporation (UMC), Power chip Technology, and Vanguard International Semiconductor Corporation (VIS), with global market shares of 56.7%, 7.7%, 2.4%, and 1.5% respectively (see Figure 4). The combined output from these four Taiwanese companies accounts for 68% of the world's semiconductor market (Sacks, 2023).

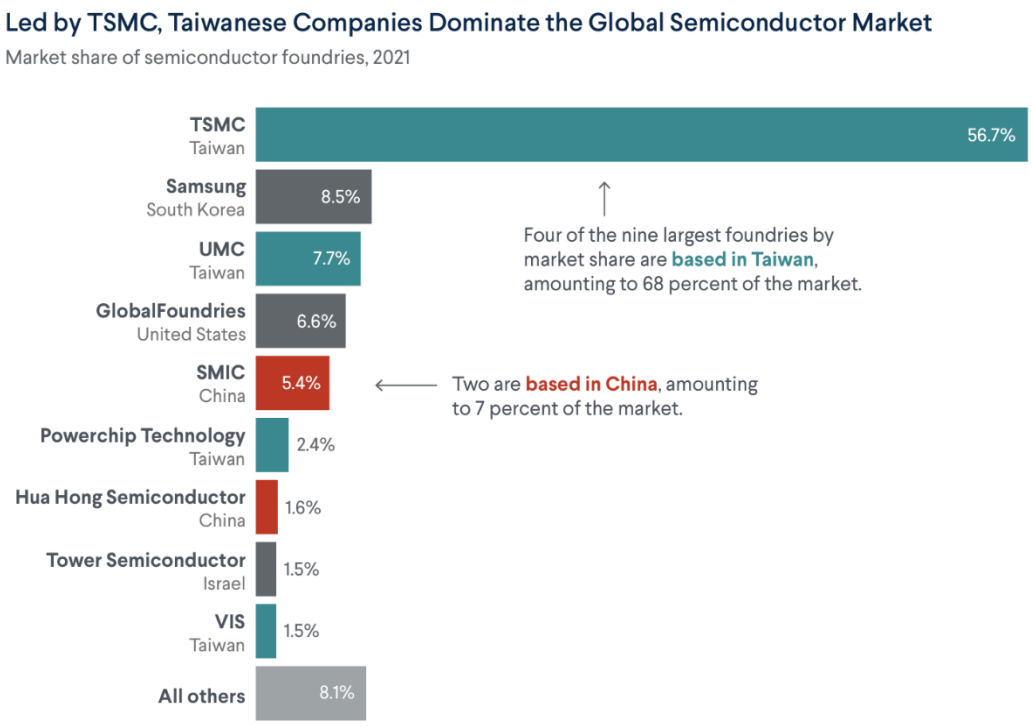

Figure 4: Largest Taiwan Semiconductor Companies (Sacks, 2023)

TSMC shipped two million 5nm technology wafers in 2022, used in various IoT devices including sensors, smartphones, AI, networking, and High-Performance Computing (HPC) to countries including the United States, China, Japan, South Korea, amongst many others (*TSMC – Customer Newsletter*, 2022).

Additionally, TSMC has amassed a comprehensive portfolio of Mixed Signal (MS) and Radio Frequency Complementary Metal-Oxide-Semiconductor (RF CMOS) technology (MS/RF), ranging from 0.5µm to 6nm, which supports a wide range of communication applications. Notably, their RF technology played a crucial role in enhancing the cost-benefit ratio of 5G technology, making it more accessible and efficient (MS/RF - Taiwan Semiconductor Manufacturing Company Limited, 2010). Other TSMC's offerings include the 40nm Silicon on Insulator (SOI) process for 5G sub-6 GHz RF Front-End Module (FEM) applications and the N28HPC+ process for 5G millimeter wave (mmWave) FEM designs. They were also the first foundry to offer 5G-specific process technology with the introduction of the 16nm FinFET

Compact Radio Frequency (16FFC RF) node, which can find applications in Wi-Fi6/6E, True Wireless Stereo (TWS) earphones, 5G RF transceivers, and automotive radar sensors. Furthermore, TSMC provides N6 radio frequency (N6RF) technology, enhancing power efficiency for future generations of Wireless Local Area Networks (WLAN), TWS earphones, and 5G RF transceiver integrated circuits (*MS/RF - Taiwan Semiconductor Manufacturing Company Limited*, 2010).

Semiconductors are necessary for developing and manufacturing modern technology. Their role in powering 5G, AI, and IoT and the impending arrival of 6G is undeniable. TSMC's dedication to advancing semiconductor technology ensures that it will continue to be a driving force in shaping the future of communication technology. Additionally, TSMC's innovations contribute to the country's societal and economic development, nurturing technological innovation, fostering job creation, and attracting investments. As researchers and manufacturers delve deeper into the intricacies of 5G and prepare for the arrival of 6G, it is evident that the semiconductor industry's evolution will remain closely intertwined with worldwide technological progress.

2.2 Impact of internet access on Taiwan's social development

Taiwan has seen significant growth in its electronics sectors, and in conjunction with that comes growth in telecommunications. Both sectors have tremendous effects on its economy, and with growth to the economy comes growth in social development. This section will unpack the impacts of telecommunications and internet access on social development in Taiwan.

A study conducted in the United States analyzes the impact of computer technology on a society, coming to two hypotheses that both point towards technological advancements improving the economy. The study focuses on the United States, but the claims support the fact that Taiwan's economy will benefit from advancing telecommunications technology (*The Internet*

and the New Economy, 2000). Examining the effects of internet access on productivity, two key hypotheses emerge: the Diffusion Hypothesis and the Concentration Hypothesis. The Diffusion Hypothesis suggests that the lag time between the creation of the internet and its wide-spread adoption explains why the economic benefits only manifested years after its creation. This aligns with the notion that the internet enhances communication, supply chains, and business practices, impacting productivity positively. This could have also be an effect of the lag between the adoption of the internet and the world wide web. Meanwhile, the Concentration Hypothesis proposes that the computer manufacturing industry causes economic acceleration. Regardless of which hypothesis is more valid, the overall impact of the internet on productivity and the everyday lives of people around is evident (*The Internet and the New Economy*, 2000).

The effects of the internet on productivity extend to the broader economy, emphasizing the importance of technology, particularly telecommunications, as a primary source of economic growth. Trends in the United States indicate an upward trend in productivity growth, especially post-1999, correlating with the rise in use of the internet (*The Internet and the New Economy*, 2000). This correlation underscores the transformative influence of the internet on societal and economic structures. These patterns also apply to Taiwan. The effects of internet usage on Taiwan's social development are equally profound, contributing significantly to economic growth, increased productivity, and the evolution of a more interconnected and efficient society. The internet emerges as a key factor in shaping the economy, influencing how businesses operate, communicate, and contribute to the overall progress of the nation (*The Internet and the New Economy*, 2000).

Just as the internet shaped the United States' economy in the 2000s, it has also re-defined the e-commerce and advertising markets in China, as highlighted in Zhao, Xiong, and Fang's 2016 research. During the 5-year period from 2010 and 2015 the number of people shopping online in China grew 161%, from 158 million to 413 million, while their total population on the internet grew by only 42%, as seen in Figure 5 (Zhao et al., 2016, 5). This demonstrates

a massive improvement in their e-commerce sector. During this same period, their revenue from e-commerce grew 260%. This demonstrates advances in both China's online community and their ability to market to those people (Zhao et al., 2016), as well as the adoption of the smartphones and them being the leading driver in online activity in most countries.

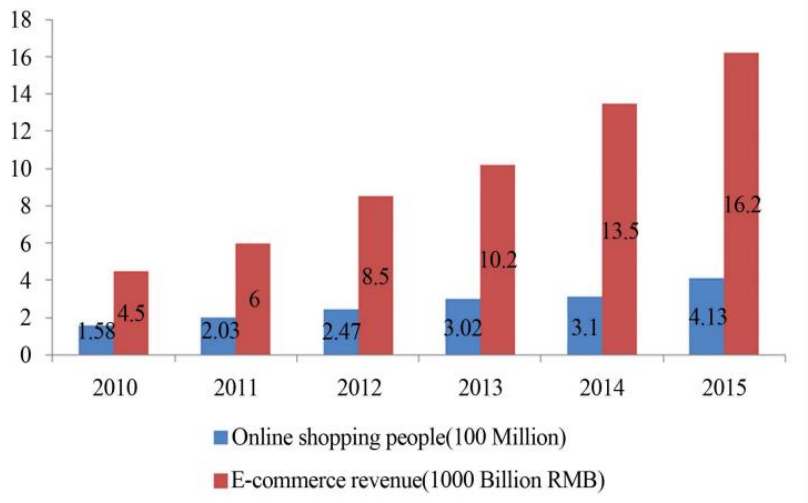

Figure 5: Chinese E-commerce revenue and people shopping online vs year. RMB is China's currency (Zhao et al., 2016, 6).

Seeing these statistics makes the correlation between internet usage and economic prosperity clear. The study goes further and mathematically proves this correlation using the data, finding that China's GDP is positively correlated to the number of people on the internet (Zhao et al., 2016). Other studies have verified the link between internet usage and economic development (Chen & Zhang, 2015; Manyika & Roxburgh, 2011). If China follows the predicted trend, their economy will surpass the GDP of the United States in 2030, due to this giant increase in revenue from the internet. China's shift into the digital world has not only affected their economy but has also led to changes in various sectors, including a potential decline in online product resellers, and reduced reliance on traditional communication methods (Zhao et al., 2016). As Taiwan navigates its own path of social development, the insights gleaned from China's experience with internet-driven economic growth can serve as a valuable guide, offering

lessons on adaptability, connectivity, and the vast potential for positive transformation (Zhao et al., 2016).

Internet access in Taiwan has a profound impact on the quality of life for its residents, as evidenced by Liang's 2011 study. His research reveals that the internet has a significant positive effect on various aspects of quality of life. With 90.4% of Taiwan's residents owning computers and 80.59% having internet access in 2006, the study surveyed 3024 respondents using a questionnaire that covered 24 items on quality of life and 26 items on internet usage (Liang, 2011, 2-3). Results indicate a positive correlation between internet usage and quality of life, including factors like social-economic status and self-esteem. Access to government services over the internet is particularly impactful as it shows people tangible manifestations of their tax money. While the study notes potential negative effects, such as isolation for those relying on the internet excessively, overall, the findings underscore the internet's positive contribution to enhancing the quality of life for individuals in Taiwan, especially in areas like daily life, business, and government interactions (Liang, 2011).

With the vast benefits brought about by internet access, those without it are left behind. This phenomenon, the digital divide, is a gap between those with access to modern technology and those without (Sparks, 2013). The digital divide in Taiwan includes a substantial gap in internet access between high and low-income groups. In high-income brackets, 96% enjoy internet connectivity, whereas only 26% of those in low-income brackets have access, a disparity exacerbated by the increasing number of low-income individuals since 1995 (Huang & Cox, 2016). This division harms disadvantaged communities, hindering learning opportunities and impeding alternative revenue streams, perpetuating a self-reinforcing cycle of inequality; those with access to the internet can leverage it for personal gain, while those without it are left behind.

A 2022 meta-study by Lythreatis et al. identified several other contributing factors to the digital divide. The most prevalent factors the paper identified are socioeconomic – as discussed

above – sociodemographic, and personal-related (Lythreatis et al., 2022). Personal-related factors include trust, privacy concerns, and religion among other things. The breadth of these factors highlights the scope of this issue. No single effort will be able to tackle this issue, but it will require a widespread effort and awareness combined with ample time (Lythreatis et al., 2022).

One study took a different approach, focusing on the necessity of matched hardware, software, and infrastructure (Huang & Cox, 2016). These three elements need to be from similar technology generations to be interoperable, making incremental upgrades challenging. In general, vendors strive for backwards compatibility, but only so many different generations of technology can be fully compatible. This also causes issues with smart phones; phone carriers only support cellular versions so far back. Ultimately this can lead to situations where people have limited access to the internet for hardware, software, or infrastructure due to reasons out of their control. Huang & Cox attempted to overcome this challenge in their 2016 paper by proposing a social entrepreneurial system – applying an entrepreneurial approach to social problems. The study advocates leveraging homeless shelters as internet access points and innovative funding mechanisms, such as taxing IT suppliers. These multifaceted approaches, combining government and community-based solutions, are crucial to ensuring inclusive internet access and mitigating socio-economic disparities (Huang & Cox, 2016).

2.3 Current state and development of 5G in Taiwan

Before delving into the development of 6G, it's imperative to reflect on and refine past implementations, particularly in Taiwan's current telecommunications landscape. This section not only explores the early stages of 5G development and adoption but also addresses challenges in implementation and ensuring secure adoption to propel future communications technology developments.

2.3.1 Current 5G Industry in Taiwan

Understanding the efforts towards future deployments is crucial as they signify the transition towards faster and more efficient communication infrastructures, essential for supporting emerging technologies and fostering economic growth and innovation. This section primarily focuses on Taiwan's efforts to achieve digital inclusivity by deploying 5G technologies and transforming its telecommunications landscape.

Taiwan is making significant efforts to achieve digital inclusivity, bridge the digital gap, and ensure fair access to high-speed internet across all communities by maximizing the potential of 5G technologies and future technological developments (*Communications Market Report*, 2022). Additionally, the telecommunications landscape is undergoing a significant transformation with the introduction of 5G technology alongside the continued presence of 4G/LTE networks. While 5G is steadily gaining traction, 4G and LTE maintain a dominant position in the market, especially considering its established infrastructure and widespread adoption. In Taiwan, for instance, in a 2022 National Communications Commission survey, 70% reported still using 4G, with reasons including satisfaction with the existing speed of 4G connections and concerns regarding the maturity and readiness of 5G networks. Some security concerns included personal information leaks and internet fraud. However, these issues and concerns stem from the current state of 5G, which is still in its infancy stages of development and adoption. Developments and advancements in the field will continue to address these concerns. Moreover, device compatibility issues were among the reasons for customers not switching, as the transition to 5G requires newer and more expensive mobile phone models (*Communications Market Report*, 2022). This further compounds the ongoing digital divide as it exacerbates disparities in access and affordability.

The push and adoption of 5G worldwide is apparent, with over 210 telecommunication operators launching commercial 5G services and more than 620 million 5G users globally as of

the first quarter of 2022 (*Communications Market Report*, 2022). 5G technology provides significantly faster data speeds, lower latency, and increased network capacity, which are essential for supporting emerging technologies like IoT, Augmented Reality (AR), Virtual Reality (VR), smart manufacturing, and smart cities. Moreover, projections indicate a substantial rise in 5G users, with an estimated 4.4 billion users expected by 2027, surpassing the number of 4G users (see Figure 6) (*Communications Market Report*, 2022).

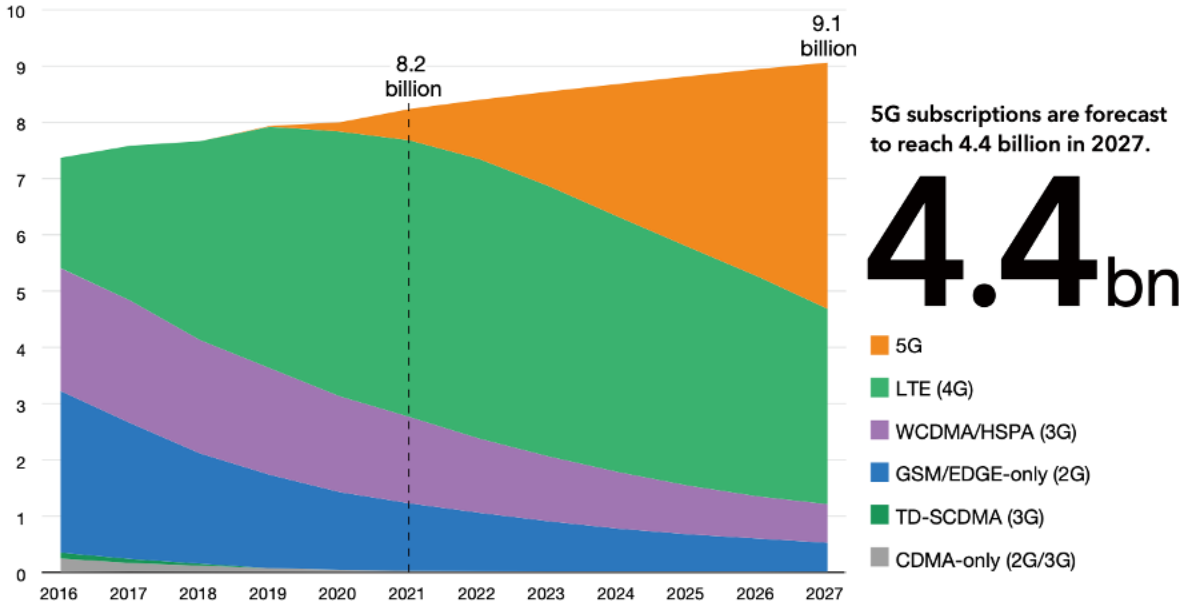

Figure 6: Global Users of Mobile Communications (Communications Market Report, 2022)

The major telecommunication operators in Taiwan are Chunghwa Telecom, FarEasTone, Taiwan Mobile GT, and T Star. Among them, Chunghwa Telecom provides the fastest 5G data speeds, with a median download of 361.83 Mbps. FarEasTone and Taiwan Mobile with median download speeds of 284.70 Mbps and 217.78 ranked second and third place, respectively. GT and T Star ranked fourth and fifth, with median download speeds of 190.48 Mbps and 113.85 Mbps (see Figure 7).

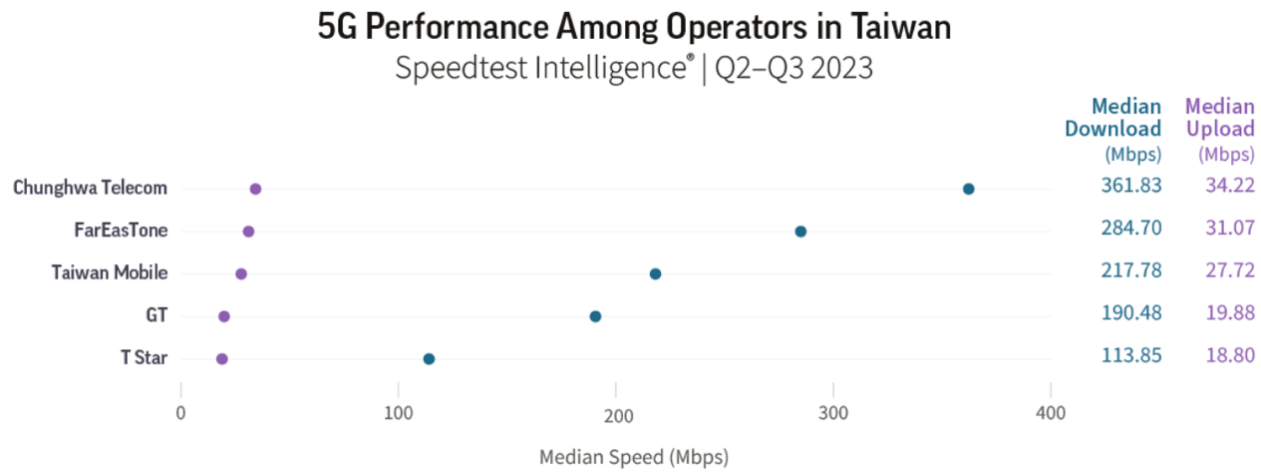

Figure 7: 5G Performance Among Operators in Taiwan (Johan, 2023)

Furthermore, Chunghwa Telecom also leads in 5G coverage, reaching 97.6% of serviceable locations in Taiwan with 5G coverage (see Figure 8); FarEasTone and Taiwan Mobile are close behind, having 88.9% and 85.6% coverage, respectively (Johan, 2023).

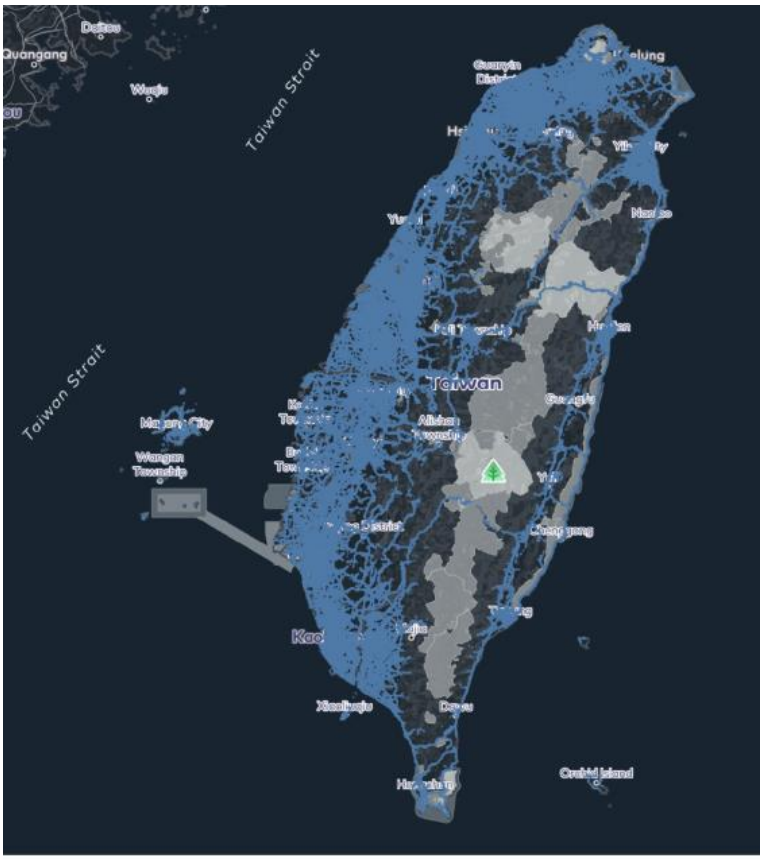

Figure 8: Chunghwa 5G Network in Taiwan (Johan, 2023)

Taiwan’s recent development of 5G is evident. Taiwan’s 5G network achieved a median download speed of 263.35 Mbps in Q3 2023, which outperforms neighboring countries like Vietnam (257.95 Mbps), China (245.94 Mbps), Hong Kong (136.51 Mbps), the Philippines (124.58 Mbps), and Japan (102.72 Mbps) (Johan, 2023). This affirms Taiwan's commitment to technological advancement and its position as a leader in telecommunications innovation.

2.3.2 Challenges in 5G Rollout and Development

As Taiwan prepares for the development and deployment of 6G, it is crucial to assess and evaluate the initial acceptance and progress of 5G. This section focuses on the challenges and risks encountered during the initial phases of 5G implementation in Taiwan, including issues with network performance, regulatory barriers, and technical limitations, underscoring the ongoing digital divide within the country.

5G network implementation in Taiwan has faced significant challenges, leading to inconsistencies and problems in the technology's performance, such as slower signals and connections, especially in more rural areas. Despite being several years into the rollout, the current state of 5G in Taiwan has yet to meet the initial expectations. One of the reasons is that “most network operators began their 5G rollouts by deploying non-standalone 5G networks” (Koziol, 2023). This means that it is built upon existing 4G during the initial deployment stages, and while it is more cost-effective, building upon existing 4G architecture has also resulted in less efficient networks than standalone 5G systems.

Furthermore, regulatory barriers and permitting issues with 5G infrastructures and towers, particularly in densely populated urban areas, hindered the expansion of 5G networks and the deployment of new cell sites. One of the most difficult challenges “is simply finding a spot to put a new cell site in the first place” (Koziol, 2023).

In addition, Taiwan faced numerous challenges with millimeter-wave deployment, a technology which offers lower latencies and higher data rates. Technical limitations and the high

cost associated with millimeter-wave technology have limited its uptake, especially in suburban and rural regions where its short propagation distance poses challenges (Koziol, 2023). These struggles highlight the complexities inherent in deploying new cellular technologies.

The challenges encountered during the initial phases of 5G implementation and development in Taiwan underscore the ongoing digital divide within the country. While rural regions continue to face challenges with millimeter-wave deployment, urban areas face challenges in permitting and finding areas to deploy new cell sites. The gaps within 5G development hinder equitable access to high-speed internet and worsen socioeconomic inequalities, as 5G leaves behind in the rapidly evolving digital landscape individuals and communities with limited access to 5G technology. Taiwan strives to bridge this divide, addressing infrastructure gaps and implementing policies to ensure widespread and inclusive access to 5G networks foster technological advancement and societal progress.

Additionally, implementing new technologies such as 5G pose inherit risks, and addressing these risks carefully is crucial to ensuring network security and integrity. Policy makers often overlook the issue of using components from untrusted companies, which could expose individuals to various vulnerabilities, such as malicious software, hardware flaws, and counterfeit components. These risks not only jeopardize the confidentiality, integrity, and availability of network assets but also make classified data vulnerable to interception, manipulation, or disruption when traversing untrusted telecommunication networks (*Overview of Risks Introduced by 5G Adoption in the United States | CISA*, 2020).

Furthermore, the increased number of components and complexities within the 5G network expand the potential for malicious actors to exploit vulnerabilities. Despite security enhancements, discovering new vulnerabilities remains a concern, especially considering the integration with legacy networks like 4G LTE, which may cause 5G to inherit existing weaknesses. Compatibility challenges further these risks, as custom 5G technologies from untrusted vendors may not meet compatibility and safety standards, leading to difficulties in

maintenance, updates, and replacements, potentially driving up costs and delaying deployment (*Overview of Risks Introduced by 5G Adoption in the United States | CISA*, 2020). Overall, mitigating these risks requires careful planning, government regulations, robust security measures, and manufacturing and industry collaboration to ensure the safe and efficient adoption of 5G technology.

Looking ahead to the development and deployment of 6G, reassessments and strategic adjustments are essential to overcome the challenges encountered during the initial rollout of 5G in Taiwan, which includes:

1. Adopting a proactive approach to network architecture, focusing on standalone 6G systems from the beginning, that can enhance network efficiency and performance. This may involve companies and the government investing more in research and development to address and offset the potential costs.
2. Addressing regulatory barriers and streamlining permitting processes for 6G infrastructure deployment will be critical to accelerating network expansion, particularly in densely populated urban areas.
3. Anticipating and mitigating challenges associated with millimeter-wave technology, such as technical limitations and high costs, will ensure the widespread adoption of 6G, especially in suburban and rural regions.
4. Managing risks related to the increase in complexity and components, potential vulnerabilities, and compatibility challenges would decrease the disruptions in network operations and reduce threats to data privacy and security.

Collaborative efforts between industry stakeholders and government bodies will be of utmost importance in navigating these complexities and positioning Taiwan at the forefront of 6G innovation and deployment.

2.4 Current State of 6G Research and Development

2.4.1 Technical Implications of 6G

The entrance into a new era of the internet with the development of 6G wireless networks is underway. Experts anticipate that this technological leap forward will significantly enhance the capabilities of digital communication systems, enable the realization of a fully interconnected and intelligent world, fill the gaps in the existing 5G network, and revolutionize data transfer (*Vision and research directions of 6G technologies and applications*, 2022). As the foundational technologies for 6G begin to emerge, the team can now analyze the current vision for 6G, its innovations, global initiatives, key technologies, challenges, and Taiwan's role in this global endeavor.

The integration of 6G promises to dramatically enhance the capabilities of the Internet of Things (IoT). With 6G's capacity for higher data rates, lower latency, and increased reliability, IoT devices can finally achieve more sophisticated levels of autonomy and intelligence. This evolution will harness the power of edge computing, where data processing occurs closer to the destination, dramatically reducing response times and enabling real-time analytics (Ziwei et al., 2024). Furthermore, 6G will facilitate a denser network of IoT devices, supporting the deployment of billions of sensors and actuators capable of interacting with their environment in unprecedented ways. This innovation derives from the inter-machine communication that is set to improve operational efficiency. This will unlock potential for IoT ecosystems across diverse sectors including healthcare, where remote monitoring and precision medicine can thrive; in urban planning, through smart infrastructure capable of adaptive, real-time responses to city life; and in agriculture, with precision farming techniques that optimize resource use and crop yields (Nižetić et al., 2020). The combination of 6G, AI, and IoT promises a future where seamless

connectivity and intelligent automation pervade every aspect of daily life, making the concept of a truly smart, interconnected world a reality.

The vision for 6G is to transcend the limitations of current and forthcoming 5G technologies with the integration of additional frequency bands, such as sub-6GHz and others, to support a vast array of applications requiring massive data transmission capabilities. The advent of the Internet of Everything (IoE) and the exponential rise in machine-to-machine (M2M) broadband subscriptions have highlighted critical security challenges and the demand for unprecedented levels of data transmission capacity. By 2030, experts estimate a leap to 257GB per month in per-user internet data usage, a stark increase from the current average of 5.3GB (*Vision and research directions of 6G technologies and applications*, 2022), reflecting the massive data demands of future applications. Researchers believe 6G will revolutionize sectors with substantial data transmission requirements and introduce capabilities enabling innovations like ultra-reliable low-latency communications (URLLC), massive machine-type communications (mMTC), and enhanced mobile broadband (eMBB). These innovations will facilitate advancements in smart cities, autonomous systems, virtual reality, and more, offering a glimpse into a future where digital and physical realities converge (*What's the Latest on 6G?*, 2023).

2.4.2 Social Implications of 6G

In addition to these technological advancements, 6G advocates expect this technology to address and significantly improve the social aspects of internet access. The hope is 6G will reduce the digital divide by providing universal, high-speed internet coverage even in remote and underserved areas, thus enabling greater access to education, healthcare, and economic opportunities for all. By improving connectivity and supporting smart city initiatives, 6G could enhance the quality of life and foster more sustainable, efficient, and livable urban environments. Moreover, with its focus on security and privacy, 6G promises to create a safer digital environment, enhancing trust and promoting wider usage of the internet (*6G Enabled*

Smart Infrastructure for Sustainable Society, 2021). This holistic approach underlines the vision of 6G not only as a technological leap but also to advance societal well-being and inclusivity.

However, alongside the potential benefits and technological advancements that 6G technology promises, there are significant concerns regarding privacy, security, and the potential for increased surveillance. One of the primary apprehensions is the risk of government overreach or "Big Brother" scenarios, where governments use the enhanced capabilities of 6G for invasive monitoring and control over individuals' lives. These concerns are not unfounded, as instances of privacy invasion and extensive surveillance in countries like China serve as cautionary tales. The sophisticated infrastructure of 6G, capable of supporting a vast amount of data transmission at unprecedented speeds, raises the potential for misuse in the hands of authoritative regimes, aiming to tighten their grip on information flow and personal freedoms (Tsuruoka, 2018).

For example, China's implementation of its social credit system and widespread surveillance network, leveraging existing telecommunications technology, illustrates the potential for technology to monitor and control citizen behavior extensively. The integration of advanced AI, facial recognition, and data analytics into public monitoring systems has sparked international debate over privacy rights and ethical governance (Yang, 2022). The deployment of 6G technology, with its enhanced data processing and connectivity capabilities, could exacerbate these issues, providing even more tools for pervasive surveillance and data collection without adequate privacy safeguards.

The development and global rollout of 6G technology thus necessitate a balanced approach, where the potential for societal advancement and increased connectivity is carefully weighed against the risks of privacy infringement and surveillance. It underscores the importance of establishing robust international standards and ethical guidelines to ensure that 6G technology serves the public good while respecting individual privacy and freedom.

2.4.3 Recent Developments in 6G

Government bodies, academic institutions, and the private sectors are leading research initiatives laying the groundwork for 6G (*Europe Launches the Second Phase of Its 6G Research and Innovation Programme | Shaping Europe's Digital Future*, 2022). These efforts encompass a broad spectrum of activities, including theoretical research, technological development, and establishing international standards. With its strong semiconductor manufacturing and telecommunications hardware foundation, Taiwan is positioned to play a crucial role in this global effort to move 6G forward. The commitment of the island to technological innovation, coupled with its strategic position in the global ICT supply chain, positions it as a key player in shaping the future of 6G technology.

The development of 6G is entirely anchored to cutting-edge technologies such as advanced AI, terahertz (THz) frequency bands, and next-generation mobile broadband. These technologies promise to deliver faster data rates, lower latency, and higher reliability compared to their predecessors. However, the realization of these benefits is not without challenges. Researchers and developers alike face technical hurdles, such as the development of THz components and the integration of AI with telecommunications networks. Moreover, regulatory challenges related to spectrum allocation and global interoperability standards also present significant obstacles. The journey towards 6G is still in its early stages, with companies extending the initial phases of research and development through the early 2020s (*Europe Launches the Second Phase of Its 6G Research and Innovation Programme | Shaping Europe's Digital Future*, 2022). Goals for prototype demonstration and the commencement of standardization processes should materialize by the late 2020s, leading up to initial deployments in the 2030s, as seen in Figure 9.

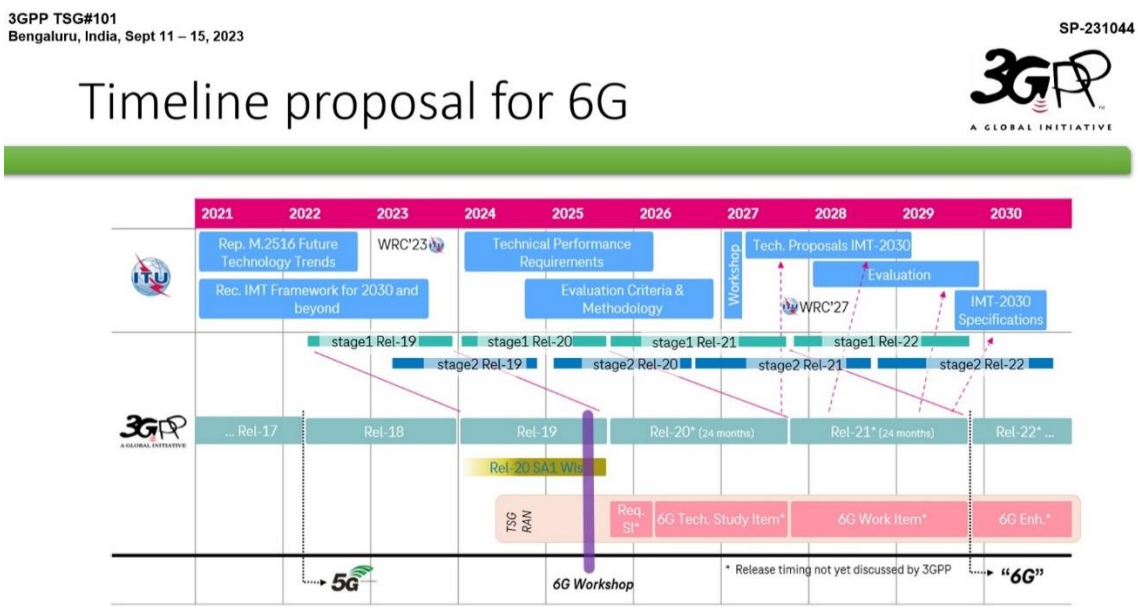

Figure 9 Timeline proposal for 6G (Free 5G Training [@5Gtraining], 2023)

These timelines, while tentative, hope to highlight the ambitious nature of 6G development efforts, aiming to deliver a transformative framework that will bring in the next era of digital innovation.

2.4.4 Taiwan's Role in 6G

The contributions of Taiwan to 6G research will likely be multifaceted, leveraging its strengths in semiconductor technology, telecommunications infrastructure, and international collaboration. Taiwanese companies and research institutions dominate the forefront of developing semiconductor technologies critical for 6G, from advanced chipsets capable of handling THz frequencies to innovative solutions for network equipment. Furthermore, Taiwan's active participation in international trade and partnerships underscores its commitment to contributing to the global 6G standards and technologies. These collaborative efforts not only amplify Taiwan's technological advancements but also ensure the country plays a role in shaping the future of telecommunications.

Taiwan is a major contributor to the manufacturing of information and communication equipment utilized globally. More specifically, the country has had a significant role in the development of 5G (see Section 2.3), and with 5G established they have already begun pivoting towards 6G. In parallel with developing wireless communication technology, Taiwan is working on the Internet of Things (IoT), with the IoT market expected to reach a revenue of US$9.27 billion in 2024 (Statista, 2023). The country has been such a powerhouse of technological development due to various advantages within the nation, specifically hardware. For global communication technologies, the hardware of superconductors is vital, and Taiwan is a leading developer and manufacturing of these key components being utilized. The Taiwan Semiconductor Manufacturing Company (TSMC) revealed in their 2023 report that the company's total revenue for the year was NT$2,161.74 billion (TSMC, 2024). Externally Taiwan continues to build its connections with the world for 6G development; the Alliance for Telecommunications Industry Solutions formed the “Next G Alliance” in Taiwan on October of 2020. The purpose of this newly founded alliance was to construct 6G research and standardization, along with network architecture and system equipment with the final deployment in mind. This new alliance helped create an ecosystem of a new communications industry, which will impact the future 6G landscape heavily. The 3rd Generation Partnership Project (3GPP) standards organization worked closely with Taiwan and is a part of their existing 6G group with planned collaborations with Innovative Optical and Wireless Network (IOWN) and Open RAN (Chen, 2022). The 6G-Sandbox project and Industrial Technology Research Institute’s (ITRI) “memorandum of understanding” (O’Halloran, 2024) has initiated collaboration between European and Taiwanese companies for the research of 6G. These connections show the continued effort from Taiwan to collaborate with global industry leaders of 6G.

Given Taiwan’s semiconductor and wireless communication equipment manufacturing and internet research, the country has proven it will continue to play a substantial role in the development of 6G alongside many of the other countries trying to get into this research space.

Globally, the nation has made many alliances with countries and industries to maximize progress efficiently and collaboratively. With so many global powers coming together, there have been many discussions around the actual timeline and feasibility for the development and adaptation of 6G (O'Halloran, 2024).

2.4.5 Future of 6G

From the initial research and development stages all the way to its rollout, 5G took nearly a decade to develop for commercial use, and 6G will likely have a similar projected track. The Thales Group noted that 3GPP will establish the technical specifications for 6G, with the initial definition process expected to commence in 2025. This groundwork will culminate in the release of the first 6G specification by the 3GPP in 2028, aiming for commercial deployment by 2030, as illustrated in Figure 9. One of the first significant milestones in the research of 6G occurred in June of 2023, when the International Telecommunication Union - Radiocommunication Sector (ITU-R) released their standard for 6G technology in a framework document. ITU-R is one of the three sectors of the ITU, which plays a critical role in the management of global radio-frequency spectrums and satellite orbits (ITU, 2024). The document covers key information and concepts of the usage of 6G, along with projected capabilities and timelines for the commercial use of the standard (Thales, 2023). As of late 2023, the research on the 6G wireless network is just beginning and is not yet fully realized and more of a concept. A research lab in China recently reached wireless speeds of over 200 gigabits per second using 6G technology (Remmert, 2023). Despite the lab conducting this experiment under controlled conditions, it still gives insights into the capabilities of 6G. Research and development will continue globally for the next half a decade at least with the end goal to create a commercial use wireless internet standard with incredible power and capabilities while also being extremely versatile. In parallel to global developments in 6G,

cellular companies and organizations in Taiwan have been researching telecommunications, spreading the benefits of social and economic growth to more people.

2.5 Summary

Exploring Taiwan's telecommunications landscape reveals a sector in significant transformation. Rapid advancements in 5G technology, the foundational role of semiconductor companies, and the broad socio-economic impacts of internet access drive this change. Furthermore, early research into 6G technology signals a future of continuous innovation and development. The resurgence in mobile communications revenue in 2021 underscores the positive influence of 5G, affirming Taiwan's ambition to reinforce its status as a global leader in Information and Communication Technology (ICT). Through innovative ventures such as Rakuten Mobile's Open Radio Access Network (O-RAN) in Japan and initiatives in Low Earth Orbit (LEO) satellite communications, Taiwan demonstrates its commitment to pushing the boundaries of telecommunications infrastructure (Abdel Hakeem, Hussein, & Kim, 2022).

The critical contributions of the Taiwan Semiconductor Manufacturing Company (TSMC) in 5G development, through advanced semiconductor production, highlight the indispensable nature of semiconductors in modern technology and their ongoing relevance as the industry pivots towards 6G. The analysis further sheds light on the profound influence of internet access on societal development, addressing the digital divide with innovative solutions aimed at providing equitable access to technology.

The Internet of Things in Taiwan plays a vital role in the progression of society and connectivity in the country, allowing for the exchanging of data between devices and systems efficiently. The development and application of 6G will enhance IoT with greater speeds and enhanced connection within its systems to allow for even greater and rapid societal

development, along with the positive effects on important industries and their research and development.

The examination of 5G's current state in Taiwan reveals the challenges in deployment and the potential risks introduced by adopting new network technologies. Looking ahead, the strides towards 6G research and development signal Taiwan's continued contributions and collaborative efforts in this emerging field. Taiwan's blend of technological innovation, strategic foresight, and international collaboration places it at the vanguard of the telecommunications industry, shaping the future of global connectivity and digital innovation.

In summary, Taiwan’s telecommunications sector is characterized by dynamic change and relentless innovation, propelled by developments in 5G and the preparatory steps towards 6G. This landscape raises crucial questions about the trajectory of technological advancements, their socio-economic impacts, and the challenges inherent in adopting such new technologies. These issues not only provide context for our research, but also shape the investigative paths and methodological approaches that the team undertook in the following chapters.

3 Methods

The methodology chapter delves into the approaches, methods, and procedures, which address the research questions and objectives regarding the current state of 5G in Taiwan, its implications for social development, and the anticipation and challenges of 6G implementation. This chapter begins with a concise overview of the research questions and their alignment with the problem statement. The next section details the research design approaches, providing the team with a robust framework that combines qualitative and quantitative methods and fits the needs and requirements of the project. Additional sections then delve into the rationale of the chosen methods, specific design and analysis of the surveys and interviews, ethics, and challenges faced during the research. By utilizing these methods, strategies, and reflections, the team aimed to identify the major hurdles for 6G delivery in Taiwan.

3.1 Research Questions

As stated in the *Introduction*, the team had three research questions, understanding the impact of internet access on social development, the state of 5G in Taiwan, and the state of 6G research. These questions focused on the social impacts of telecommunications and the technical aspects of 5G and 6G. Ultimately, these topics laid the framework for the methods section. The research questions have led to two main objectives for the project:

1. To determine the technical feasibility of 6G, and the historical issues of 5G.
2. Determine the public perception of 6G, IoT, and AI.

To satisfy these objectives, the team employed two methods:

1. An interview with industry experts on 5G and 6G adoption and development.
2. A survey with people in Taiwan on the application of 6G and AI in IoT

The methods both worked together to satisfy these objectives while – evaluating the expected hurdles in implementing 6G in Taiwan. Figure 10 condenses all this information graphically. Interviews with experts in Taiwan and the United States provided information about the technical side of the industry and development, and a survey focused on ascertaining people's perceptions of the application of 6G and AI in IoT. Together these methods yielded a broad dataset to answer the objectives and ultimately enabled the team to evaluate the hurdles in 6G implementation relevant to Taiwan's industries and society.

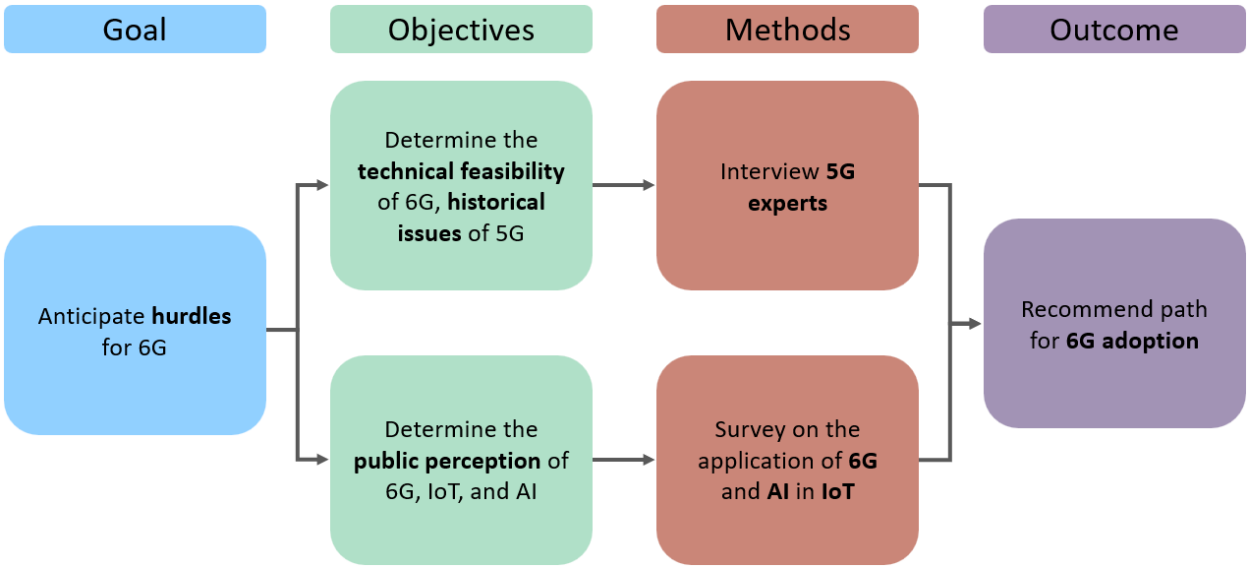

Figure 10: Methods Diagram, showing the goal, objectives, methods, and outcome

3.2 Research Design Approach

Prior to designing the research methods, the team considered different approaches, as this helped guide and form the basis of the investigation. To conduct successful and efficient research, the team first had to evaluate the advantages and disadvantages of qualitative, quantitative, and mixed methods methodologies. This guided the team's approach to addressing the complexities of the project.

Quantitative research approaches are ideally suited for addressing problems that require understanding the factors or variables influencing an outcome. Additionally, it allows the team to quantify, measure, and evaluate data, offering insights through trends, correlations, and other patterns in the data. This method typically involves surveys with Likert scale questions, which provide a quantitative description of a population's tendencies, attitudes, or opinions through a sample. Through closed-ended responses such as those found in questionnaires, quantitative research commonly aims to generalize findings to a larger population, given that the sample is unbiased and randomized (Creswell & Creswell, 2018).

Conversely, qualitative research is a type of research that focuses on understanding research problems by exploring the concepts behind them. It allows the team to gather information and gain deeper insights that may not be evident from surface-level data. In an unstructured interview, interviewees share their stories and experiences in a specific field without facing the bounds inherent in questions. On the other hand, a structured interview typically involves more open-ended questions, allowing the participants to share their ideas freely and capturing the essence of experiences related to the problems or phenomenon under study. Moreover, semi-structured interviews combine aspects from both structured and unstructured interviews (Creswell & Creswell, 2018).

Mixed methods research integrates both qualitative and quantitative approaches, allowing for a more comprehensive analysis of the research problem. This integration utilizes the strengths of each approach: qualitative data's open-ended insights and quantitative data's structured, numeric information. By merging these two data types, researchers can better understand the topics and problems. Three standard designs in mixed methods research are convergent mixed methods, explanatory sequential mixed methods, and exploratory sequential mixed methods, facilitating a nuanced interpretation of the overall results. In convergent mixed methods, investigators typically collect both forms of data roughly simultaneously and then integrate the information into interpreting the overall results. In explanatory sequential design,

researchers conduct quantitative research first, then build on the results and explain them in more detail with qualitative research. Exploratory sequential mixed methods are the opposite, where researchers first begin with a qualitative research phase, then they will use the information to build into a second, quantitative phase (Creswell & Creswell, 2018).

A convergent mixed methods approach enabled the team to best address the research objectives by offering a more holistic approach to the problem and help anticipate some of the hurdles in 6G in Taiwan.

3.3 Methods Rationale

The team decided to carry out semi-structured interviews with industry experts on 5G technology to collect detailed insights into the technical and operational challenges encountered during the 5G rollout. These experts, directly involved in the development, deployment, and troubleshooting of 5G networks, offered essential knowledge that illuminated potential challenges and successes relevant to the transition to 6G. The team structured interviews to allow experts to answer the research questions while having many opportunities to share their thoughts and opinions on the matter. The team designed the interview questions to encompass a range of experiences, focusing on involvement with 5G development, identification of roadblocks, ongoing issues, and views on 6G development. The team provided the interview questions in Appendix A: Telecommunication Experts Interview Questions. The method for identifying interview participants involved utilizing connections in the WPI (Worcester Polytechnic Institute) ECE department from team members connection and snowball sampling with knowledgeable individuals working in TIER. This qualitative method facilitated a thorough exploration of the complexities in telecommunications advancements. Figure 11 provides details about the interviewees. The team chose this number of interviews as a realistic balance between gathering enough data and leaving sufficient time for analysis.

Date Interviewed	Name	Profession	Location
4/4/2024	Ron Malenfant	Head of 5G strategy and Architecture for 5G America	USA
4/13/2024	Farinaz Edalat	Wireless/Satellite Communications Engineer (MIT PHD of electrical engineering)	USA
4/18/2024	Joseph Murphy	Research Associate at Worcester Polytechnic Institute	USA
4/19/2024	Aurelius	Assistant manager at Media Tek Inc	Taiwan
4/22/2024	Bob Everson	Sr. Director of Mobile Architecture and Ecosystem for Cisco Systems	USA

Figure 11: Interviewee Details – Date, Name, Profession, and Location

To augment the qualitative insights from the expert interviews, the team created surveys targeting Taiwan's general population. The team developed the survey questions in Appendix B: Public Survey. The survey presented the public with a potential use case of 6G and IoT in their lives, which enabled the team to gather the concerns and benefits that may potentially arise from these new technologies. Additionally, surveys gave the team an idea of how willing the Taiwanese public is to adopt new technology. This quantitative strategy allowed for data collection from a broad demographic and provided the team with a comprehensive view of consumer behavior and expectations. This information is critical for infrastructure development, guiding service offerings, and shaping policies and regulations for 6G technology implementation. Surveys aim to be extensive and cost-effective, so that the team could send it to many people for a generalized understanding of the population's views on these issues. The team sent out surveys using an email list provided by TIER, consisting of business partners. Additionally, the team performed in-person surveys near the metro stations in Taiwan and other popular areas to access a wider sample of the public. With this public access, the team hoped to receive 200 responses to the survey. The team chose this target as a realistic number of surveys to analyze in the given time.

3.4 Survey Methods

3.4.1 Design

The team designed the survey to gather insights into the public's perception of the integration of 6G, AI, and IoT (see Appendix B: Public Survey). The survey started by collecting demographic information, including age, gender, location, and familiarity with 5G and AI, to establish a contextual background for each respondent. Then, the team presented a hypothetical use case, depicting how these technologies could revolutionize the MRT and public transport experience by streamlining processes, enhancing convenience by eliminating physical payment methods and utilizing data-driven insights for service improvement (see Appendix B.3: Scenario Explanation). The team asked the respondents to evaluate this scenario, reflecting on their preferences and concerns with the proposed system. Then, the survey discussed potential pros (such as increased convenience and insightful data accumulation) and cons (including privacy risks and technology dependence) of the system (see Appendix B.5: Pros and Cons). Finally, the survey revisited the initial questions to determine if the respondents' views shifted after being presented with some advantages and disadvantages.

The team used the MRT example to provide a relatable scenario incorporating 6G and IoT. The team chose this use case because the expectation is 6G will be most applicable to businesses early on in its development. Asking the respondents the same questions again, allowed the team to examine how educational exposure could alter perceptions of emerging technologies.

The team distributed the survey to evaluate a comprehensive set of the population of Taiwan, encompassing several channels. This included in-person surveys at Taiwan's Taipei Main Station and at the Soochow University (SCU) campus, online surveys through social media, and an email list provided by TIER. The team intended to collect a broader demographic

reach through Taiwan's MRT station. While effective, this approach proved to be much too slow to garner large amounts of responses. The in-person surveys at Soochow were limited because the majority of Soochow students live in surrounding areas. To counterbalance this, the team utilized social media and email lists, expanding the demographic breadth, and ensuring a more representative sample. This multifaceted approach aimed to capture a wide-ranging view of societal readiness and concerns regarding the next wave of technological evolution in 6G, AI, and IoT.

3.4.2 Analysis

The team created a custom python script to process the large amount of survey data. Python is a general-purpose scripting language designed to be quick to write, making it perfect for this analysis. The data gets exported from Qualtrics as a CSV, a text file format, and passed into a python program to perform the analysis and generate graphs for the results. The final python program can be found here, on GitHub.

The program contains around 700 lines of code, most of which re-arranges the data and formats graphs. First, the team processed the data, converting the Likert scale questions to numerical values. Then, the team filtered data to only include complete responses from people living in Taiwan. With this processed data, the program makes an assortment of graphs. The team also applied more complex math to the data to pull out correlations between the questions, and to see how people's answers changed after being shown the pros and cons of the system.

3.5 Interview Methods

3.5.1 Design

The team conducted the interviews over the course of the project, which provided an expert look into the world of internet standards and what to expect for the future. The team designed the questions for the interviews to efficiently gather information from various experts. The interview questions are in Appendix A: Telecommunication Experts Interview Questions. The team chose topics that focused on 5G and the internet standards rollout and development, as well as any impacts the technology had on our society.

After the questions on 5G, the team focused on the development of 6G and its possibilities, connecting it back to the 5G rollout to garner the experts' opinions and beliefs on the future standard. The team designed the interview questions to connect seamlessly with the background of the paper, with the history and current state and development of 5G, and the process of 6G research and its possible applications being the focus. The team cut down the structure and content of these questions to have a more focused and applicable scope, as well as making the length of the interviews more manageable and to avoid gathering too much information that the background already covered.

Before the interviews, the team would send the interviewees the questions to allow them time to gather their thoughts. During the interviews, two members of the team would start a call with the interviewee to ask them the questions, probing for more information where applicable. The team members rotated through to give everyone a chance to perform interviews. Most of the interviews were conducted directly in English, so there were no language issues. The only exception to this is the interview with Aurelius. Details for this specific interview can be seen at the top of Appendix H: Interview with Aurelius Transcript.

After conducting the interviews, the team created a transcript by inputting the recording of the interview into the video editing software VEED.io, which created captions for the video. Each interview provided the team with new, valuable perspectives and opinions on various questions, as each expert's background and experiences were unique from one another.

3.5.2 Analysis

The team opted to conduct a qualitative analysis on the interviews. Initially the team planned to perform coding; however, the team realized the limited number of interviewees and their varied backgrounds would restrict the amount of applicable data that coding would yield. Ultimately, the team highlighted and analyzed the important aspects of each interview in the results section and using quotes when applicable. To mitigate bias, the team reviewed the analyses in pairs to allow for separate perspectives on the information. The team then compared notes and decided on the most neutral analysis. When discrepancies appeared in the notes or analysis, the team would review the interview together, discuss each of the analysis with reasoning and evidence, and finally come up with a unanimous conclusion.

3.6 Ethics

Before conducting any research, it was critical for the team to go through the proper channels to get approval. This involved obtaining approval from the WPI Institutional Review Board (IRB) to ensure the methods met ethical standards. Additionally, it was essential that the research ultimately benefited participants and contributed positively to society, the team showed this in the background section (see Section 2.2) (Creswell & Creswell, 2018). Another important factor before starting the research was understanding the dynamic between the team and TIER.

TIER being an independent think tank allowed the team's research to be very holistic, focusing on both the technical and social aspects of 6G. Ultimately this facilitated a more ethical research environment because the team was not under pressure to provide any specific outcomes.

During the research process, obtaining permission from subjects and transparently disclosing the study's purpose upheld ethical principles (Creswell & Creswell, 2018). The team used disclaimers with this information in *Appendix A.1: Interview* disclaimer and in the surveys, *Appendix B: Public Survey*. Additionally, the team acknowledged the importance of respecting cultural norms and conducted research to understand expectations for surveys in Taiwan, ensuring that the methodologies align with local customs and practices. The team did this by working with their sponsor, TIER, in Taiwan before sending out the survey. Some local customs include a heightened respect for seniority, face-saving, and respecting others' time (Taiwan - Culture, Traditions, Festivals | Britannica, n.d.). The team considered this when designing the methods by having them politely worded and brief to not disrespect anybody and to respect their time.

After data collection, ethical responsibilities persisted in the analysis and distribution of findings (Creswell & Creswell, 2018). The team analyzed the data ethically, with careful consideration given to maintaining the privacy and anonymity of participants. Overall, the team's commitment to respecting the privacy and confidentiality of participants' information underscores the team's dedication to ethical research practices and upholding the integrity of the study.

4 Results

This chapter offers a detailed analysis of telecommunications advancements and challenges through expert perceptions and public feedback. The team interviewed four experts from the U.S. and one in Taiwan to help gather both technical and social implications of 5G, 6G, AI, and IoT. Additionally, the team conducted a comprehensive survey to assess the perception of the Taiwanese public regarding the next generation of 6G and IoT systems. The expertise and data gathered from the expert interviews and public feedback provide an understanding of the current state and future trends in telecommunications.

4.1 Interviews with Telecommunication Experts

4.1.1 Interview with Ron Malenfant

The team’s first interview was with Ron Malenfant, who presented a unique perspective derived from his extensive engagement at Cisco and Sienna, as well as his position on the board of governors for 5G America. His vast experience provided understandings into the evolution, current state, and prospects of 5G and 6G technologies. Additionally, his experience with key industry players yielded a unique viewpoint about developing and strategically implementing telecommunications technologies, especially in sectors like smart cities and the commercial industry.

Malenfant expressed 5G's critical contribution to urban development, emphasizing its role as an evolutionary step in telecommunications that supports smart city infrastructure through various applications, such as densification and enhanced IoT capabilities. Densification is a process involves increasing the number of network connections within a given area to improve the network's capacity, coverage, and performance. This is especially relevant in urban

settings where the demand for high-speed mobile data and the density of users are both high. Malenfant says, "we're seeing vehicle to vehicle communications in the cities. We're seeing the need for private 5G for first responders, things like that going on. We're seeing 5G on the side of the massive IoT." As technologies become more complex and advanced, it is imperative to ensure that the network can meet the growing demands for data-intensive applications, like vehicle-to-vehicle communications and IoT, where many devices are connected and communicating. His perspective on equitable access to 5G underlines the importance of policy and strategic partnerships to extend coverage, particularly to underserved areas. Furthermore, having the government work with enterprises on initiatives and policies in the telecommunications sector to mandate coverage could serve as a model for addressing the digital divide.

Reflecting on the early adoption of 5G, Malenfant advocated for a more calculated approach to 6G, cautioning companies to "stay away from some of the new shiny widgets that have not been proven." He highlighted the importance of obtaining lessons learned from these experiences to avert similar issues with the 6G rollout in the future. The initial adoption of 5G technology came with numerous challenges, including steep implementation costs, complex integration with existing systems, and unforeseen technical hurdles. These challenges served as a stark reminder of the risks associated with deploying nascent, unrefined, and unproven technologies. From his experiences, Malenfant underscored the need for a more cautious and deliberate strategy when transitioning to 6G. He proposed that stakeholders should prioritize efficacy and reliability rather than rushing to be first, ensuring that new technologies are robust and secure and deliver on their promised benefits before widespread implementation. He stressed the importance of building on proven technologies and resisting the allure of untested innovations until the government and enterprises have thoroughly vetted the technology.

Malenfant is uncertain about the future of 6G technology since it is too far away to make an informed comment on its impact, cost, implementation, and public acceptance. However, he

recognized and acknowledged 6G's transformative potential, particularly in the IoT space. He believed that advancements in ORAN and energy-efficient technologies could bring a new era of development and compatibility. Additionally, he anticipated 6G to offer substantial benefits for businesses, industries, and enterprises, suggesting a shift in the field's focus from the general consumer market to a more specialized commercial application, which could exploit advanced features like network slicing and edge computing. Both network slicing and edge computing are advanced techniques that provide flexibility and more appropriate allocation of resources for these applications.

Malenfant discussed the ongoing journey of 5G development, hinting at the expansive scope for optimization and enhancement that 5G implementers still need to explore. His views on the strategic considerations for 6G, from IoT applications to AI integration, reflect a forward-looking stance on leveraging telecommunications advancements to shape future societal and technological landscapes.

4.1.2 Interview with Farinaz Edalat

The team's second interview was with Farinaz Edalat, a Wireless/Satellite Communications Engineer with a PhD from MIT. She offered profound insights into the forthcoming capabilities and potential societal impacts of 6G technology. With her extensive background in integrating satellite communications with terrestrial networks, Edalat is uniquely positioned to discuss the expected synergies and enhancements that 6G will likely bring to both these technologies.

Edalat explained that 6G will build upon the achievements of 5G by incorporating non-terrestrial networks (NTNs), which include satellites and high-altitude platforms. This integration has the potential to create a truly ubiquitous global communication network that extends reliable service to underserved areas, including remote and rural regions currently lacking any real service. The team expects this approach to bring revolutionary changes in global

communications, providing seamless coverage and more consistent service across diverse landscapes. Highlighting technical advancements, Dr. Edalat stated that “6G could dramatically reduce latency while significantly increasing throughput”. These improvements are essential for supporting real-time data-intensive applications such as remote medical procedures, autonomous vehicle operation, and advanced virtual and augmented reality experiences. Furthermore, she emphasized the crucial role of artificial intelligence (AI) in managing the increasingly complex data routes and network demands expected in a 6G environment. AI's ability to optimize network resources and energy consumption will be critical in maintaining the efficiency and sustainability of these expansive networks.

On the societal front, Edalat discussed how 6G could serve as a pivotal technology in bridging the digital divide—a persistent issue across global regions. “By providing high-speed, universally accessible internet connectivity, 6G could enable equitable access to critical educational and healthcare services,” thereby enhancing social and economic development worldwide. This could transform lives by opening new learning opportunities, facilitating innovative health solutions, and boosting economic growth in previously disconnected areas. However, she also cautioned against potential downsides, such as the risks associated with increased surveillance and privacy concerns. These issues could emerge as more sophisticated and pervasive network capabilities become commonplace with 6G deployment. She stressed the importance of adopting a cautious approach to the deployment of 6G technologies, highlighting the need for robust security measures and ethical considerations.

Throughout the interview, Edalat advocated for proactive and collaborative efforts among policymakers, engineers, and regulatory bodies to establish comprehensive frameworks that address these challenges. She urged that strong ethical standards and effective regulatory measures should guide the development and implementation of 6G to ensure that the technology enhances global connectivity without compromising individual rights and privacy. In summary, Edalat’s perspective not only emphasizes the technical potential of 6G but also

frames the technology as a tool for social equity, albeit one that requires careful and considerate handling to fully realize its benefits while mitigating associated risks.

4.1.3 Interview with Joseph Murphy

The team's third interview was with Joseph Murphy, a Research Associate at Worcester Polytechnic Institute in the Electrical & Computer Engineering department. More specifically, he works in the Wireless Innovation Laboratory, which researches wireless communications systems and focuses on Machine Learning (ML) aided communications systems. Murphy's team researched several areas, including security, user authentication, and data transfer. The interview with Murphy provided the team with understanding into the versatility of AI, ML, and 5G and how experts can apply them in wireless telecommunications.

Murphy expressed that one of the downsides of current 5G systems is that there is only one central system, and when it gets hacked, all users connected to the system will lose signal. Although there are usually alternate possible routes for networking, he spoke about the principle of the single node system. More specifically, Murphy describes how "If you deploy a network that has that cell tower that does all the management, that's a very weak center point, that if you were able to knock that node out, you'd cripple the entire network." He then suggested that shifting towards interconnected mesh networks would allow for not only increased efficiency but also to ensure a whole system does not fall when one network disconnects. He suggested using the RF Fingerprinting process, which is when a cell tower identifies your phone through specific physical characteristics of your device, which would further decrease the chances for cyber-attacks. Additionally, AI and ML would improve the security of a network by enabling it to identify and adapt to these attacks efficiently. Murphy further explains that "the reason for using these Machine Learning and AI applications is because they can do things a lot faster than a traditional system could, and most of the time, if you train them correctly, they can identify things that… you wouldn't think to program your system to identify."

Reflecting on the current state of 5G, Murphy highlighted that few cell phone applications require super-fast connectivity despite companies constantly advertising the need for faster speeds. That said, the benefit of 5G is that it allows support for a higher subscriber base while still maintaining “a high level of quality service.” He then went on to say that the 5G standard initially did not support IoT. That said, moving forward, 5G will focus more on IoT implementations, creating more interconnected systems.

Furthermore, Murphy stated that resource allocation in 5G not only helps bring internet to rural areas but also makes it easier for providers to do so, reducing the digital divide. He pointed out that for rural areas, it is easier to use a satellite and provide a remote connection rather than take the time and resources to put down fiber and cell towers in small rural communities. He described the difference in speeds between fiber and satellite and how, as it stands, satellite speeds are far slower than that of fiber networks. Despite their differences, Murphy believes that “there are uses for all of these different methodologies in different places, and it’s just a question of… figuring out which ones work best… satellite would never work in New York City just because there’s so many people. But at the same time, there’s no reason to put… a 6G tower in the middle of a town of 50 people out in the middle of Kansas.” This shows that experts can utilize different forms of wireless communications in different ways to allocate resources and reduce the digital divide more effectively.

Regarding the future of 6G, Murphy, like most experts, is still unsure about it as it is still far away. That said, Murphy did mention that “the trend we’ve seen is… everything is always moving up in frequency, because the higher the frequency the more data you can send per second, [but] the trade-off is range.” The trade-off between higher data transmission rates and reduced signal range and penetration is a critical consideration in developing future technologies like 6G. This is because if the frequency range is reduced, there will be a need for densification, or in other words, more cell towers and sites.

Overall, the interview with Joseph Murphy focused on how AI and ML allow us to effectively allocate resources within these internet systems because of their versatility and ability to identify and adapt to situations and threats. With 5G moving forward and focusing more on IoT, AI, and ML will play vital roles in ensuring the public's safety and improving the standard overall. Additionally, the use of different forms of wireless telecommunications, including towers and satellites, will continue to bridge the digital divide. As the industry moves towards higher frequencies with 6G, the ongoing debate about balancing speed, coverage, and security continues to shape the future of telecommunications, ensuring it meets the evolving demands of its users.

4.1.4 Interview with Aurelius

The interview with Aurelius, Assistant Manager at MediaTek Inc. and Winstron-Neweb Corporation, gave his opinion on the role of 5G in advancing urban development and addressing the digital divide. His background in the research and development of 5G low-power chips provided a unique lens on the potential of 5G and its evolution into 6G. This particularly applies in the realm of Internet of Things (IoT) and smart factories. Aurelius highlighted the subtle yet significant impacts of 5G on urban settings, primarily through its integration with IoT. He stated during the interview that "optimization of processes through 5G connectivity leads to tangible improvements in [industry] productivity." In other words, this integration has notably enhanced the efficiency of smart factories and businesses by optimizing processes and improving productivity. This transformation, while not immediately evident to the everyday consumer, signifies a pivotal shift towards a more interconnected urban environment. The potential for this technology to facilitate a seamless connection between devices heralds a transformative era, especially in industrial operations where efficiency is paramount.

Regarding equitable access to 5G, Aurelius pointed out the critical role of government intervention. He emphasized that government actions "including funding allocation, regulatory

[promotion], [encouragement of] public-private partnerships, and support [for] digital literacy programs" are essential to ensure that 5G technology reaches rural and underserved areas. This approach reflects a proactive stance towards mitigating the digital divide that often leaves these regions behind in technological advancements.

Looking ahead to 6G, Aurelius anticipates a continuation of the trends observed with 5G but with greater enhancements in connectivity and integration of AI and machine learning. He anticipates that these advancements will propel the massive connectivity required for ambient IoT, further embedding technological interactions in everyday life. However, he is cautious about the immediate impact of 6G on the average person, stating, "[6G] won't have an impact in the short term." This further suggests that significant benefits may take time to materialize until the technology matures and is more widely implemented. His perspective underscores the importance of global standards and backward compatibility with existing 4G infrastructure, which could minimize disruptions during technology rollouts. These considerations are crucial for avoiding the struggles that marred the early stages of 5G development, such as high implementation costs and technical challenges.

Overall, Aurelius's insights contribute to a broader understanding of how 5G technology has shaped urban development and how 6G might further influence technological integration in everyday life. His emphasis on government role in ensuring equitable technology access and the strategic approach to technology deployment provides a pragmatic framework for addressing the challenges and opportunities that lie ahead with the advent of 6G. This early adoption by businesses necessitates a strategic focus on 6G readiness. Businesses that fail to anticipate and prepare for potential 6G applications risk falling behind in a rapidly evolving technological landscape. It is imperative for businesses to stay informed and engaged in the development and standardization of 6G technologies to secure a competitive edge in the future.

4.1.5 Interview with Bob Everson

The team engaged in a comprehensive interview with Bob Everson, who brought an extensive background in telecommunications through his work as the Sr. Director of Mobile Architecture and Ecosystem for Cisco Systems. Bob’s work encompasses a broad range of the networking industry, ranging from direct engagement with equipment vendors to strategic partnerships with telecom operators on a global scale. Everson's expertise extends to collaborative projects with enterprise-level clients and governmental agencies, positioning him at the intersection of technological innovation and socio-economic development. His insights are valuable in understanding the transformative impact of telecommunications technologies like 5G and the emerging 6G.

Everson's commentary traced the trajectory of mobile network technology, from its rudimentary 3G phase to the sophisticated and ever evolving 5G era. He highlighted the transformative nature of 5G, pointing out that its most significant contributions go beyond enhancing consumer connectivity and deeply impacts IoT and businesses. Its integration into the urban landscape is reshaping public services, city management, and even the small aspects of everyday municipal operations. Everson provided concrete examples, such as smart traffic systems and responsive public safety networks, illustrating how 5G serves as the backbone for smarter, more efficient cities. By facilitating a high-density network of connections, 5G is set to elevate urban environments into more connected and responsive spaces that can adapt to the needs of their inhabitants in real-time.

Access to 5G technology has become a focal point in discussions regarding technological equity, and Everson emphasized the necessity of strategic government action to bridge the gap in connectivity. He pointed out that while policymaking can lead the charge in spectrum allocation, ensuring that the benefits of 5G reach every corner of society requires concerted efforts across sectors. According to Everson, public-private partnerships could serve

as a catalyst for deploying 5G in traditionally underserved communities, leveraging both governmental funding and private sector ingenuity to bridge the digital divide. Reflecting on the early stages of 5G, Everson underscored the need for a deliberate and informed approach toward adopting new technologies like 6G. Additionally, he “[recommended] that [experts] take more of an outside approach, and truly understanding the applications [of the technology].” His narrative was cautionary, warning against the allure of innovation for its own sake. Drawing from the challenges witnessed during 5G implementation—ranging from technical integration hurdles to economic barriers—Everson made the case for a strategic, evidence-based approach in adopting 6G. He argued for the importance of a rollout strategy that is iterative and responsive, learning from the past to build networks that are not only advanced but also practical and user centric. This perspective is crucial for ensuring that 6G technologies fulfill their promise of driving societal progress without repeating the missteps of the past.

In the conversation regarding the future of 6G, Everson acknowledged the uncertainty surrounding its development but expressed optimism regarding its potential. He envisioned a future where 6G technologies further advance the capabilities brought forth by 5G, particularly in the realms of automation and artificial intelligence, stating, “6G [is] hopefully an incremental step on top of 5G versus a completely new generation.” These advancements could enable an even broader array of applications in both personal and industrial contexts. However, he also cautioned that the full benefits of 6G would only be realized through careful planning, community engagement, and industry-wide collaboration to ensure that the technology meets the evolving needs of society.

Throughout Everson's interview he emphasized a critical forward-looking perspective to the ongoing conversation about the future of telecommunications, underlining the need for thoughtful progression towards a more interconnected and technologically empowered world.

4.1.6 Interview Similarities

Despite their diverse backgrounds and specific areas of focus, experts agreed on several topics on the development of 5G and the implementation of 6G. All five experts emphasized the importance of equitable access and the need to address the digital divide, unanimously acknowledging the crucial role of partnerships between governments and the private sector in ensuring widespread connectivity. They collectively advocated for a cautious approach to new technologies, with Malenfant, Edalat, and Everson specifically advising that lessons learned from the deployment of 5G should guide the rollout of 6G to avoid past pitfalls such as high implementation costs and integration challenges. Malenfant and Everson further suggested that building off existing infrastructure is one way for businesses to decrease the high implementation cost.

Additionally, all the experts recognized the transformative potential of 6G to enhance IoT and AI capabilities, which could revolutionize a range of sectors, including autonomous transport, urban management, and healthcare. The interview with Murphy and Edalat highlighted the importance of AI and machine learning in managing complex network architectures and ensuring efficient and secure communications.

Malenfant and Murphy both underscored the importance of densification when developing the 6G infrastructure. As mentioned, 6G frequencies will likely be higher to carry more data but have a shorter range. The 6G network will require more closely spaced cell towers to ensure a fast and consistent connection. Murphy and Edalat mentioned using satellites to enable connections in more rural areas and further help support the 5G and 6G networks.

Additionally, Bob Everson, Aurelius, and Ron Malenfant emphasized the significant impact that 6G will likely have on businesses. Unlike previous generations like 3G and 4G, experts predict that 6G, like 5G, will focus more on specialized commercial applications.

Both Murphy and Edalat noted in their interviews that the role of AI and machine learning will help optimize network efficiency and security. They see these technologies as crucial for managing the more complex network architectures expected with 6G.

Together, these interviews reflected a broad consensus on the crucial role of 6G in enhancing connectivity and bridging the digital divide while also highlighting the need for careful planning and consideration of societal impacts to ensure a safe and efficient transition to 6G.

4.2 Survey

The team received a total of 152 responses from the project survey, with 103 of those being usable in the analysis. The team could not use 49 surveys in the final analysis because they were incomplete, the participants were not from Taiwan, or they were under the age of 18. The team performed and distributed surveys under four distinct scenarios (see Figure 12), but despite the team's best efforts, most of the participants were young adults (see Figure 13). The train station and email list were the most effective at gathering responses outside of the 18–29-year-old demographic. Unfortunately, the team only has one member who speaks Chinese, so collecting responses at the train station was very slow. It took the team four hours to gather the ten responses from the train station. The team very quickly abandoned this strategy, and focused their time on SCU, the email list, and social media as more effective strategies for distributing the survey. Going up to students around SCU and asking for five minutes of their time to take our survey yielded the most responses per interaction.

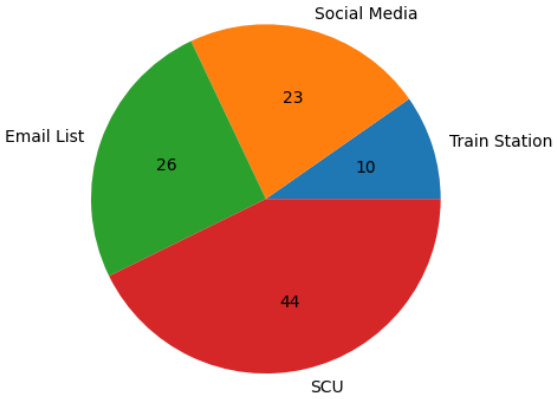

Figure 12: Response Sources (n=103).

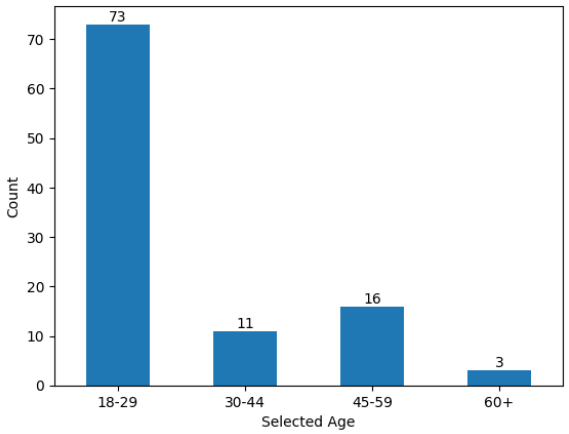

Figure 13: Age Responses (n=103).

The responses from the email list and social media helped to obtain data from outside of Taipei. However, even with these efforts a disproportionate number of responses listed their home and work as being in northern Taiwan (see Figure 14) (*Global Initiatives Symposium in Taiwan*, n.d.). This limits the scope of conclusions from the survey to these locations in northern Taiwan, and not the broader area of Taiwan.

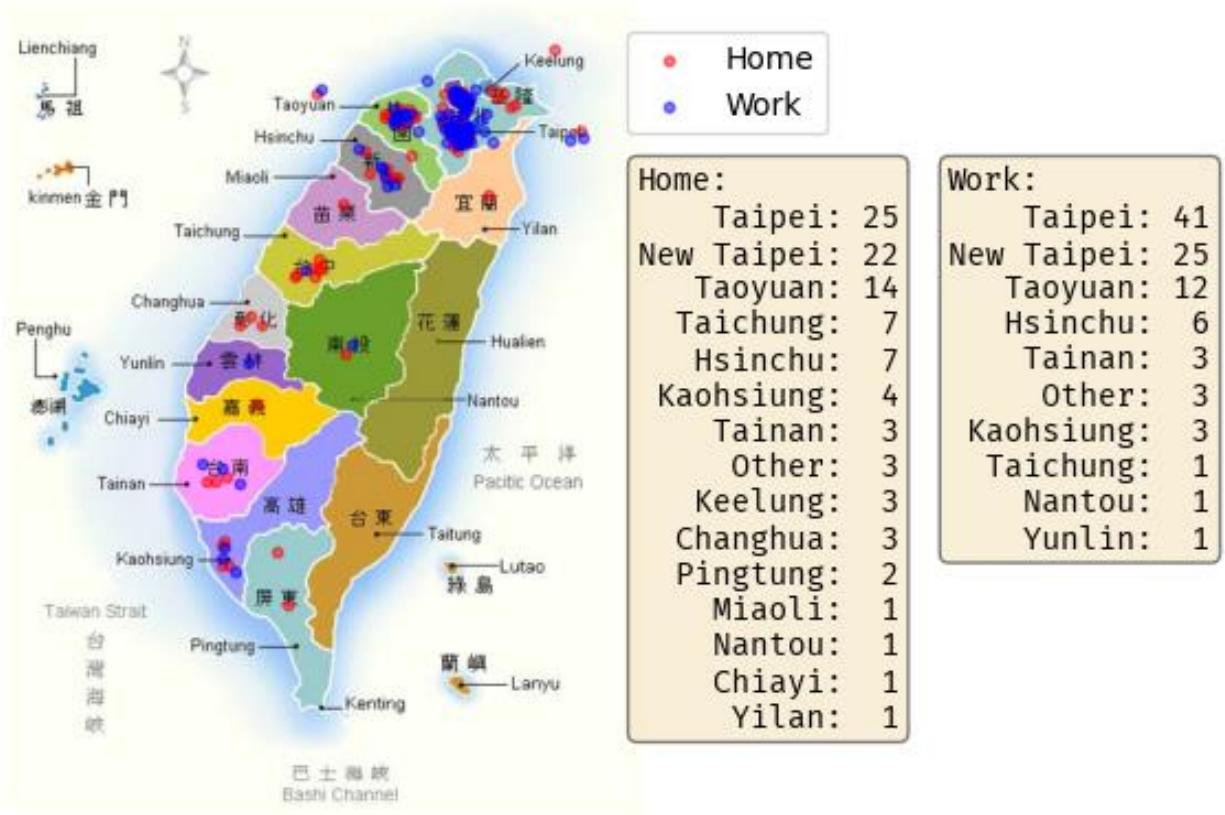

Figure 14: Home and work locations of respondents.

One of the main results from the survey is the feedback about the proposed system. TIER can use this data to gauge public opinion of the changes that will come with 6G and its effects on IoT. People did not generally say they would prefer the new 6G IoT system (see Figure 15), but a majority of people said that the proposed system would improve their quality of life (see Figure 16).

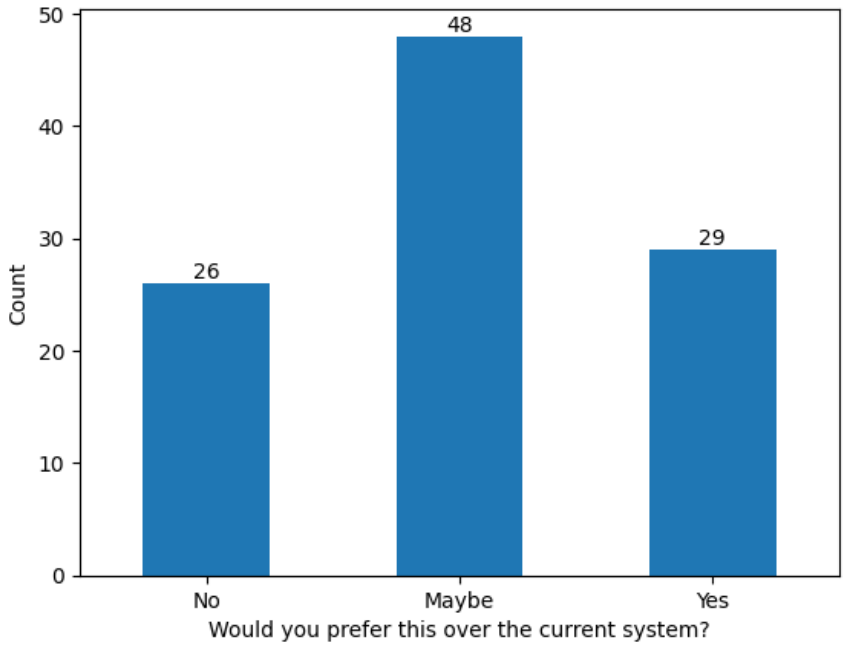

Figure 15: Preference of the proposed system (Initial) (n=103). [1]

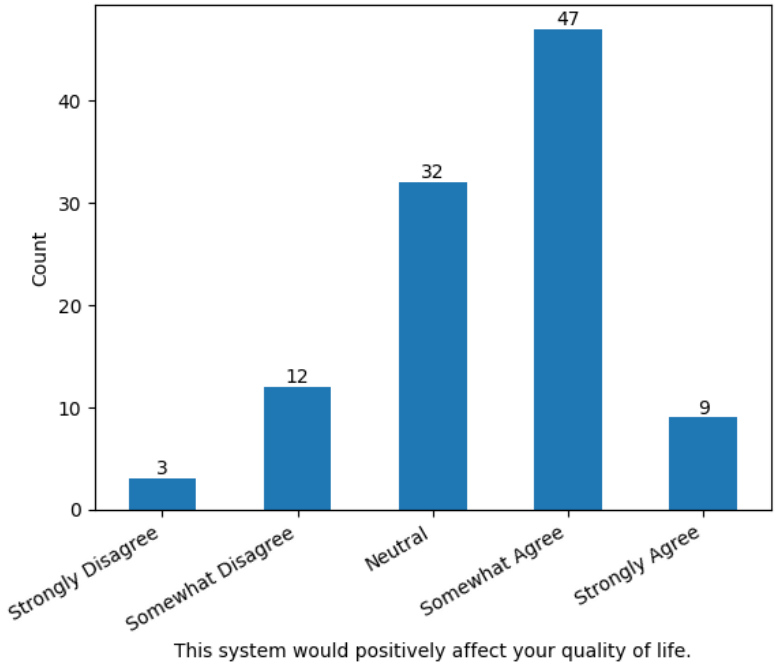

Figure 16: How the proposed system would affect people's quality of life (Initial) (n=103). [2]

[1] Note that some graphs are labeled with either *Initial* or *Final*. This is to delineate the same question being asked before (*Initial*) or after (*Final*) the respondent was shown the pros and cons of the system.
[2] The question for this graph follows a Leichhardt scale. Many other questions in the survey follow this format. This is a common way to structure questions that allows for very easy numerical analysis.

It is also critical to evaluate people's concerns with the proposed 6G system. Figure 17 illustrates that privacy and security concerns are the highest concerns while cost is the lowest. This trend is largely shared between men and women, except for concerns about the initial cost of instillation (see Figure 22 in Appendix C: Graphs). For this category, men made up 67% of responses.

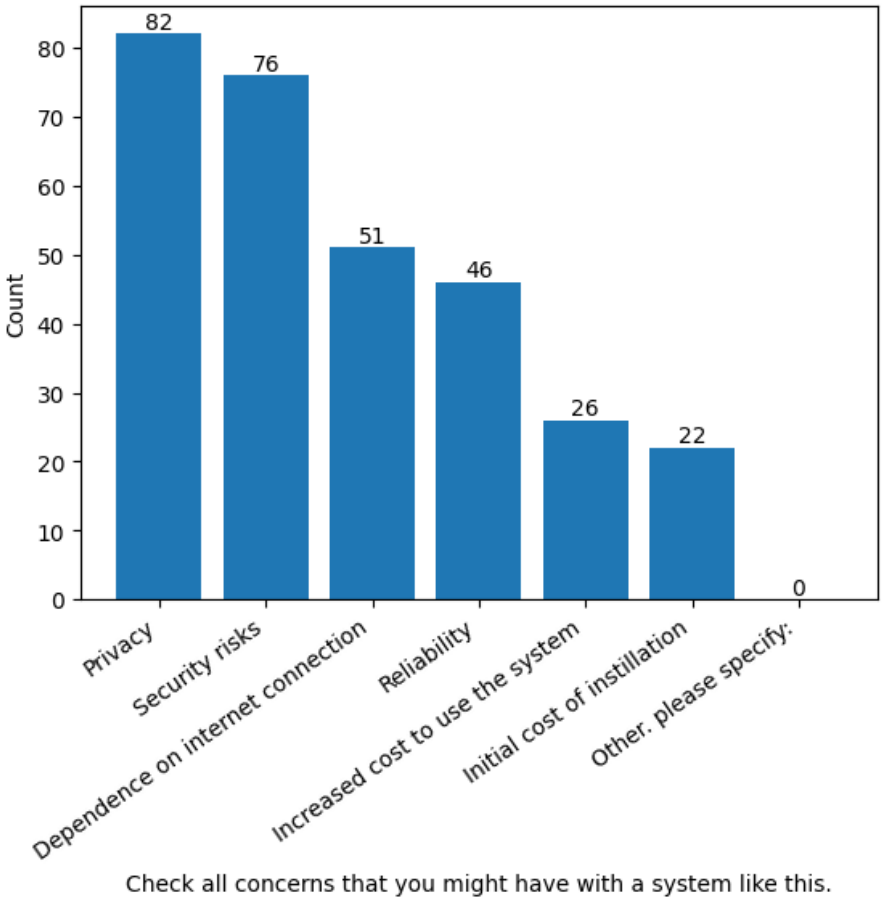

Figure 17: The concerns that people have with the proposed system. (Initial) (n=103).

Another way to view this survey data is through a correlation matrix (see Figure 18). This shows how the variables relate to each other. If two variables correlate, then the presence of one will predict the presence of the other. In this case there are three weak correlations in the data (*The Correlation Coefficient (r)*, n.d.). The correlation matrix shows that people who are concerned about privacy are more likely to be concerned about security risks, people who are concerned about the initial cost of instillation are more likely to be concerned about the

increased cost to use the system, and people who are concerned about reliability are more likely to be concerned about dependence on internet connection.

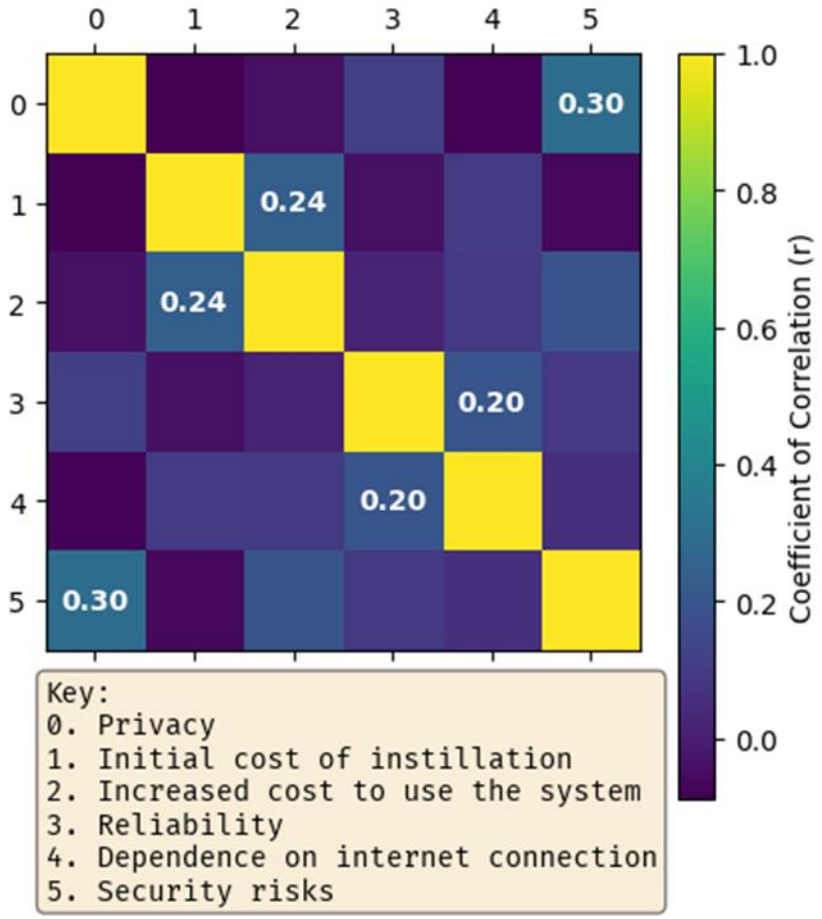

Figure 18: Correlations between the different concerns with the proposed system (n=103). [3]

The team can extend this method of analysis with the correlation coefficient to the rest of the survey results. This is because the survey largely consists of Likert scale questions. The results of this analysis can be seen in Table 1 under Appendix D: Tables. Many of these correlations are weak, but still reveal important insights. Notably, people who believe the 6G IoT system from the example would have a positive impact to their quality of life are more likely to prefer it. Additionally, people who use public transportation more often are more concerned

[3] Text on the diagonal, where $r = 1$, and where $|r| < 0.2$ is hidden for clarity. This was done to remove visual noise from statistically insignificant correlations, and to highlight any correlations above the threshold for significance (*The Correlation Coefficient (r)*, n.d.).

about the reliability of the proposed system. This shows that for people to accept a system utilizing 6G and IoT, the system should be reliable and have a positive impact on the user's quality of life.

The last way the team analyzed the data was looking at how listing the pros and cons of the system changed people's answers. The team asked respondents to share their thoughts on the system, before providing them with a list of pros and cons of the system. After this the team asked if the pros and cons changed any of the respondents' previous answers, and re-prompted the same questions if they said yes. As is shown in Figure 19, 32 people (31%) of respondents said their answers had changed. This does not mean that all 31% of people changed their answers for every one of the re-prompted questions.

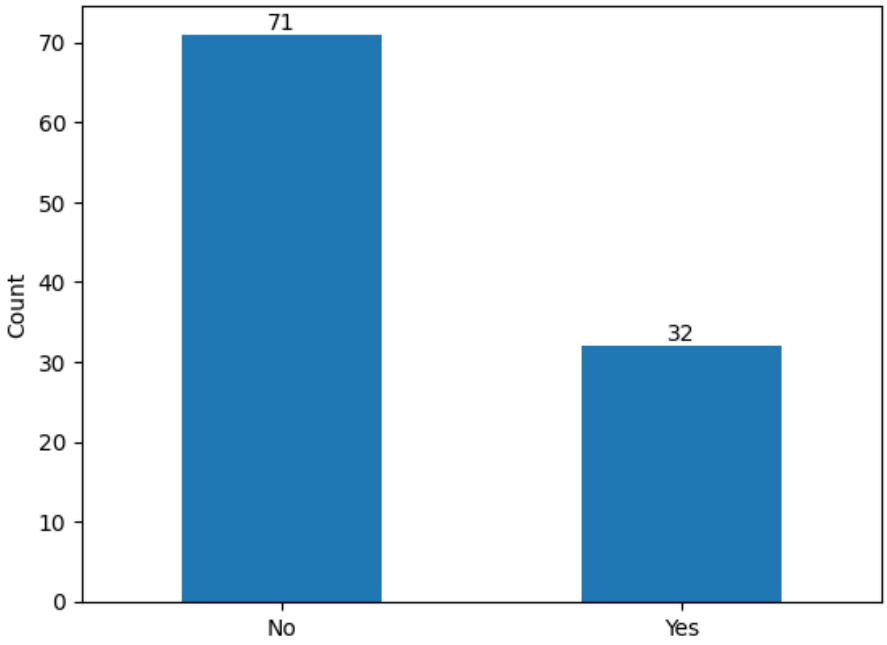

Figure 19: Did people change their answers after being shown the pros and cons? (Initial) (n=103).

Figure 20 shows how people's preference of the system changed after the team showed them the pros and cons of the system. The responses from before being shown the pros and cons are shown in Figure 15. A majority of the values on Figure 20 lie on the bottom-left to top-right diagonal, indicating no change in the respondent's answer. Values to the right of the diagonal indicate increased sentiment, while values to the left of the diagonal indicate

decreased sentiment. This method of educating people on the system did not seem to have a significant effect on their preference.

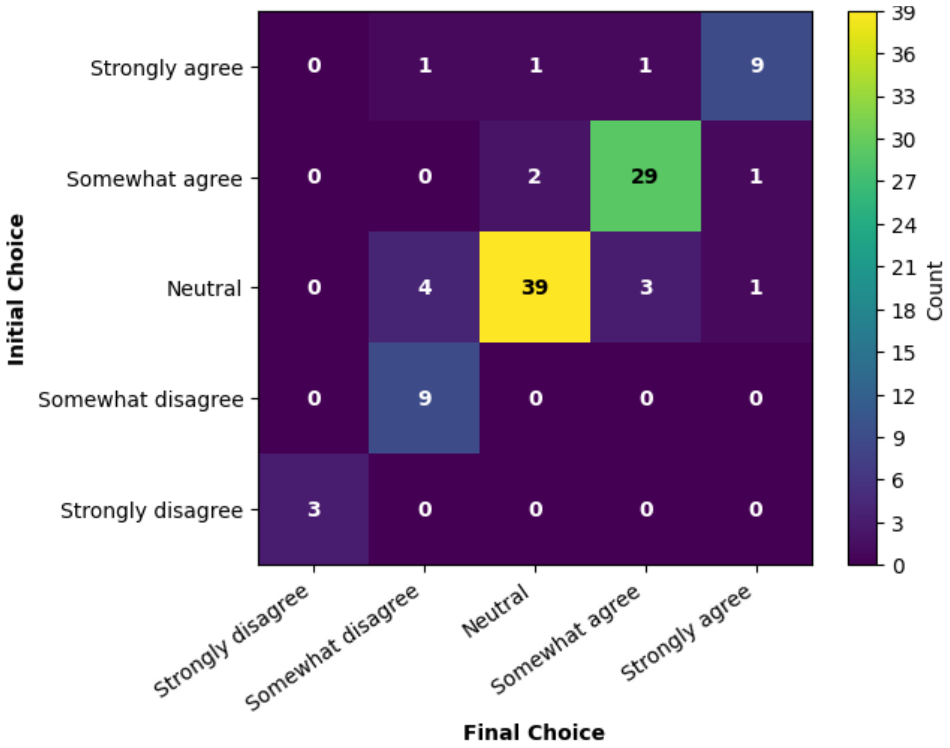

Figure 20: Change in people's preference of the system before and after being shown the pros and cons (n=103). [4]

The other question that people changed after seeing the pros and cons is their concerns about the system. Figure 21 shows the number of people who selected, de-selected, or did not change each concern after being shown the pros and cons. Very few people changed their mind about any of the concerns after being shown the pros and cons.

Even with being shown the benefits of the proposed system, people's attitude towards privacy and security concerns did not change. This could imply that individuals that already have these concerns and awareness about these issues will not be less worried about a system just because it is smarter and faster. On the other hand, there were some changes in response to concerns relating to cost. 44% of respondents changed their answers regarding the increased

[4] This graph is read row by row. Values on the bottom-left to top-right diagonal show no change in sentiment. Values on the left of this diagonal show a decreased sentiment, and values on the right of the diagonal show a increased sentiment.

cost to use the system, and 32% of respondents changed their answers regarding the initial cost of installation. However, the total number of people adding and removing these two concerns largely canceled themselves out.

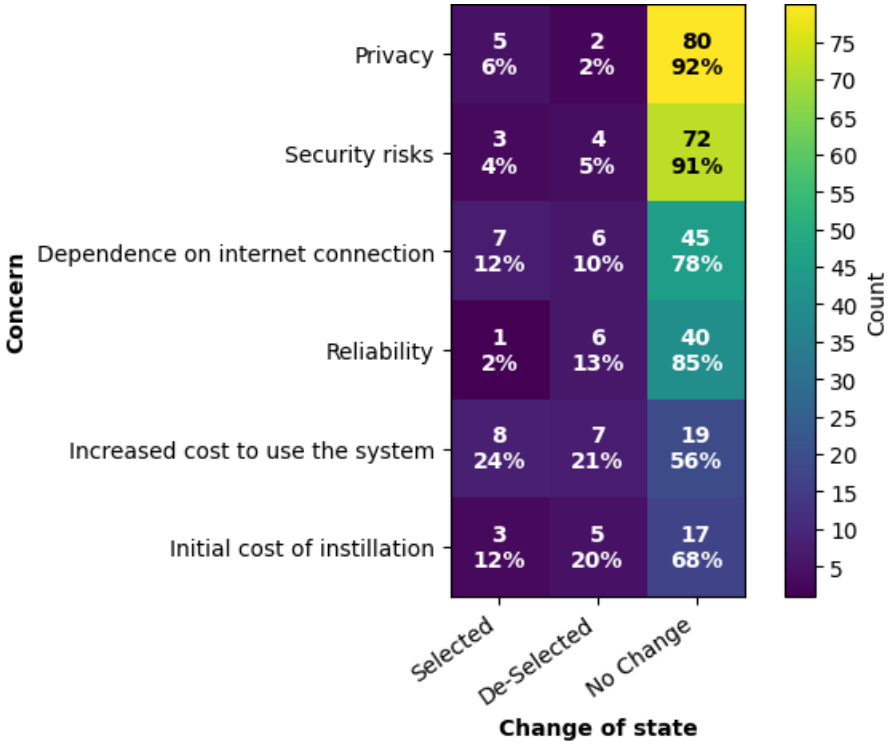

Figure 21: Change in people's concerns of the system before and after being shown the pros and cons (n=103). [5]

Overall, the survey showed that the people of Taiwan are most concerned with security and privacy in new technologies. Additionally, the survey found that people are largely steadfast in their opinions. Providing educational information did not tend to change people's minds. These findings suggest that any media created to promote 6G and IoT technologies should have its focus on the security and privacy of the system.

[5] The top number in each grid cell is the count. The bottom percent is the row-percent. The row-percent shows the percent of people who had a specific change of state for each concern.

4.3 Summary

This chapter provided an in-depth analysis of telecommunications advancements and their societal implications, drawing insights from expert interviews and performing public surveys in Taiwan. Experts with diverse backgrounds in the U.S. and Taiwan contributed their unique perspectives, allowing a multifaceted examination of the current and future potential of 5G and 6G technologies, as well as AI and IoT systems. This variety in expertise enabled a comprehensive understanding of how different factors, such as urban development, security, and network efficiency, interplay in the telecommunications landscape. The public survey complemented these insights by revealing the Taiwanese public's mixed feelings towards the upcoming 6G and IoT systems, particularly concerning privacy and security. Collectively, the findings underscore the transformative potential of these technologies and highlight the importance of strategic planning and equitable access in their development.

5 Recommendations

This section explores the recommendation framework for the adoption of 6G technology in Taiwan. The team divided the recommendations into three main pillars: infrastructure, policy management framework, and public transparency. The first pillar, infrastructure, provides recommendations for building a dense network in Taiwan and researching the viability of using satellites to support under-served areas. The second pillar, policy, defines how planning a phased rollout and prioritizing businesses will allow for a smoother transition to 6G. The final pillar of public transparency describes how governments and businesses being transparent in security measures and creating a policy for a digital trust label will instill trust among the people of Taiwan.

5.1 Infrastructure

As 6G approaches, the importance of establishing an early, robust, and resilient infrastructure becomes paramount. The team recommends that Taiwan builds a dense network system and research satellite communications.

5.1.1 Build a Dense Network System

The first recommendation is for Taiwan to build a dense network system with more cell towers. The interviews with experts Ron Malenfant and Joseph Murphy underscored the importance of densification. They mentioned that the high-frequency signals of 6G have shorter travel distances**,** which can be further hindered by physical obstructions like buildings, trees, and even weather conditions. Therefore, by having more towers closer to one another, Taiwan can ensure a faster and more consistent connection for the consumers. By establishing a

denser network of towers, Taiwan will be positioning itself to be an early adopter when 6G technologies come to fruition.

5.1.2 Research Satellite Communications

The second recommendation for Taiwan is to research the viability of satellite communications, focusing on reaching underserved areas. The interviews with Farinaz Edalat and Joseph Murphy emphasized the importance of satellite communications supporting the 6G infrastructure. They acknowledged the limitations of satellite internet speeds but highlighted the potential of satellite technology to bridge the digital divide. This would allow Taiwan to provide a more economically feasible way to extend services to historically underserved areas, ensuring a more inclusive digital expansion and progress.

5.2 Policy

As Taiwan prepares for a transition into 6G, it is critical to establish strategic policies that will optimize the rollout and maximize its impact. The team advises implementing a phased rollout plan and prioritizing business sectors during the early stages of 6G implementation.

5.2.1 Plan on Phased Rollout

The first recommendation is for Taiwan to plan for a phased rollout of 6G, meaning that telecommunications companies will not support the full 6G specification with the initial deployment. Insights from Bob Everson, Ron Malenfant, and Farinaz Edalat, support this by stressing the importance of managing the deployment of 6G in the early stages. This approach allows for addressing potential technical challenges and adapting to market needs progressively. The team advises that Taiwan begin with pilot projects in critical business sectors, followed by broader expansion based on established success metrics and learned

experiences. In addition to this, telecommunications companies should begin the public rollout by piloting their systems in small areas, protecting the companies financially and allowing a space to iron out any issues. This phased approach ensures that each stage of the rollout is robust and that adjustments can be made to optimize the network as necessary.

5.2.2 Prioritize Businesses

The second recommendation is for Taiwan to prioritize businesses in the early stages of 6G deployment. This is corroborated by the expertise of Aurelius, Bob Everson, and Ron Malenfant, as well as the team's background research. Prioritizing businesses will leverage the capabilities of 6G to enhance the operational efficiency of the IoT sector, driving significant economic growth. The team's recommended action steps include implementing incentives for early adoption among businesses and tailoring regulatory frameworks to support rapid technology uptake in the commercial sector. Along with this, businesses in Taiwan should focus on involvement with international standardization committees to remain up to date on research and development while also provide their own input. This focus will ensure that the benefits of 6G can be realized swiftly and effectively, providing a competitive edge to Taiwan's industries.
Public Transparency

5.3 Public transparency

Public trust is crucial for the installation of cellular systems. One of the best ways businesses, industries, and governments can gain this trust is by being transparent and educating the public on these systems and their development. To do this, Taiwan must create a digital trust label. The security of these systems themselves must also be strengthened and emphasized. This can be done through the integration of AI technologies, where transparency of these technologies and how they're being utilized is critical for public safety and trust.

5.3.1 Digital Trust Label

The first recommendation is for Taiwan to implement a digital trust label. This is something currently being pioneered in Switzerland (*About SDI_New*, n.d.). A digital trust label would be earned through a certification that products undergo to help consumers identify their alignments with laws regarding security and privacy. Allowing consumers to physically see that products are safe would ease the public's fear of privacy and security in new technologies and ensure that Taiwan would be more transparent. By creating a symbol of trust and safety and streamlining the process of achieving this label, Taiwan's public perception of certain technologies will become steady and trusting.

5.3.2 Transparency Towards AI in Security

The second recommendation is for the government and businesses to be more transparent behind the use of AI in 6G. As stated in the interview with Joseph Murphy and Farinaz Edalat, there are significant use cases for AI in 6G. However, many people still fear these types of technologies, as AI is a very powerful and capable tool. That is why Taiwan would also need to be transparent about how and why AI is being and how it would benefit the public. The public may respond better to the utilization of AI if it is shown to them that they can trust it and that it is for the betterment of society. The government and business can accomplish this by showing the benefits 6G and AI will provide to industries, such as public transport and medicine.

6 Conclusion

The primary focus of the project is to assist Taiwan's Institute of Economic Research (TIER) in providing recommendations to help Taiwan prepare for the eventual rollout of 6G technology. This chapter will explore the conclusions derived from this research.

To assist TIER in providing recommendations, the team interviewed industry experts and surveyed the Taiwanese public. After analyzing the results these methods yielded, the team gathered deep insights into the current landscape of 5G, the digital divide, and the potential of 6G, IoT, and AI. These efforts were instrumental in shaping our recommendations, which center around three core areas: infrastructure, policy, and public transparency.

The team's recommendations, if implemented, would bring significant benefits to Taiwan. The infrastructure recommendations will position Taiwan at the forefront of telecommunications innovation and aid in a smooth transition to 6G. By developing a dense network and exploring satellite solutions, Taiwan can ensure equitable internet access across the country, thereby closing the digital divide and fostering national growth in the digital age. The policy recommendations aim to provide a structured and strategic approach to the rollout of 6G in Taiwan, aligning with the nation's technological aspirations and economic strategies. By implementing these recommendations, TIER can facilitate a robust policy environment that supports the integration and effective utilization of 6G technology that will keep Taiwan's technology businesses at the forefront of innovation. The public transparency recommendations focus on how educating the public on technologies and focusing on being trustworthy will create a healthier relationship between the people and the systems and products that people in Taiwan use.

The team provided all these recommendations in the hopes of preparing Taiwan for the transition into 6G. With 6G technology still on the horizon, Taiwan has time to allow for careful

evaluations and implementations of these recommendations. By focusing on accessibility, reliability, privacy, and security, Taiwan can set a global standard in the next generation of telecommunications technology.

6.1 Research Limitations

6.1.1 Interview Limitations

Due to the nature of the team's research, there are several limitations. The primary limitations are the survey response demographics and a limited number of interviews. The team faced challenges when trying to find more interview candidates. Getting a hold of these groups and individuals proved to be quite difficult; as a result, the team interviewed five experts— four from the U.S. and one from Taiwan. The team found four U.S. interviews from connections, and TIER helped contact the Taiwanese interview. In the professional world, many hindrances arose with scheduling and planning meetings across time zones. Additionally, the team did not initially expect to perform many interviews with U.S. experts. Prior to leaving the U.S., the team was planning on primarily interviewing experts from Taiwan. The team could have begun arranging more interviews in the U.S. if they had finalized the intended interview demographic earlier.

Besides the limited number of interviews, the research would have also benefited from interviewees with more varied backgrounds. All the people interviewed were in technical fields. Ideally the team would be able to expand on the research about the digital divide by interviewing researchers in that field and others. The interviews with Farinaz Edalat and Joseph Murphy had a significant focus on the digital divide, but those conversations were still coming from a technical background (see Sections 4.1.2, 4.1.3). This limitation means that the conclusions of this research could be lacking important context about more social aspects of 6G.

6.1.2 Survey Limitations

Another aspect of the methods which proved challenging was identifying an appropriate demographic for the surveys. Knowing and understanding the targeted demographic for the survey questions allowed the team to clarify any biases during the surveying process. There were inevitable biases in the data because of the distribution method of the surveys. For example, the team sent out the survey to a TIER contact list of business associates, this group may be more tech savvy than the average individual in Taiwan, skewing the results. The team has identified the bias and has complemented the data with the in-person surveys. As for the in-person approach, the team surveyed the different demographic of respondents based on chance and who was willing to respond and scan the QR code that linked to the survey.

In addition to skewing the overall data, having four distinct sources of data (see Figure 12 from Section 4.2) can show misleading correlations in the data. If the average respondent from the email list is older than the average respondent from SCU, but also more knowledgeable about 5G, then the data will show a correlation between age and knowledge of 5G. This specific scenario was observed in the interview data, it can be seen in Table 1 from Appendix D: Tables. Misleading correlations like this are the reason the team did not significantly explore correlations from the dataset. Just because correlations appear in the dataset does not mean that they generalize to the public.

7 Future Research

The team's work created a strong foundation of knowledge for the current state of 5G, 6G, and the public's perception towards new technology in Taiwan. Researching into the topic of 6G provides unique opportunities for continued research because of how far away the deployment is. This section will discuss topics outside of the scope of this paper that the team identified as being important factors moving forward with 6G development in Taiwan. Due to technical nature of adjacent research to this IQP, some future research is more suited for MQPs.

7.1 Optimizing Infrastructure Deployment

Finalizing important parts of the 5G system will provide experts with a robust starting point for the 6G launch. Moving forward for the research on future systems, investigating strategies to optimize the deployment of telecommunications infrastructure will be crucial. This will include research and development of the placements of cell towers and satellite technology to ensure comprehensive coverage and the capability to support the demands of 6G, IoT, and AI technologies in Taiwan.

7.2 Security Measures for Next-Generation Networks

To address emerging cyber threats, it is important to explore more advanced security measures as a possible MQP topic. An MQP could investigate AI-driven detection systems to enable proactive identification and mitigation of unusual network activity, ensuring integrity and privacy of the systems. This approach will help improve the resilience of next-generation networks against cyber threads, providing a secure foundation for the deployment of technologies such as IoT and AI within the 6G networks.

7.3 Policy Frameworks for Technology Adoption

When moving forward with policy frameworks, it's critical to study the current frameworks in place. The scope of this paper did not allow for significant research into specific cellular policies set by Taiwan. By identifying the policies as they stand today, along with any common issues that arise, it will be easier to identify the aspects of legislation that Taiwan must work on before and during the 6G rollout. A future IQP could research policies including considerations for security, infrastructure development, bridging the digital divide, and regulatory alignment to allow for smooth transitions and rollouts on all fronts.

7.4 Global Standardization and Collaboration

A vital aspect of cellular development is the weight a standard has on a global scale. To ensure an efficient and successful rollout for 6G in the future, the research and development of the system must be collaborative across numerous global organizations and industries. Examining the role of international standard-setting organizations allows for the interoperability and security of 6G technologies on the global level. Focusing on opportunities for collaboration among countries and industry stakeholders will also advance global standards and mitigate conflicts in frequency allocation and technology adoption. Future research on Taiwan forming alliances with neighboring technically advanced countries, such as South Korea and Singapore, would also prove to be useful.

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Appendix A: Telecommunication Experts Interview Questions

Appendix A.1: Interview disclaimer

Hello, we are third year engineering students from the US studying at Worcester Polytechnic Institute in Massachusetts. We are conducting a project to identify the benefits and hurdles of implementing 6G in Taiwan (the successor to 5G cellular technology). We will be using this interview data in a report that we will publish and make available in the public domain. We hope our report will be of interest to you. You are free to skip any questions you do not wish to answer. Please let us know if you wish to remain anonymous (Y/N). Do we have permission to record the interview (Y/N)?

Appendix A.2: Interview for 5G experts

A.2.1. What companies does your experience with telecommunications come from?

A.2.2. What is your job title?

A.2.3. What is your background with telecommunications and 5G?

A.2.4. How has 5G contributed to urban development?

A.2.5. Who can take measures to ensure equitable access to 5G technology, especially in rural and underserved areas, and what measures can they take?

A.2.6. How has 5G technology affected the digital divide, both within countries and globally?

A.2.7. Looking back on the early stages of 5G, what measures would you take to avoid the struggles during the development/rollout period?

A.2.8. What was the public perception to the 5G rollout like? Do you expect a similar response for 6G?

A.2.9. How do you foresee 6G affecting the IoT space?

A.2.10. How do you foresee 6G affecting the average person in your country?

A.2.11. What are some of the potential commercial values that could come with 6G technology?

A.2.12. Is there anything you want to add that we have not discussed yet?

Appendix B: Public Survey

Survey Flow

Standard: Disclaimer (1 Question)
Block: Background Questions (9 Questions)
Standard: Scenario Explanation (1 Question)
Standard: Scenario and Question (4 Questions)
Standard: Positives and Negatives (2 Questions)
Standard: Scenario and Question Repeat (4 Questions)

Page Break

Appendix B.1: Disclaimer

Start of Block: Disclaimer

Hello, we would like 5 minutes of your time to fill out a survey. We are third year engineering students from the US studying at Worcester Polytechnic Institute. We are carrying out a project, in collaboration with Taiwan's Institute of Economic Research and Soochow University, to identify the benefits and hurdles of implementing 6G in Taiwan (the successor to 5G cellular technology). Your participation is important, and your responses are crucial in helping us understand the public's reception of 6G implementation. If you are uncomfortable or do not want to answer a question, please skip it, and move on to the next. We will be using this survey data in a report that will be published and made available in the public domain. You will remain anonymous. We hope our report will be of interest to you.

End of Block: Disclaimer

Appendix B.2: Background Questions

Start of Block: Background Questions

B.2.1 Select your age range.

- 0-17 (1)
- 18-29 (2)
- 30-44 (3)
- 45-59 (4)
- 60+ (5)

Skip To: End of Survey If Select your age range. = 0-17

B.2.2 Select your gender.

- Male (1)
- Female (2)
- Non-binary / third gender (3)
- Prefer not to say (4)

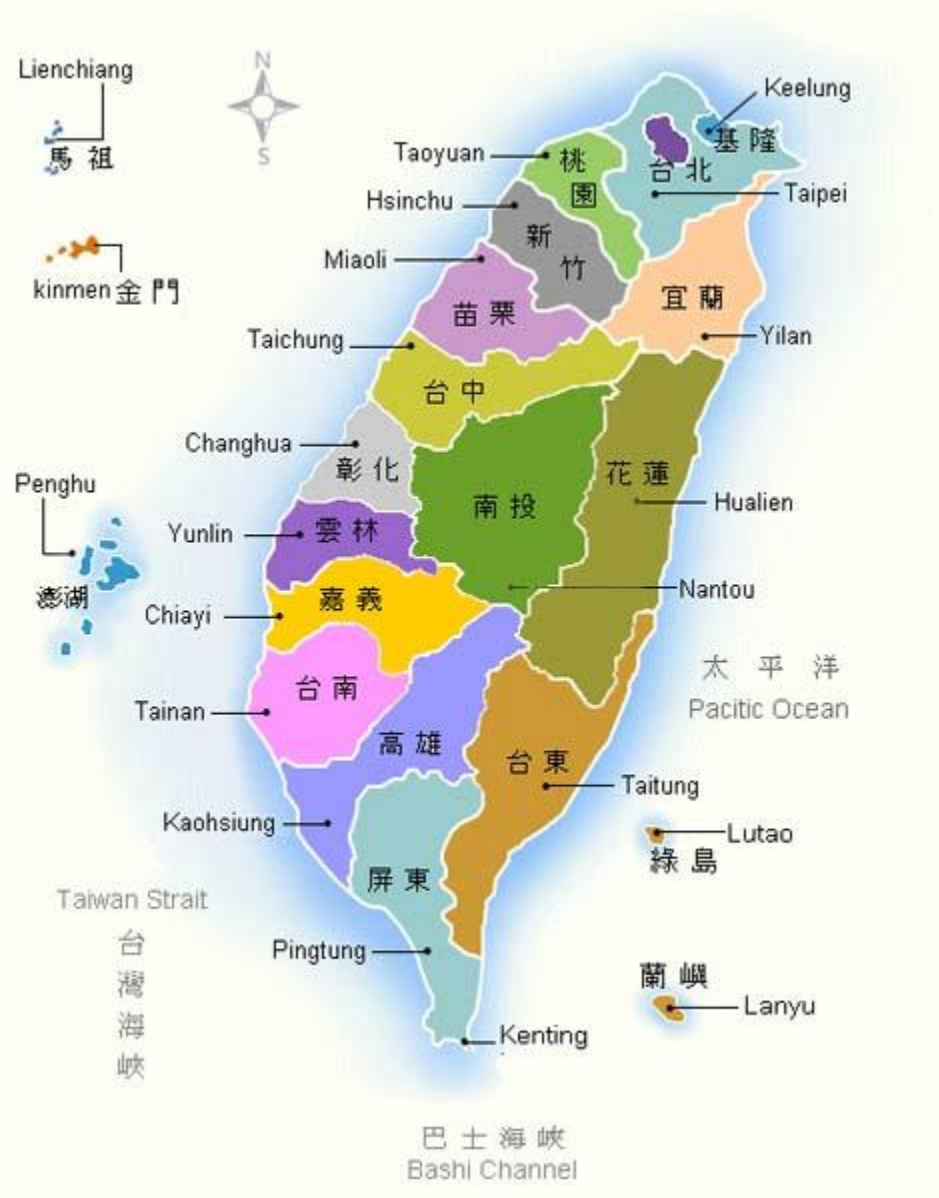
B.2.3 What country are you from?

- Taiwan (1)
- Other, please specify: (2)

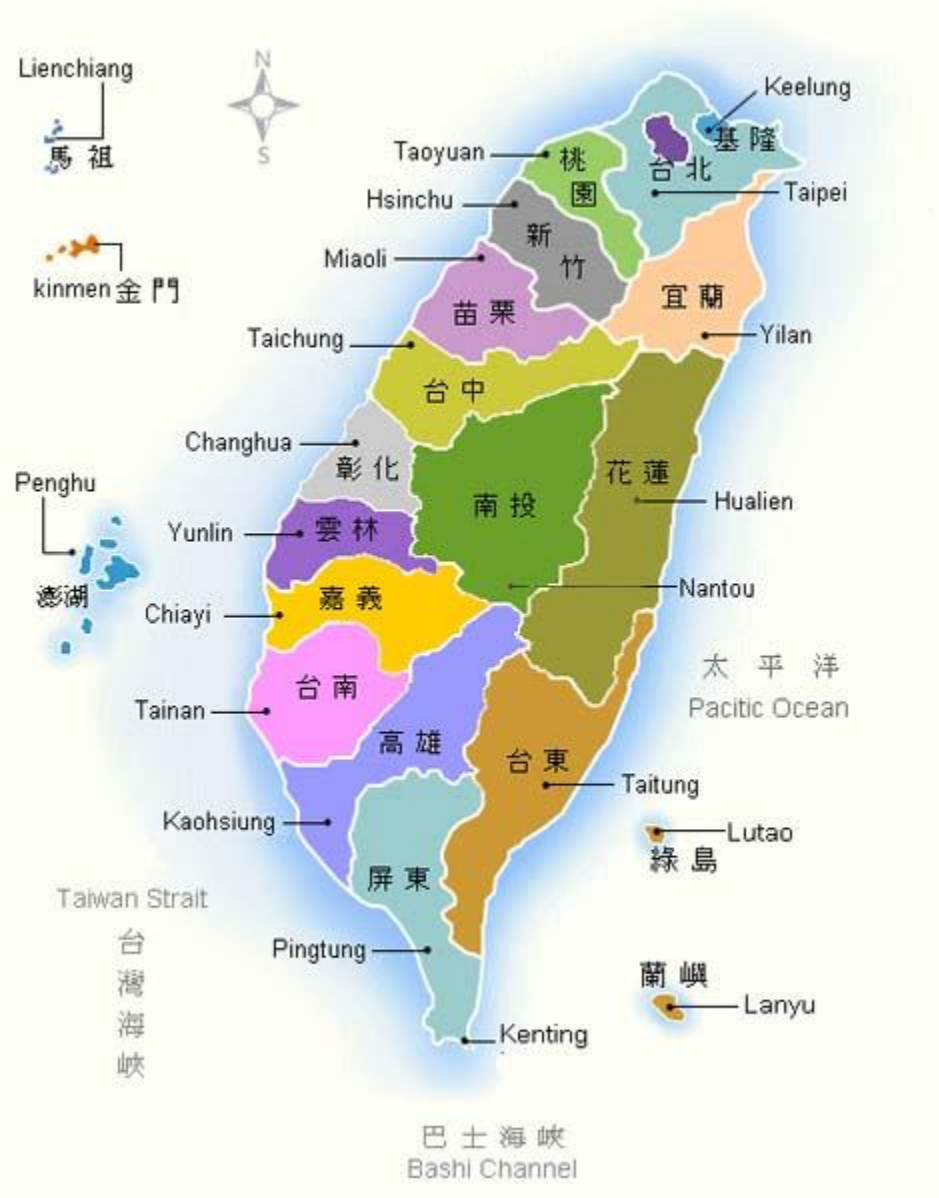
_____

Skip To: Q12 If What country are you from? != Taiwan

B.2.4 Select the part of Taiwan where you live.



B.2.5 Select the part of Taiwan where you Work.



B.2.6 How often do you use public transportation?

- Never (1)
- Infrequently (2)
- Weekly (3)
- Daily (4)
- Multiple times a day (5)

B.2.7 How familiar are you with 5G technology?

- Not familiar at all (1)
- Slightly familiar (2)
- Moderately familiar (3)
- Very familiar (4)
- Extremely familiar (5)

Skip To: Q11 If How familiar are you with 5G technology? = Not familiar at all

B.2.8 How much has 5G affected your quality of life?

- Not at all (1)
- A little (2)
- A moderate amount (3)
- A lot (4)
- A great deal (5)

B.2.9 How familiar are you with AI technology?

- Not familiar at all (1)
- Slightly familiar (2)
- Moderately familiar (3)
- Very familiar (4)
- Extremely familiar (5)

End of Block: Background Questions

Appendix B.3: Scenario Explanation

Start of Block: Scenario Explanation

In the following part of the survey we will propose a potential use case for 6G technology. This is to gauge public interest in different aspects of the technology. 6G will be largely aimed at improvements in the Internet of Things (IoT) field. IoT is the technology that allows many small devices to communicate to act as a larger, interconnected, system.

You will now be presented with the scenario and asked to answer some questions. Following this, you will be provided with potential benefits and drawbacks of the new technology and

asked to re-answer the questions if any of your opinions have changed.

End of Block: Scenario Explanation

Appendix B.4: Scenario and Question

Start of Block: Scenario and Question

Imagine stepping into any MRT station in Taiwan and walking straight through without stopping to swipe or tap a card. As you approach the turnstiles, facial recognition technology, powered by 6G networks, identifies you in a split second. Simultaneously, a network of connected sensors and cameras located throughout the station share information in real time, ensuring that your identity is securely matched with your registered payment method.

As you board the train, the network of sensors and cameras continue to track your journey, ensuring that you are charged accurately when you exit. The system charges you in real time.

B.4.1 Would you prefer this over the current system?

- o No (1)
- o Maybe (2)
- o Yes (3)

B.4.2 This system would positively affect your quality of life.

- o Strongly disagree (1)
- o Somewhat disagree (2)
- o Neutral (3)
- o Somewhat agree (4)
- o Strongly agree (5)

B.4.3 **Check all** concerns that you might have with a system like this.

- Privacy (1)
- Initial cost of instillation (2)
- Increased cost to use the system (3)
- Reliability (4)
- Dependence on internet connection (5)
- Security risks (6)
- Other, please specify: (7)

_____

End of Block: Scenario and Question

Appendix B.5: Pros and Cons

Start of Block: Pros and Cons

Our team has prepared a list of potential positives and negatives for a system like this. Please carefully consider the following:

Positives

- Convenience: The elimination of physical payment mediums simplifies travel logistics, offering a more fluid and hassle-free commuting experience.
- Data-Driven Insights: The accumulation of comprehensive data on passenger movements and behaviors could afford the MRT system invaluable insights, guiding decisions on service enhancements and infrastructural development, such as improved train timing and hours.

Negatives

- Privacy Concerns: The application of facial recognition technology entails the processing of personal biometric data, raising substantial privacy implications.
- Technological Dependence: The system's reliance on the 6G networks, IoT devices, and facial recognition technologies introduces vulnerability to service disruptions stemming from technical failures.

B.5.1 Would these considerations change any of your answers in the previous section?

- No (1)
- Yes (2)

Skip To: End of Survey If Would these considerations change any of your answers in the previous section? = No

End of Block: Positives and Negatives

Appendix B.6: Scenario and Question Repeat

Start of Block: Scenario and Question Repeat

Imagine stepping into any MRT station in Taiwan and walking straight through without stopping to swipe or tap a card. As you approach the turnstiles, facial recognition technology, powered by 6G networks, identifies you in a split second. Simultaneously, a network of connected sensors and cameras located throughout the station share information in real time, ensuring that your identity is securely matched with your registered payment method.

As you board the train, the network of sensors and cameras continue to track your journey, ensuring that you are charged accurately when you exit. The system charges you in real time.

B.6.1 Would you prefer this over the current system?

- o No (1)
- o Maybe (2)
- o Yes (3)

B.6.2 This system would positively affect your quality of life.

- o Strongly disagree (1)
- o Somewhat disagree (2)
- o Neutral (3)
- o Somewhat agree (4)
- o Strongly agree (5)

B.6.3 **Check all** concerns that you might have with a system like this.

- o Privacy (1)
- o Initial cost of instillation (2)
- o Increased cost to use the system (3)
- o Reliability (4)
- o Dependence on internet connection (5)
- o Security risks (6)
- o Other, please specify: (7)

_____

End of Block: Scenario and Question Repeat

Appendix C: Graphs

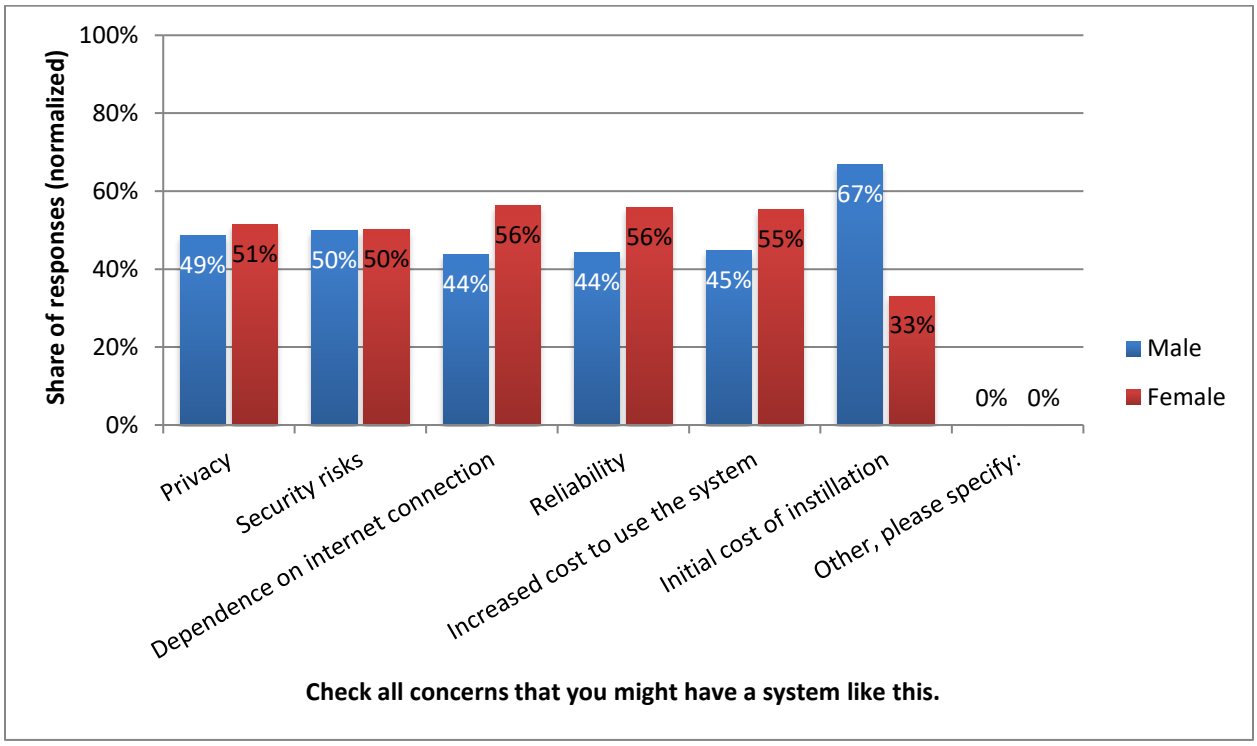


Figure 22: Difference between male and female concerns. (Initial) (n=53 male, n=50 female). [6]

Below are all the graphs taken from Qualtrics. The results section of the paper specifically filters out incomplete responses and responses from outside of Taiwan. The below graphs do not filter out any responses, which explains any discrepancies in the N value.

[6] The y-axis of this graph is normalized to account for the different number of men and women who took the survey.

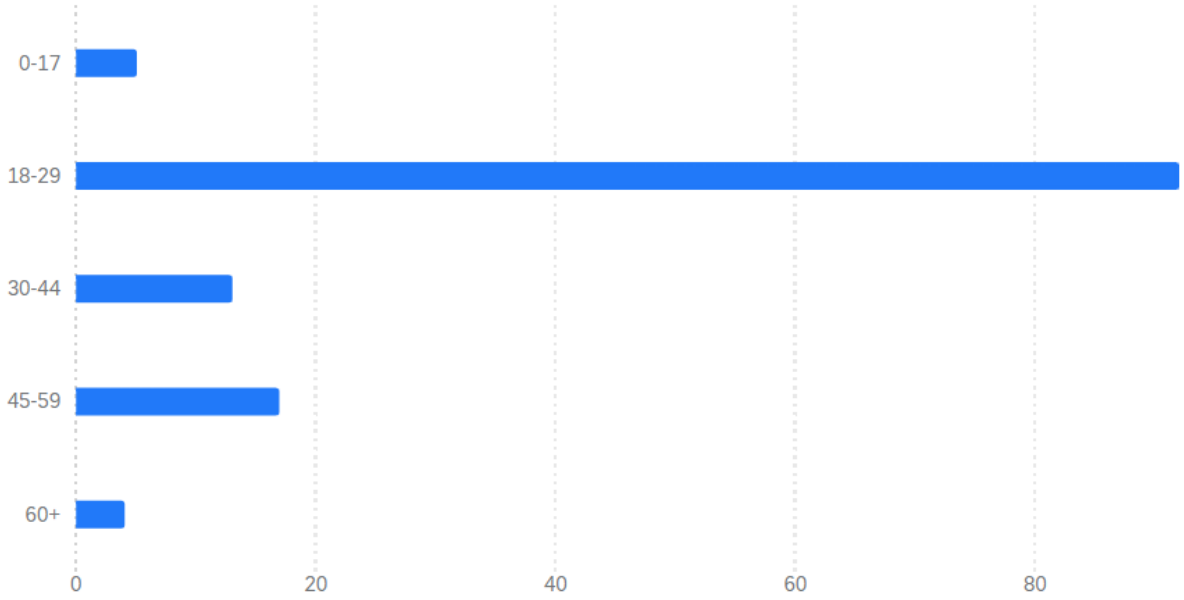


Figure 23: Unfiltered data. Select your age range. (n=131).

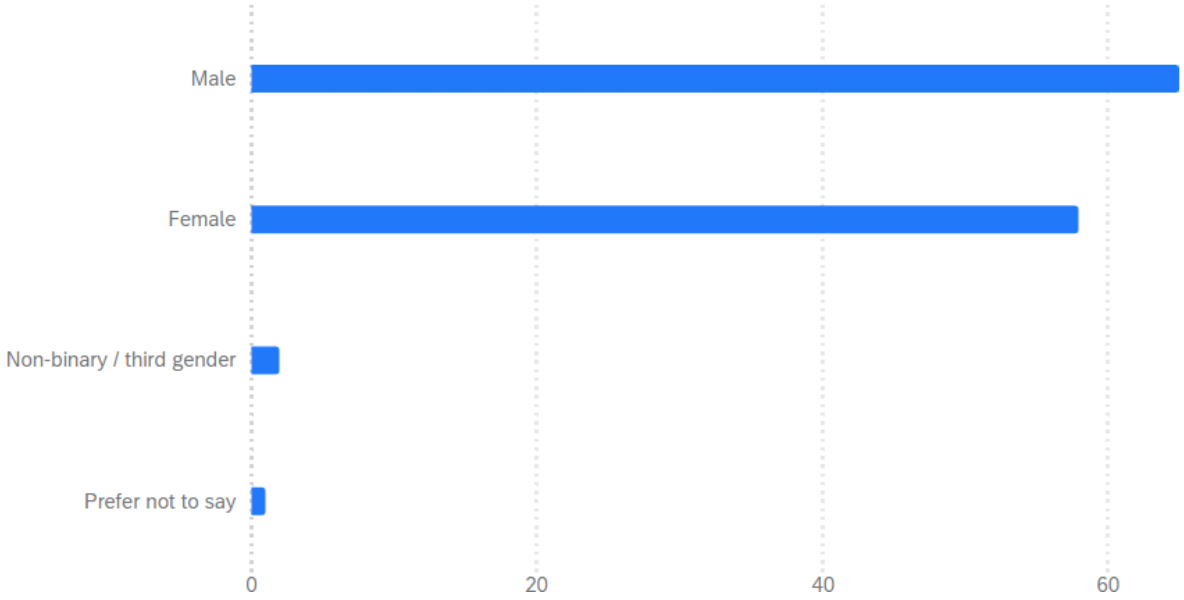


Figure 24: Unfiltered data. Select your gender. (n=126).

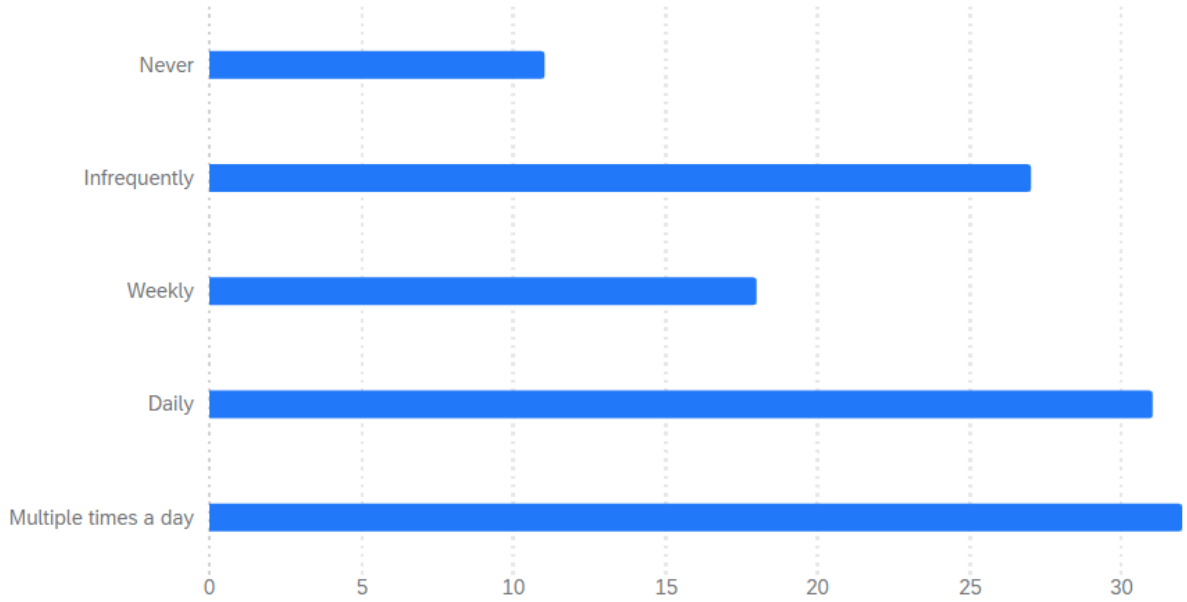


Figure 25: Unfiltered data. How often do you use public transportation? (n=119).

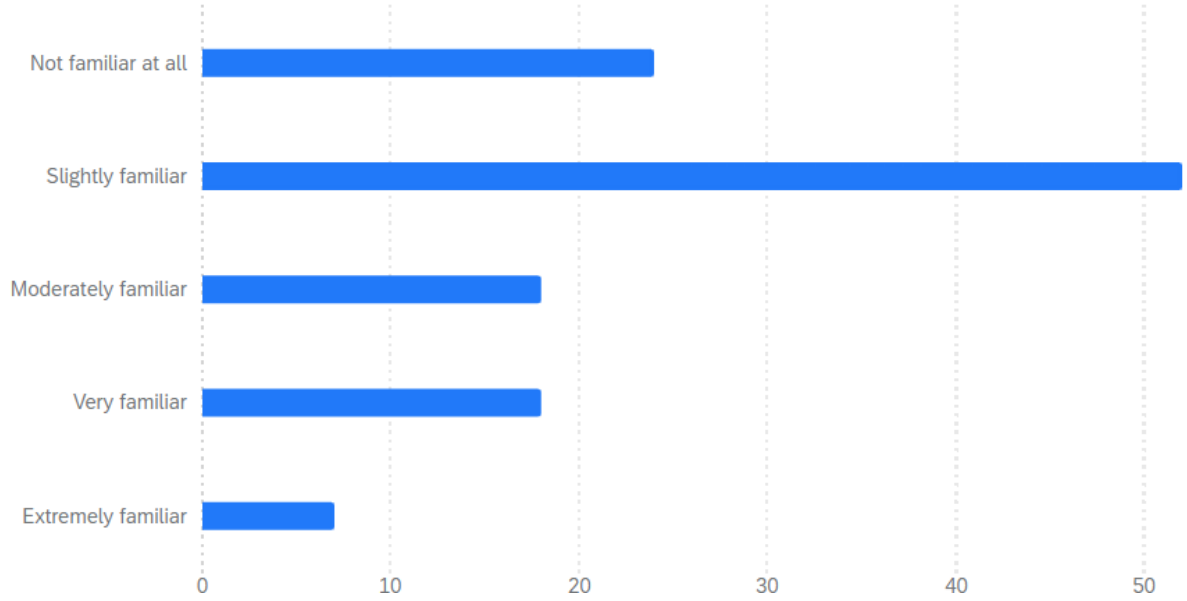


Figure 26: Unfiltered data. How familiar are you with 5G technology? (n=119).

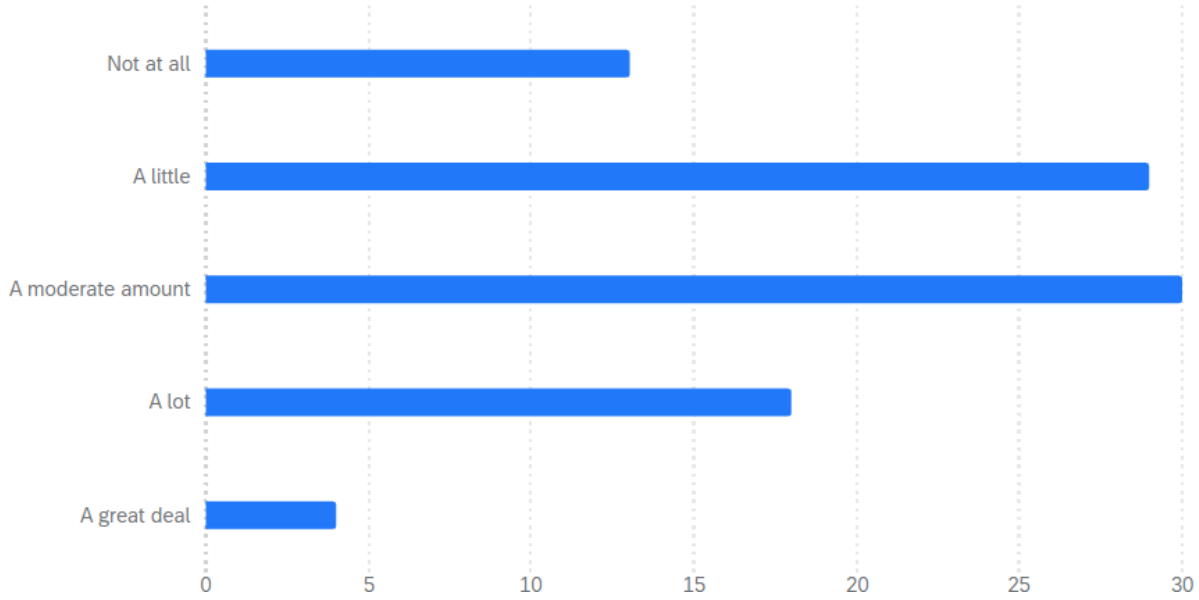


Figure 27: Unfiltered data. How much has 5G affected your quality of life? (n=94).

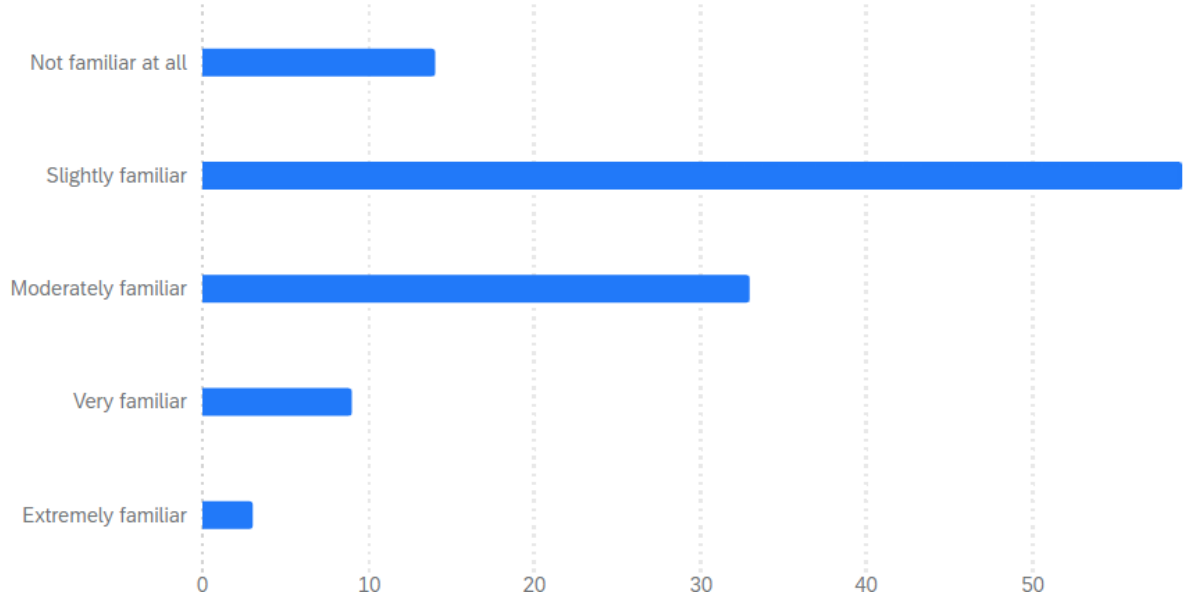


Figure 28: Unfiltered data. How familiar are you with AI technology? (n=118).

The graphs below are labeled with either *Initial* or *Final*. This is to delineate the same question being asked before (*Initial*) or after (*Final*) the respondent was shown the pros and cons of the system. Please note that the graphs labeled *Final* initially look misleading due to the structure of the survey. Respondents who said the pros and cons did not change any of their

answers were not shown the questions a second time, so the *Final* graphs below only show responses that had changed their answers in some part of that section. The graphs shown in the Results section of the paper account for this by combining the data from the *Initial* and *Final* questions to be more reflective of reality.

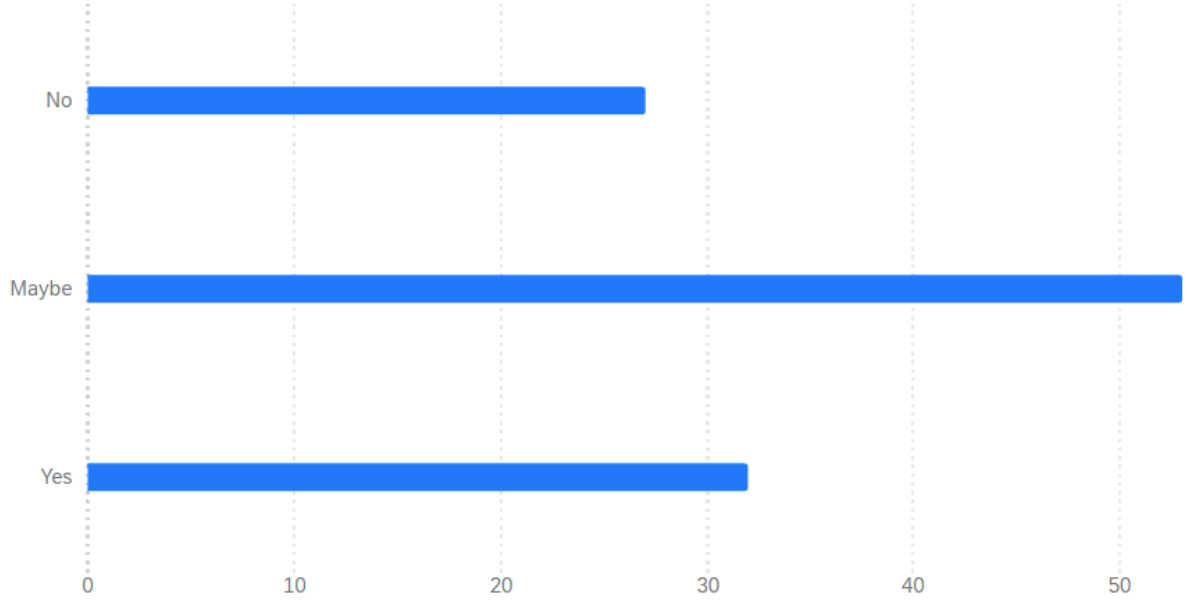


Figure 29: Unfiltered data. Would you prefer this over the current system? (Initial) (n=112).

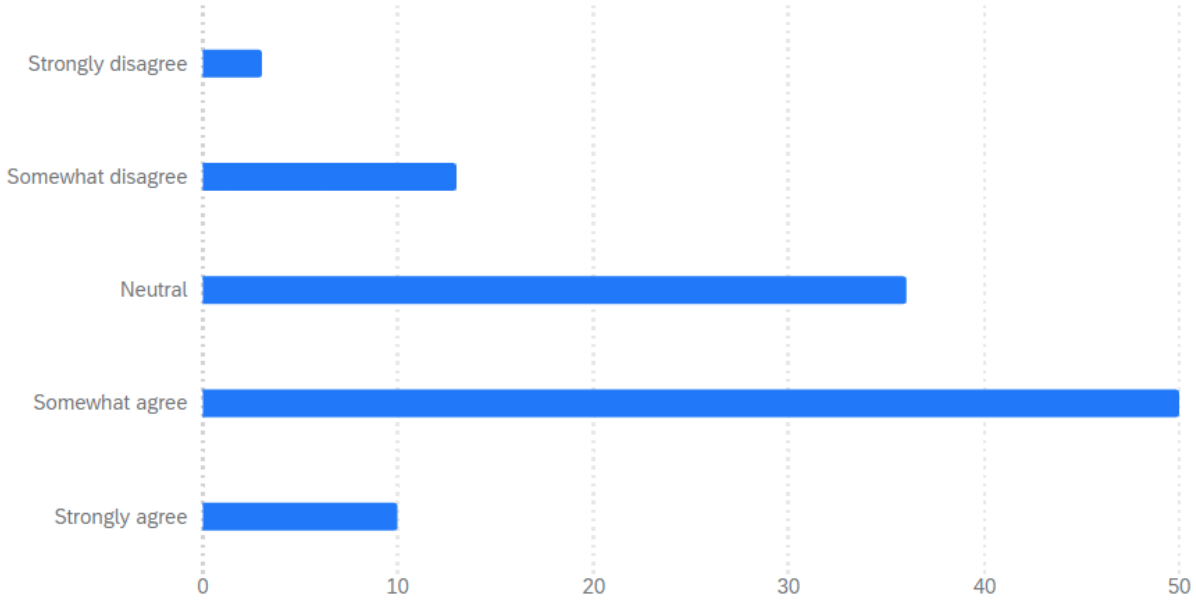


Figure 30: Unfiltered data. This system would positively affect your quality of life. (Initial) (n=112).

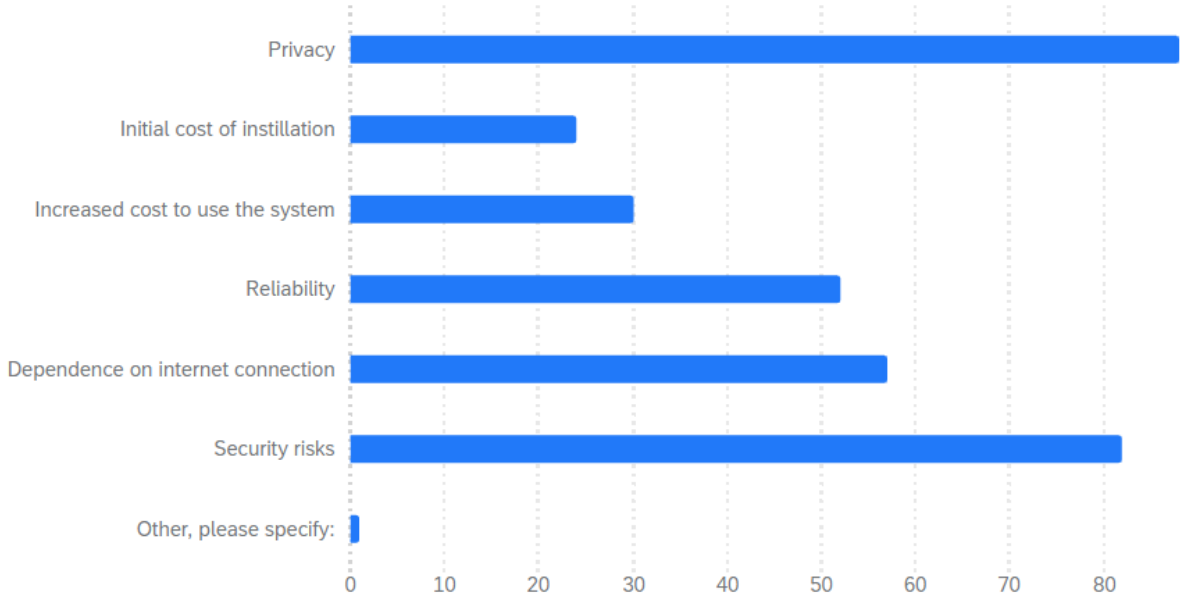


Figure 31: Unfiltered data. Check all concerns that you might have with a system like this. (Initial) (n=112).

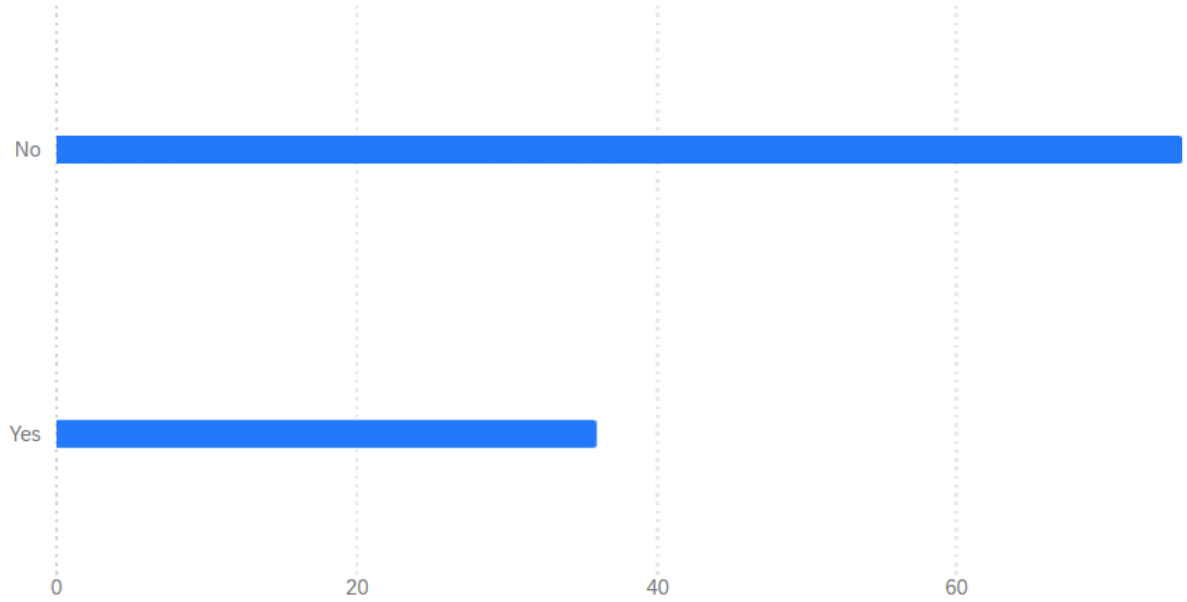


Figure 32: Unfiltered data. Would these considerations change any of your answers in the previous section? (n=111).

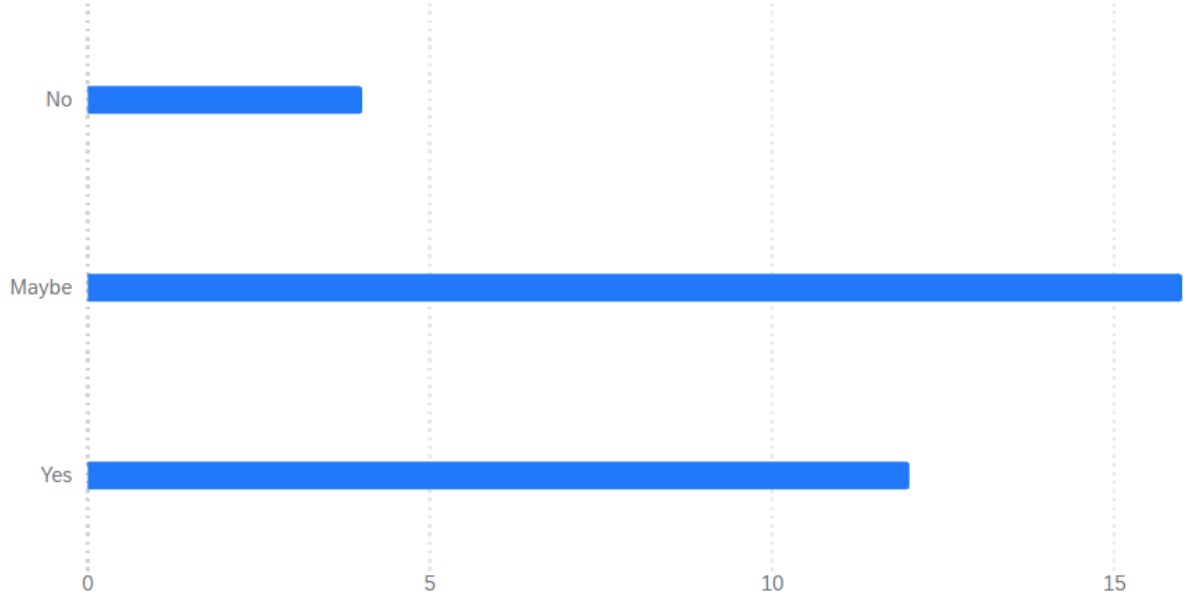


Figure 33: Unfiltered data. Would you prefer this over the current system? (Final) (n=32).

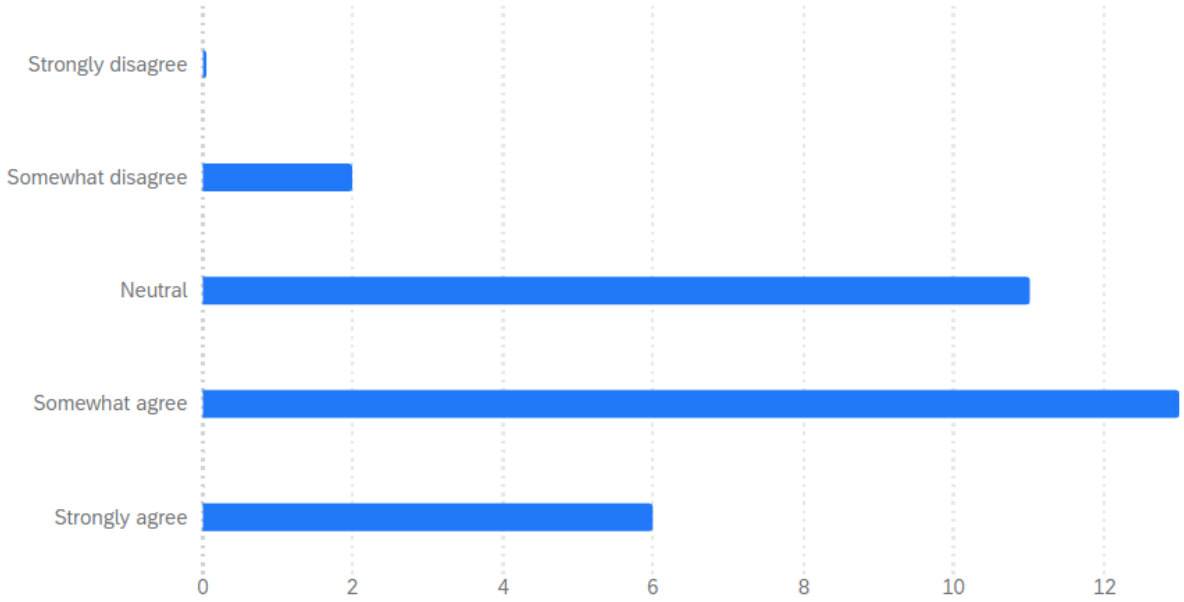


Figure 34: Unfiltered data. This system would positively affect your quality of life. (Final) (n=32).

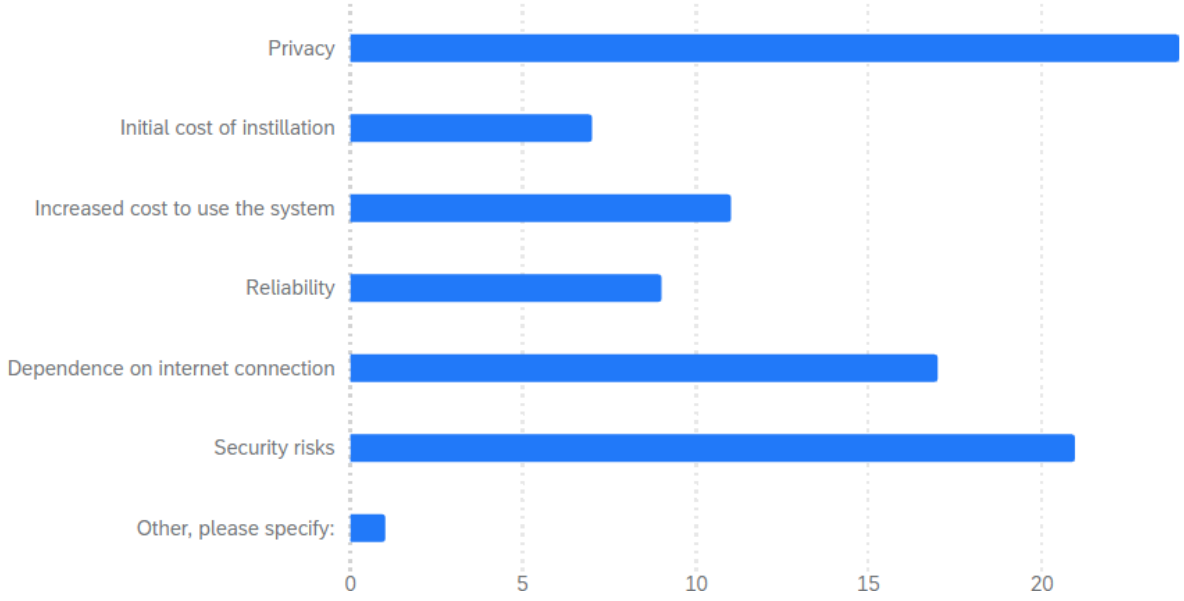


Figure 35: Unfiltered data. Check all concerns that you might have with a system like this. (Final) (n=32).

Appendix D: Tables

	Correlation Coefficient	P-value	N
Would you prefer this over the current system (Initial)? has a strong positive correlation with "This system would positively affect your quality of life (Initial)."	0.622	0	103
How familiar are you with 5G technology? has a moderate positive correlation with "How familiar are you with AI technology?"	0.472	0	102
How much has 5G affected your quality of life? has a weak positive correlation with "How familiar are you with AI technology?"	0.351	0.0012	82
How familiar are you with 5G technology? has a weak positive correlation with "Select your age range."	0.272	0.0054	103
How familiar are you with AI technology? has a weak positive correlation with "This system would positively affect your quality of life (Initial)."	0.219	0.0271	102
How often do you use public transportation? has a weak positive correlation with "Initial concerns - Reliability"	0.209	0.0342	103
How often do you use public transportation? has a weak positive correlation with "Select your gender."	0.203	0.0397	103
How often do you use public transportation? has a weak negative correlation with "Select your age range."	-0.218	0.0271	103
Would these considerations change any of your answers in the previous section? has a weak negative correlation with "Initial concerns - Privacy"	-0.233	0.0178	103

Table 1: Correlations between survey questions. [7]

[7] Ordered by decreasing correlation coefficient (r). Questions that appear multiple times in the survey are denoted with “Initial” or “Final”. The team denotes specific selections for multiple choice questions after a hyphen. Correlations shown in this table cannot be generalized to the public for reasons explained in section 6.1.2.

Appendix E: Interview with Ron Malenfant Transcript

The Interview Began Thursday April 4th at 11:56AM EST.

Bryce: Hi Ron my name is Bryce.

Owen: My name's Owen.

Ron: Hey, Bryce. How’re you doing?

Ron: Okay. Um. So, um. Yeah, when you say WPI, it's...

Ron: Worcester Polytechnic?

Bryce: Yes, sir.

Ron: Yeah, yeah, yeah. I'm from that area. I grew up in Lowell, Mass.

Bryce: Oh wow, that's funny. Yeah. So, first of all, I’d just like to ask a little bit about just any quick introductions from you. What do you do and...

Ron: Yeah, yeah. Great. My name's Ron Malenfant. I'm head of 5G architectures and strategy here at Siena. On the sales side, sales CTO side. I've been here about three years. Prior to that, I was vice president at JMA Wireless, a US radio 5G company. And then prior to that, I was 22 years at Cisco. Chief architect, mobility, and IoT. So, focused a lot. I do a lot of work with smart cities, enterprises, the DoD, fed space. You can think about the NFL, John Deere, anything, as they're trying to plan and going to... What's that? And what that entails. The use cases, the architecture, all that stuff. I'm also on the 5G Americas board of governors, that leads up the mission charter for 5G adoption here in the United States or the Americas, actually.

Bryce: Incredible. So, starting off. So, we have an interview here that we're going to read out. We have some pre-written questions. So, first of all, just read out our disclaimer. We're third year engineering students from the Worcester Polytechnic Institute. We're conducting a project to identify the benefits and hurdles of implementing 6G in Taiwan. We will be using this interview data in a report that will be published, and we will be making it available in public domain. We hope our report will be of interest to you. Feel free to skip any questions you do not wish to answer, and please let us know if you wish to remain anonymous. Do we have permission to record? We already established the first two questions so I'm going to just skip ahead...

Bryce: Moving into the third question, what is your background with telecommunications?

Ron: Pretty much what I went through. It's all been that, right. So, I'd say over about 30 plus years, very focused on telecommunications. Naturally, 5G wasn't the start of it. I was involved in mobile during 2G, cell phone cloning, all these security attacks, and then the evolution from 2G to 3G to 4G, very involved in the standards and some of the top carriers and where their architecture would go. And then as we move to 5G, it becomes very much an enterprise opportunity. So, working very closely with the enterprises, specifically around private 5G and how they would leverage that.

Bryce: Awesome. Building off what you just spoke about, the following question fits perfectly. How has 5G contributed to urban development?

Ron: Well, when people think about 5G, you need to realize that it's an evolution, right? So with 5G, there's a standards body that basically provides all the features and functions. And that's called the 3GPP organization, third-generation partnership. So that defines everything around cellular mobility. And with 5G, there is a vision, but initially, there's stages of what can be actually deployed. So we're actually in the advanced stage of 5G. So we've been talking about 5G slicing and things for a long time. But 3GPP and the functions, the releases that they come up with, there were certain releases that were needed by cities and other enterprises that until recently were just adopted. So they've ratified these releases. So we're seeing the case for 5G densification. We're seeing vehicle to vehicle communications in the cities. We're seeing the need for private 5G for first responders, things like that going on. We're seeing 5G on the side of the massive IoT. So you look at the different layers of 5G, massive IoT. So I have these sensors that can provide all my telemetry. I don't necessarily need that massive bandwidth. I just need a lot of distance, a lot of function, and the telemetry that I'm providing back into the network.

Bryce: Awesome. Thanks.

Owen: Hold on, really quick before we move on. First-time backgrounds. I know Bryce mentioned we're in Taiwan.

Ron: Yeah, I would love to talk about that a little bit too because. Very interesting what's going on today and what's happening there.

Owen: Yeah. So just for some more context, we're doing our research on 6G. We're working with TIER. They're a think tank here. They're doing research for the government and private companies.

Ron: Yeah. So what's the name of that company?

Owen: TIER, Taiwan Institute of Economic Research.

Owen: So. And that they're hard to research. We tried in the US because their whole website is... It's kind of tricky doing stuff here

Ron: Maybe CIA funded. Stealth. (said in a joking manor)

Ron: Yeah, something like that. But... But yeah. So that's off the record, guys, pause the recording. (again in a joking manor)

Bryce: So we're trying to get like the social aspects of 6G for them. So eventually here, as we go through the interview, there's gonna be questions about that and like figuring out like the non-technical aspects of 5 and 6G and also the technical stuff, but just for some context before we go into some of the next questions.

Ron: Yeah, awesome. Very good.

Bryce: Going into our next question, it's asking who can take measures to ensure equitable access to 5G technology, especially in rural and underserved areas? And what measures can they take?

Ron: Yeah, that's a great one. I mean, a lot of that is government funding and private partnerships. You know, there's an opportunity there. So I think on the government funding side, in the US, like, we've done a lot to start to build out for the underserved. And whenever you do, even non-rural type of opportunities isn't underserved in our major cities. Right. So there's areas of cities that are underserved and the ability that when somebody comes in and builds a network, say a mobile operator, you know, builds a network, that it's conditional that they also build in the underserved areas. Right. So this is really the public-private partnership that you need to really set those groundworks, but also a lot of government funding, right, to get access,

because it's not a normal way for enterprises or a mobile operator to make money. They make money on the masses, they make money on the people who have the wallet. So you have to set some policy, you have to set some funds. And then when the public-private partnership comes in, you can also look at ways to monetize it. So you can look at know venture capital coming in, private equities coming in, but potentially monetizing that over so many years. So they can help fund it, but there's a revenue stream that they'll get their money back with this x amount of interest. And it brings an incentive for a whole ecosystem to come in and actually build.

Bryce: Just building off what you just said about that financial divide, how has 5G technology affected the **digital** divide both within countries and globally? And that is just like people being able to connect with one another.

Ron: Yeah, I think what you're seeing with 5G is on the digital divide. Again, I think the same answer I had applies there. But there's also other things around the technology itself where 5G, again, I mentioned there's an evolution and with some of the recent releases, release 18 of 3GPP. There's also 5G via low Earth orbit satellites. Right. And so you're going to now start to see the ability to deploy in the areas that really didn't make a lot of economic sense in parts of Africa and South America, leveraging satellites as the radio towers for 5G. Also, we're seeing a renewed surge. Prior, so many years back, there was a thing called Google Loon where they got behind these balloons that were basically base stations in the air. We're seeing a resurgence of that again, of looking back in certain areas where there'll be these balloons and the ability now to provide 5G services via the air and not have to build out potentially these long fiber access that are very expensive in these regions.

Bryce: The next question is, looking back on the early stages of 5G, what measures would you take to avoid the struggles during the development rollout period?

Ron: Say that question one more time. Sorry.

Bryce: Looking back on the early stages of 5G, what measures would you take to avoid the struggles during the development rollout period?

Ron: Yeah, I would say one is not being an early adopter. If you were really looking at, you look at the early adopters, especially in Asia like Rakuten and their deployments, and they looked at a part of 5G which is called Oran. Right. Opening up the Ran for multiple vendors to interwork. Unfortunately, it was a very expensive, time-consuming on that end customer to do that. They had the resources, but it was a lot to prove out. Eventually, 5G, when we get to 6G, Oran in 6G will be. The hope is it will be defacto. So ORAN by the gate. It works. Right now you have certain dish just trying it, a bunch of customers are trying it. It's very hard on enterprises to do this, governments are trying this. But it's really complex and it's a learning stage. And ideally, you don't want to be in that learning stage. Leverage what people have done and what they've worked through and try to maybe stay away from some of the new shiny widgets that have not been proven.

Bryce: And then moving over to the social aspect, what was the public perception to the 5G rollout like? And do you expect a similar response from that of 6G?

Ron: So this is just an interesting one, the public perception of think we're in a little bit of a dilemma here. I think there's usually a ten-year cycle for these Gs, right? You know, we're more than halfway through that. And the challenge was initially it may have been over marketed and what it can do. And the reason I say that is if you look back what I just talked about, there's, there's a release train to get you to that full cycle. So the full promise of 5G is not available when it comes out. It's, it's going to, all of it's going to be available eventually. And so things like slicing, we told the industry and the world, well, how powerful slicing was. Well, to a consumer, it's probably nothing. Not really relevant to him to date, to enterprises, very relevant. But we've only recently got to the point where we could start to deploy slicing. A lot of it had to do with. There was deployments called 5G SA and 5G NSA. Most of the carriers in the US, when they deployed 5G, it was really around marketing. How do I get that 5G logo on my phone? But what it was was really 5G NSA, which means I have a 5G radio and I have on the backend. Everything else is all the 4G infrastructure. So it's an easy way to migrate. But I can't take advantage of all those really cool features and functions yet until I get fully to 5G SA. I think there's a balancing act that's needed when we get to 6G. Hopefully, we've learned a little bit that let's set the proper expectations with enterprises and consumers on what they'll get. Consumers, I think, really don't care. They see the 5G logo, they can do a speed test. If it's pretty damn good, if it looks good, if it's better than what they had before, that's a success for them. Enterprises are looking for a little bit more detail, and that's where we need to make sure that we set the right, be able to deploy that 5G. That's going to solve their business problems.

Bryce: So, moving to the next question. This is a shift we had recently in our project, but I think it's a very relevant question. Starting out, we had a really high emphasis on 6G and AI deployment, but we actually moved more towards how 6G is affecting the IoT space after

having another meeting. And I would like to have your opinion on how you foresee 6G affecting the IoT space.

Ron: Well, to be honest, I have to say is we're still in the evolution of 5G. So when we say 6G, there's a lot of questions, other than the new radio bands, what does it really mean? So that's yet to be determined. So it probably wouldn't be fair if I say that. I could just say the expectation is what we've learned, where we've struggled in 5G, where things like Oran and others are a work in process that in 6G, it's kind of work. Other than that, I think there's a lot of speculation. I can answer it more in the 5G world where we see, okay, what the features and functions that need to happen in IoT, and you'll see that that will be defacto in 6G. Things like Redcap and other features which are going to save the battery life when we start putting IoT sensors in the ground in cities, there's a Dig one strategy. I want those sensors to last a long time, the ability for those, that battery power saving capability. So in 5G, just recently we've announced things like Redcap that allow those power saving capabilities. We see things like energy harvesting. How can I use sensors that can harvest solar and thermal to keep perpetually powering those sensors? I think you're going to see more of that coming in 6G also.

Bryce: That's awesome. So it's another 6G question, but how do you foresee 6G affecting the average person in your country? Since we're asking you in the US, they'll be in the US.

Ron: I think that the question needs to be asked is what's the target market and what's the real benefit? Again, I'll go back. There's still a lot of what is 6G? We're still figuring out 5G. We're not done with it. We're on the advanced stages. So other than a few high-level stuff, what else is going to be with 6G? So I think we need to say is in 5G, there was initial thought that 5G is

going to be, we're going to monetize 5G for the enterprise. That was very new. Others were enterprises, were consumers of it, but much like a consumer. And 5G now with slicing all the value-added services, the control plane, user plane separation, MEC, all that stuff that made enterprises very interesting. The question will be, what is 6G to an average consumer? What it comes down to is, is it going to be worth it for me to get more speed? And that's really what it comes down to. Initially, for the consumer adoption, you got the players who want the coolest new technology, but is it worth it at the price point? And am I going to get that 6G logo? But all the other stuff, I think the question is, is 6G most likely it will be another one that's more geared for enterprises and other use cases. But with the consumer use case, it's speed, performance versus the cost. And is 5G good enough for how long?

Bryce: That's actually kind of in concurrence with what our sponsor had actually talked to us about, is that they also believe that it would be more used in the business aspect and less than the individual thing on people's phones. And that does kind of lead to the next question also is what are some potential commercial values that could come with 6G technology, especially since you highlighted things in the business industry. What businesses do you think could benefit from hypothetical 6G?

Ron: I think one is just the higher level frequency availability in 6G that that's going to bring. I think, again, going back to all the other subsets, there's still to be determined what they will be. What will 6G be, the business benefits. I do think private networks will be a little bit easier for them to deploy because we're working out all the other challenges in 5G. So in 6G, that should work and work better and be more easily consumed by enterprises there. I think the business models will be an interesting area on taking advantage of, whether it's public 6G with a carrier

and things like slicing and mobile edge compute and then AI. How do I push AI as far out to the edge as possible? I get these far edge AI, it's going to be consuming a lot. There's going to be a lot of these GPUs needed, but I need to push them closer to the edge too, so I can co-locate them with the user plane function of a network, which would be very interesting there.

Bryce: Okay, so that actually wraps up....

Owen: really quick on that question, actually. Like Bryce had said, we met with our sponsor and they were kind of pushing us more towards the business side of this with the IoT stuff. One of the other things we're doing in addition to these interviews is surveys. So one of the use cases we explain in our survey is we're in Taiwan and they've got a really trained system. So IoT like on a train system in terms of a bunch of sensors with cameras and everything linking up. And then something else our sponsor had mentioned was, like you were saying, in businesses like here in Taiwan, sensors on the motors and things, I'm curious if you think those are reasonable use cases for the CTEC.

Ron: Yeah, I'm in the middle of working with subway, major subway systems here in the US and other places. And that's something with 5G. So that's why when you say 6G, it's hard to say because these are stuff with 5G. Right. Everything from telemetry control, mission-critical. So one is, I need those trains to have secure coverage so they can kind of monitor their location so that feedback can be sent to other trains. So prior it was using other older technologies and that would be. So then there's the case of, well, I don't necessarily want that spectrum to be the average consumer spectrum off of a mobile carrier. I may want that to be mission-critical. So a lot of countries have spectrum defined as mission-critical. So in the US there's a band, N79, the

upper band, that is geared for mission-critical, so trains can use that for positioning. Now, the bigger use cases you mentioned, same thing, 5G video surveillance, first responder push to talk all the comms, I could have those on basically mission-critical slices. You know, I could have, you know, Internet connectivity on another slice. Right. You know, all the sensors providing, you know, telemetry of the train itself or even, you know, gunshot sensors or, you know, radiation sensors. All that providing back to a big data lake that I can start to now do AI and start to figure things out. Right. And I can adapt my network appropriately. So that's stuff that's being figured out in 5G that I think you'll see more standard right away in 6G.

Bryce: Okay, so that concludes all the pre-written questions. We do have one more question that is like more open-ended. Is that, do you think there's anything else that we didn't touch that you think would be really, really useful to be added to this analysis section of our paper or anything that we didn't talk about that you think is really big that could be a potential use for 6G?

Ron: Yeah, I would say is because you guys are very defined on 6G, I would say if you're not already completely committed, I'd really be make sure that you think that they realize that we're still in the development of 5G. So there's a lot of unknowns with 6G. So everything you're asking is 6G should really be also in 5G because we're not done with 5G. There's still new stuff, so keep that in mind. It's funny you mentioned that in our first meeting with our sponsor. They show us the timeline. We're all the way over here on the left, and it's like 2030, it's going to be finally a thing, and then after that it's going to be even longer. So it is really such a long-term thing here. It's a ten-year cycle basically roughly on that. So we're halfway through that, and that's why it's key. So you may have some people it's important to talk about 6G, but we still haven't fully optimized or delivered of. So all those things that we're working through that are challenges. Ultimately, the hope is that we'll be de facto in 6G. I think AI will be de facto in 6G. We're still

learning where the use cases would be. Like on the Ran side, I can use AI to adapt the Ran on spectrum utilization and power utilization and things like that. But in 6G, it should be part of the specs. It should be in there, right. So, yeah.

Bryce: Um, I think that's, that's all I have to ask on. Do you have anything?

Owen: Are you... I don't think so. You want to take our survey?

Sends link in chat

Ron: Sure. Sure. And I also say you guys got my contact anytime. Feel free to reach out more than happy and love to keep following where this goes. So anything I do when you guys come back, you know, be happy, even if I need to go up and visit you guys, you know, let me know.

Bryce: Yeah. You ever been to Taiwan?

Ron: No, no, but I've been doing a lot with the DoD, NATO and others, and that's one of the areas also where there's a heavy, a sense of urgency with what we need to do with 5G and 6G. Even in NATO countries, it's a sense of urgency where, you know, at any moment, you know, they, they need that for their protection.

Ron: Yep. Great. Well, it was awesome talking to you. Like I said, you know, you guys got my contact, you know, anytime more than happy. And so when you guys come back, happy to meet up in person, follow up, any stuff.

Owen: Okay.

Bryce: All right. It's incredible talking to you. Thank you so much for taking time.

Ron: All right, guys. Take care. Have fun. Goodbye.

Bryce and Owen: Bye.

Appendix F: Interview with Farinaz Edalat Transcript

The Interview Began Sunday April 14th at 9:00AM EST.

Bryce: Okay, so starting off is what companies research does your experience in the telecommunications or electrical engineering field come from?

Farinaz: So I'm director of system engineering at RKF Engineering. We're a consulting firm. And over since 2017-18 I had been working with coalition of companies and this coalition was like any company that had interest in bringing Wi-Fi, expanding Wi-Fi. So from the chip manufacturers, so like Qualcomm, Broadcom, Intel, like in the laptops to the content providers like Facebook, Google, Apple. Apple could be both. Well I guess no, mostly chip manufacturer HPE like the enterprise or Cisco. So like Microsoft and a few others, they all came together and they hired us to find a new band. It's in the 6 GHz band for Wi Fi devices. And so that was back in 2018. So we did this study, we showed that they can coexist with the incumbent which are like fixed microwave stations. So they got the band. We did the studies internationally, they got part of the band in Europe, in India, we did the same thing in Mexico. And the next phase of that was for the high power devices. They need to have a frequency coordination system like a server that would tell them that would do this live based on a database of the in command services, so it does an interference analysis and then comes back and says you guys can only operate in these frequencies at this power level so that you don't cause interference. So we also developed that server in an open source format. So Facebook, well Meta, Broadcom and Cisco hired us to develop that code. So we did that and it's now open source actually. So then one of the next things I'm working on right now is called AFC, automatic frequency coordination,. So

FCC has certified a few of the operators but including the operators that use our code but it hasn't really been used yet because one of the early users would be actually Cisco. They already have their access point certified, the standard power access point certified, but they're going to be their AFC at the start would be at a different company but eventually they want to use this open source software. One of the other studies that is very hot right now is the sharing in Europe actually. The sharing between these Wifi devices and IMT which is the cellular technology because over that portion of the upper part of the band in the 6 GHz there's the IMT, the cellular. I guess proponents want to use the band as well. So now they're kind of like we're doing studies on the Wifi side to see how they can share with the IMT services. And I think that's more like the impact to the Taiwan on the 6G cellular depending on how that goes.

Bryce: That's incredible. You just answered our first three questions. With that one bit alone. Thank you so much.

Bryce: Yeah, so the next questions were like what are your job title and what is your background with telecommunications industry? I feel like you just went above and beyond and answering that for us

Jameson: Definitely, very helpful.

Bryce: So moving to our real social aspect, questions that we really would like your input on are how do you think 5g has contributed to urban development.

Farinaz: How we would be saving it?

Bryce: The question was how has 5G contributed to urban development?

Farinaz: I know there are a lot of companies, like we did another study for this and its not public, that's why I can't talk about it. For Dish in the 12 GHz band that they want to use the spectrum that is used by currently SpaceX for satellite communication. So they have these antennas that's called Starlink dishes that basically they can get like Internet or even like, you know, data. Well Internet and yeah, not really voice, data services through Internet. And then we did a study that, you know to you that 5g would be used to share the band with them. So I guess to your question I'm trying to see how to answer that. I guess definitely in the urban areas the 5G cellular system would be more affordable because as you go to the rural areas then because you have less people going on, on that service, you have to see economically if that's feasible because there's a lot of cost of the infrastructure to put the tower and everything in place and if there's only going to be a few users then it's not economically it's not feasible for them. And that's where mostly like the satellite communication tries to serve more. Like when SpaceX had their fighting for that 12 GHz originally they said oh, we're going to be focusing more on the rural areas, but now they're kind of like expanding. They said no, we're also going to be operating in the suburb and in the urban areas. But definitely, well I guess the impact in the urban. So in urban areas there's, with the increase of the data usage by people and like high density of users there's more. They're now like it's becoming more and more challenging to meet that with the limited spectrum that are available. So sometimes they have to put in these micro cells where like smaller cells for like a high density, you know, area, because just putting one micro cell is not sufficient for the, for the amount of users, you know, in that place. So that probably doesn't really answer your question.

Bryce: I think that's great, it's very technical and we appreciate a lot of technical aspects as well.

Farinaz: A little bit does maybe. Yeah, so like all these, like the IMT Wi Fi, again, like the first concentrate in the urban areas because that's the part, that's the area that's going to be most, it's the first target of that application with the IMT or the cellular. So they try to resolve there first.

Bryce: Actually, I think you unknowingly answered the next question again, somehow, actually. The next question was how can you take measures to ensure equitable access to 5g technology, especially in rural and underserved areas? I feel like you answered that perfectly with all the things about SpaceX and Starlink. So thank you so much.

Farinaz: I'm trying to think. I mean, there are definitely these, the IMT or the 5G that we did for dish, they're definitely trying to be everywhere. But like, if you, when you go to like a really, really rural area, then that's where, yeah, what happens is when you go to that, then the actual, the coverage area would be larger, that the tower, they're going to put the tower at a higher height so that it can cover a larger area. So that's, that's one way they kind of deal with that. But it's still, yeah, not completely, you know, some part is not feasible economically. Yeah.

Bryce: Moving on to a very social oriented question. That's more of just what your opinion is on this is how has 5g technology affected the digital divide within countries and globally? And are you familiar with what the digital divide is? Or.

Farinaz: Um.No, I would be guessing, like, what that might be. Maybe if you could. Um. Yeah.

Bryce: So to our understanding, what the digital divide is, it's more the access to Internet people have, whereas, like, in rural areas, people might not have as much Internet access. So they're like, put in a lower tier of society compared to people who are more wealthy and have more access to Internet. And it kind of just creates this divide between the population.

Farinaz: Can you repeat the question?

Bryce: How has 5G technology and improvements to cellular technology affected the digital divide?

Farinaz: Well, I mean, if the 5G is that it becomes accessible more and more everywhere, then it's going to remove the digital divide, I guess because, I mean, again, I don't know how it's like, um, in a reality, how this is working. I know, like, you know, from the studies, they definitely have, like, you know, system parameters for the urban versus suburban versus rural. So it's not supposed to be just for urban suburban, you know, but. And, like, for rural, as I said, by having a larger size tower, you know, the antenna being higher up, then you can, you know, just by the physics of it, that the, you can, the signal can propagate farther. I think they might have the gain, like, you know, the transmission power also higher. I have to try to remember what those were. But, yes, they designed the system so that you can actually have them operate in everywhere. Yeah.

Jameson: And, I mean, we're off an island, off of mainland China, and we definitely have pretty good connection with 5G. So I think even we've seen that, like, increased radius of connection, and we definitely haven't had a hard time with connecting to 5G.

Farinaz: You guys have a good speed there?

Bryce: Oh, yeah. So we took, like, a weekend trip to an island. It's part of Taiwan that is, like, you can see mainland China from the island, actually. It's called Kinmen. It's the closest part of

Taiwan to mainland China. And you can actually connect to Chinese cellular networks from there, which is kind of cool.

Farinaz: Oh, wow

Bryce: Yeah.

Farinaz: Oh, so it must be, like, really close.

Bryce: Oh, yeah. You can, like, see the buildings from.

Farinaz: Oh, okay, great.

Bryce: So.

Farinaz: Oh, interesting.

Bryce: But yeah, so moving into some not, like, entirely technical questions, and just a little thing, it's like, this is not the most technical paper. It's more going on the, like, just expert opinions. It's kind of just getting your guys opinions and your views on some of these questions. But, like, looking back, or current question, A.2.7, is looking back at the early stages of 5G, what measures would you take to avoid struggles during the development period? And some of those struggles were, like, costs and things like that.

Farinaz: So, again, I wouldn't say I'm an expert on this, but I think over time, let's see, what measures have they taken? I mean, definitely by doing this, like, as people have gotten, like,

doing these studies that ahead of time, they would know. Well, okay, so I think one is the, so before they put their network coverage, there are all these, like, models of, like, the past loss that they call it a propagation loss that models how the signal from the tower to the, to the user, you know, how much attenuation it, you know, is affected without having, you know, without actually deploying in the field. So they've been, you know, creating these, making these models, just making them better and better by taking a lot of measurements and fitting, you know, coming off with a empirical model that fits the measure data. So there's, I see, like, there's a lot of, there has been a lot of work on that upfront on that front. And that would, you know, by, by doing the studies, analysis, you know, in, on computer, on paper, you know, paper basically ahead of time, that would save a lot of cost because then if you have a model that resembles reality better, then there's a higher chance that you have a successful network at the end. So there's propagation model, there's a lot of simulation modeling, we don't do that for an operator, but I'm sure operators have that, do kind of that thing all the time. We do more like interference study, but it's the same. We actually use the same propagation models that is used by planning a network. So I would say yes, by doing the study smarter, having more accurate propagate. Like one example of accurate, more accurate propagation models, even they have model the propagation situation inside the building or like penetration from the, from the building to outside. You know, there are like models for that and the different models for urban, suburban, rural areas. What else they might have been doing? Yeah, I'm not. I'm not sure. Well, also, I guess data interference, because now, there's more data demand now more and more, you have these services operating in bands that they share it with another service. So they have to find a way to co share the band. So again, doing those interference analysis properly to ensure that, you know, once they get the band, then, you know, neither system would be impacted is very crucial because then, you know, then you can, you know, do the whole development. You have things in the field and then at the end of the day, can't use it because they cause a lot of interference to the other service or vice versa. So then, you know, then that would be a really

waste of costs and stuff. So. So, yeah, I would, I guess from my perspective, those are the two things I would pinpoint.

Bryce: Thank you so much. I think. Yeah, definitely what we've been researching in the past few months have kind of been in parallel with what you just said. I think everything you just said has been a great impact with, like, what we've been looking at. And you pretty much said what we've been looking for. We really want to get down, like, what to avoid with the rollout of 5G and some of the problems and implications. Cost has definitely been a big one that we've seen come throughout a lot of papers, so that was really good perspective.

Farinaz: Yeah, yeah, I know this, you know, making sure like planning this macro micro, which of these system you would deploy is very, you know, like economically it has a direct impact.

Jameson: Yeah, absolutely.

Farinaz: They have to, yeah. Based, so based on the demands they need to, you know, plan that accordingly.

Bryce: So a little more background before we get into our next question is we're working with the Taiwanese Institute of Economic Research, which is the second largest think tanks in Taiwan. They are currently working with the Taiwanese government and helping them plan out their rollout of 6G cellular. They give us a rough timeline of around 2030 according to some other companies they consulted with, of when they think that technology is going to start to appear and start to be able to be ready for the market. We're really tasked with two different things. One is working for our sponsor. The goal was to try to get background around 6G and 5G technology on the technical side and the social side. And then for IQP through WPI, those

are social qualifying projects where it's across all majors, you come together and you do a research paper. It ends up being a little bit over 100 pages. It's a very detailed report. And being mostly engineering students in this program, it really teaches us how to like write and do super technical research. And like moving to some of the next questions. They're primarily the social questions.

So the next one coming up is what was your reaction to the public perception of the 5G rollout and do you expect a similar response for 6G?

Farinaz: Yeah, to the public reaction to what?

Bryce: To 5G cellular technology rollout.

Farinaz: Oh, I think it's been great. Right. I mean, I was happy when my, my phone was able to, I felt, I think the connection was better because like, as they go, you know, there's always improvement. Right. That's not getting worse, only, you know, it's only getting better. Higher data rates, what else they might be doing. Yeah, I mean, there's like so many factors that go into how to get the higher data rate, but, you know, from the end user it's really the data rate and not having, you know, not having downtime. Right. Like that's too much fluctuation that, you know, most of the time you have a high data rate kind of thing. So. Yeah, I mean, I think the public would, I mean, every, I think anytime there's improvement, there's for sure would be good for everybody.

Owen: Really quick. I think an interesting point to bring up is that with the research we've done on the population of Taiwan, a lot of people preferred 4G over 5G. I think it was because they were unsure of the technology as well as the cost. So they would rather stick to what they know than switch to 5G. But I think as the years progress, they become more and more open to

switching to 5G. That was just something that we noticed in our research and that we'd like to bring up to you.

Farinaz: So maybe, like, I mean, I can understand why the cost could be impacting. I mean, if the 5G is more expensive, then, and, you know, 4G is working for them fine, then why would they switch? But I wonder why they had, there would be more hesitation besides cost. I mean, you know, the only other thing I could think of is the security aspect of it. Or, I mean, because I wouldn't think they would think that the, you know, their experience would get worse. It should only get better. Or maybe. Maybe they would think that if they switched to 5G, they would have limitations on where the 5G is available. Maybe. And that's why they. 4G has been established for a long time. You know, everywhere they go, 4G is available. Maybe that's another aspect.

Jameson: The other part of the project is doing surveys on the public. And so that's kind of what we're trying to gather from those surveys is their perception of 5G and other things. So we're trying to get that on top of doing interviews with experts.

Farinaz: Right. So I think as long as in their marketing, you know, they really say, you know, how the 5G kind of address all the concerns in their marketing campaign, then that should probably help a lot.

Jameson: Yeah, we noticed that they're, sometimes they're kind of afraid to use some words in their marketing because they don't think they'll get as much business. So we're kind of trying to gather research and input on that.

Bryce: One other interesting point before we get into the next question is that you mentioned that 5G has better speeds. That would essentially be like, oh, well, why would I not like this?

And I feel like with the previous interview we did, too, with another 5G expert or engineering expert. People in the engineering field and people who are familiar with, relatively familiar for this technology are a lot more adopting to it because they see better speeds, and then there's not really this stigma or fear around it because they understand it and they know what it's doing, and they're like, yeah, this is great, but people who don't understand the technology as well are more hesitant to do it, which is a little interesting to see, but it's just an interesting trend that I just noticed again in this interview of how adopting you were to it and then related to your knowledge in this field is also very interesting.

Farinaz: Right, yeah, yeah, I can see that. Yeah.

Bryce: So this is kind of leading into our questions about 6G, which is currently in its state entirely like a hypothetical thing, and it's just kind of looking for the future. So there's been no actual 6G standards set, no data rates, anything. But from our current understanding, 6G is going to be the next generation of cellular technology following 5G, and it's just going to be more used in the IoT sector, in the business side for connecting sensors. And it's just going to be primarily aimed at high data transfer for massive computing issues that can't be transferred over 5G cellular. Instead of having to run fiber or run Ethernet through something, you could just use 6G.
The first question is that one, is what do you expect the public perception to 6G roll up to be like? And do you think it will be anything different from the public reception to 5g rollout?

Farinaz: I mean, I don't know much about 6G, but if, based on the description you provided, if there's not really, it's not going to improve the ordinary experience of cellular for people, then they probably don't, you know, see a need to switch. If it's mainly for like factories and I don't

know, like utilities and stuff like that, then probably the public doesn't really care to switch, I would think. Unless there's really improvement for that, for that sector too.

Bryce: Yeah.

Jameson: So what we heard from some other experts and professionals is that it'll be more for business and industrial use rather than commercial use, at least initially. So I think the public at this point anticipates that 6G will be more for them. But I think it's going to be more for the business side, like more for smart city initiatives, other stuff like that.

Bryce: So the next question we have, we have two more questions following this one and then we have like a free response. Anything else is this one is how do you foresee 6G potentially affecting the IoT space?

Farinaz: Again, this is not really my field. I mean, if, I think it's great, I mean, I would think, you know, if there's provides better connectivity for the sensors and, you know, for the factory applications, I guess like some, you know, company like Amazon would be very helpful for them, then it's for sure. I mean it's, you know, probably gonna reduce their. Their cost, you know, their labor cost, and, you know, getting the data more quickly, you know, monitoring things more efficiently or something. So if, if what you, you mentioned about the 6G becomes true, then I can see how it would really benefit the companies that would be using it.

Jameson: Here’s a really quick follow up. How do you see 6G affecting the average person in your country?

Farinaz: Well, I mean, if the application is more IoT, then I don't think it would impact us directly. Maybe. Maybe the way it would impact us indirectly, maybe it would reduce our utility bills or products we bought, which I doubt. Right. Like, normally prices go up. No doubt. It would really probably increase their profit margin. You know, those companies. Yeah. Also, like, I don't know if that, how that impacts the jobs, people's jobs. Maybe they would need less people.

Jameson: So you think there would be more, like, indirect impact on people?

Farinaz: I would think at some point there would be some indirect impact, but I don't. I guess I don't truly understand the, you know, how much it really benefits the companies, you know, that would be using it directly to then say, okay, then this movement would be. But that would be interesting to find out.

Jameson: I don't think we will understand for a good while. I think it's still very much so in the early research and development stages.

Farinaz: Is the IEEE working on 6G right now? You guys know?

Owen: I don't believe so.

Farinaz: That's the standard. You know, that's the standards that would be working on it. Or three GPP. IEEE or 3GPP.

Bryce: Yeah, we. We had an interview with uh Ron Malenfant, who was, he's on the board of directors for 3GPP. And at least from what we came to understand, is that 6G is more of a buzzword used by networking companies to kind of throw 5G or something at people. And that's

why we're using it very cautiously and making sure we don't group it with 5G, because we were told that 5G is going to be improving for the next probably five years and above, and that network generations usually last for about ten years. And given that 5G was just implemented, it's going to be a while before we see anything even regarding 6G. And a lot of this paper is really just kind of finding the hypothetical backbone of what 6G could be used for and how it could affect society as we do it.

Farinaz: I see. Okay. Yeah. That's what you guys were hired to work on. To help out with right. Defining this. I see, this interview, too.

Jameson: So I think you kind of answered it a little bit. But we'd like to, like, elaborate a little bit is what do you see some commercial values of 6G in the future with what you might think it might be like?

Farinaz: So I guess I'm trying, I'm just thinking out loud. So, like, I heard, my friend works in Amazon, and she said, like, now they try to make things more streamlined. So I'm not too great at the IoT applications either. So if, like, if, I guess if they have a lot of sensors, I guess it could reduce, it could provide more, you know, I guess the manufacturing process, you know, like, they have, like, particular steps that needs to be done. And if there's, you know, better, you know, instead of like a manager being there or something, then they can. I'm really making this up. I don't want to.

Owen: That's what this question is kind of designed for, is to kind of hear what your input is about what you think it might be like.

Bryce: There's no, like, supported by research aspect of this for something that doesn't exist. So.

Farinaz: Okay. All right. Yeah. I mean, so, like, maybe like, you have the, I mean, they already, so, like, when they delivered the package, right, they would take the picture and then they, you know, send it, you know, because you can see it on your app. Um, well, I guess what could, what could those, you know, in the factory, what are, what things could they do with the IoT? May, I don't know, somehow help with packages don't get lost because sometimes they send, like, wrong packages. Right. Or they send something twice.

Jameson: Yeah. I mean, that's the first time we've heard about Amazon in our research and our interviews. So I think it's, that's a really good perspective because we haven't thought about that yet.

Farinaz: My friend works there, and one of the recent projects is to make things like, using robotics and stuff in, in Amazon factories. And I saw that I would think the IoT would be a good fit there. I just don't know if they're going to use it.

Bryce: So that does bring us to our final question. And then one last thing, because I don't have the premium version of Zoom, we currently have about two minutes and 50 seconds left before it kicks us all out of the meeting. But I think the final question is just, is there anything else that you think might be relevant to this project that we haven't discussed yet?

Farinaz: So now that I understand better. So what are you guys doing exactly to find the social impacts of technology that hasn't been realized yet?

Bryce: Yeah. So it's more interviewing the public on their opinions and surveying them about 5G technology and 6G technology to kind of get that social aspect as we do background research to help advise TIER about what people really want in these technologies.

Jameson: Kind of what their personal concerns are and what they're like. Their initial reaction to hearing about what 6G might be like and how it might affect their daily lives.
Farinaz: So your research. Your research is not just for 6G, but it's also for 5G?

Jameson: Yeah.

Farinaz: So I would say, like, it would be helpful to know how the 5G is working for people. What are some still experiences that they wish it could be resolved or challenges that people are facing if the network quality is not good, are those being addressed somehow with the next generation of 5G or in 6G? I mean, I would say my cellular coverage is still pretty bad where I live. So where Bryce lives, hahaha or where his parents live.

Jameson: So you're saying they should address their immediate concerns rather than progressing forward.

Farinaz: Yeah, I mean, are those like. Because of the 5G, they have 5G in Taiwan, right. Right now?

Bryce & Jameson: Yes.

Farinaz: Yeah, so how is that working? Is there, I mean, if it's working great, then. But if I don't, I mean, I would doubt that would, you know, they would say everything is working great, but I

guess none of these are perfect either. I mean, you don't expect to have perfect cellular coverage everywhere, that's why people have the Wi-Fi. They have to augment it with other technologies. But I think it would be helpful to understand how people's experiences are with, well, I guess that's. You guys are doing that already. On the 6G? I mean, what would you, would you ask public if they. We don't even know what 6G is. That's, that's kind of like. I don't understand that part.

Jameson: We did provide an example of how 6G may be utilized in the future, and how it may impact them in their day to day lives, then asked how they felt about these possibilities. We are running out of time, however.

Bryce: That wraps up all the questions we had for today. Farinaz, we can’t thank you enough for sharing your insights and experiences with us. It's been incredibly informative and helpful.

Jameson: Yes, thank you for your time and expertise.

Farinaz: You're very welcome! If you have any more questions in the future or need further clarification, feel free to reach out. Good luck with your research and the writing!

Bryce: Definitely will do. Thanks again, and have a great day!

Farinaz: You too, take care!

Appendix G: Interview with Joseph Murphy

Transcript

Due to Joseph Murphy being a Research Associate at Worcester Polytechnic Institute and having differing experience with the telecommunications industry than the rest of the professionals we interviewed, the team believed it was appropriate to move forward with a separate, but similar, set of questions more appropriate for the interview.

The Interview Began Thursday April 18th at 10:00AM EST.

Jameson: Alright so, those interview questions we sent you, we made some new ones so that it would be a little bit more appropriate for this interview.

Joe: Okay.

Jameson: And to start us off, what field does your group primarily focus on and what have you guys been doing as of late?

Joe: Alright, so yeah, I'm Joseph Murphy, Research Associate at the Wireless Innovation Laboratory at WPI. We are one of the labs on campus that does research related to various wireless communications systems, a lot of our work right now is focused on machine learning aided communications systems because that's one of the kind of big areas that a lot of these different groups are looking at is, how can you use that AI enabled stuff to optimize

communications, whether that's the way you set up the network, the way you kind of have users allocated, stuff like that. My research specifically focuses a lot on the development of platforms to test on these kind of systems, you know, setting up emulation systems, kind of things that you know set up, do the testing on, I'm working with a couple of Mechanical Engineers on a design lab for autonomous ground vehicle communication work, so various stuff like that.

Jameson: Great, so you do a lot of the testing for these applications?

Joe: Yeah, so setting up, partly testing, setting up of the platforms to test on, 5G stuff, you know various different wireless protocols, like 5G is obviously one the things we look at a lot, there's other aspects of these networks too that we look at since we do research rather than deployment of hardware systems for usage in various environments.

Jameson: Yeah, so a big part of our project is looking at the publics perception, and obviously you did your IQP.

Joe: Yup.

Jameson: Uh, its pretty much tying it back into the social aspect, and how we did that was we looked at the public perception of 5G and AI in Taiwan, we figured this would be more of a technical interview, which does not hurt, considering none of us really have too much of a background in this kind of stuff, and so we figured this would be a great help, kind of understanding that too, since you cant have one without the other, the social aspect and the technical aspect. So I guess we kind of wanted to garner some more questions about 5G, then move a little bit more into 6G. And, so what work have you and your group done for 5G?

Joe: So one of the kind of big things is the security aspects of 5G, so uhm that can include things like user authentication, we have one PhD student finishing up that does, it's effectively called RF Fingerprinting, the idea there is if your cellphone connects to a cell tower, can it use certain physical characteristics of like the computer components and processing components in the phone to determine that it is your phone, and not somebody who has the password for authentication for example. We have a project currently that is looking at intelligent jamming, so if you have someone with malicious intent can they set up a jammer that goes undetected by various means, you know is it, one of the easiest ways to jam is to just kind of flood the electromagnetic spectrum or just a bunch of noise so nothing communicates, but that's very obvious to see and easy to track down the jammer, so if you can kind of have a bit more finesse with it, maybe take out very small parts of the signal that are essential, then it's harder to find you, but then you basically cripple their communications system.

Jameson: Great, yeah, so using it for more of the security aspect.

Joe: Yeah.

Jameson: So a big part of our IQP right now is public perception, but that also is in parallel with public concern, and the biggest concern we've seen with the surveys we're doing is security, so I'm glad you mentioned that, Aaron do you have any comments on security?

Aaron: Not really, nothing in particular, we definitely talked a lot about security, it seems like the public seems to be, like that's their primary concern.

Jameson: Yeah and I guess anything that would make them feel more secure about their data and their own privacy I think is for the best. We actually had a meeting with our sponsor this

week, and we talked about policy, and how can companies and professional organizations create these policies to make consumers feel more secure. So they might be doing similar things here.

Joe: Yeah so I know with a lot of our research its based on group sponsoring, a lot of it is defense applications with national security, stuff like that. So we do do a lot of stuff that is a lot more, you know, secure than what you'd need for an average user, but it does end up trickling down into the system, so if you know, the army or some other defense organization wants to have something that is super secure for their application, obviously things we learn from that will fall down into these public applications, and so that kind of is a lot of where the security comes from. It's always a race of we create a new secure system, adversaries trying to crack this secure system, so we have to keep going, it's a back and forth. When you're working with groups that have such high security requirements obviously, naturally you're going to need to keep on top of that stuff, so.

Jameson: Oh yeah absolutely, absolutely.

Aaron: So following that, you said you do a lot of work with AI, Machine Learning, and communications, so I was wondering how that might impact the security of the system, does it improve it, or does it like?

Joe: Yeah depending on how you apply it it can improve it, so the project I mentioned that does the kind of finger printing, a big part of that is obviously can you take a Machine Learning model and train it to identify these fingerprints, you know maybe there's certain, cause when you go to, like spoof device, or you want to impersonate somebody stuff like that, there are only so many ways you can really do it that are undetectable, so if you can train some sort of Machine

Learning system to pick up on those common attributes, and have it kind of just look at the users and connectors and things like that, you can see if you identify somebody that 90% of spoof devices show up with this weird quirk, if we find that then we can pull that aside and look at it more deeply to see is this coincidence, is this a spoof device, and a lot of the time with the reason for using these Machine Learning and AI applications is because they can do things a lot faster than a traditional system could, and most of the time if you train them correctly, they can identify things that you wouldn't think to train, not train, you wouldn't think to program your system to identify, so they can kind of pick up on stuff that is similar but not something directly accounted for.

Jameson: Yeah, and I'm glad you're mentioning all the security stuff, because a lot of our background research that we did in ID2050, a lot of it was on security, so we only did, we did a good amount of research on that, but, you're hitting more specific thing that I think will help build up what we've researched so far.

Aaron: Yeah, so I guess, moving on, what can you say about the current state of 5G. This can be relating to the security, the speeds, anything.

Joe: So, the current state of 5G, especially kind of the publics perception of it, it is most people think 5G and they think of the idea of 5G on their cellphones, my cell company is advertising it as faster, maybe they advertise it as more secure, the big thing is that its faster. That is true, it is faster, you do get higher speeds and stuff, but a lot of the time, what people don't think about, is when you're on your cellphone you're not really doing that many applications that require super fast connectivity, you know, the most intense thing you're doing is either file transfer, or streaming video, and for those a lot of the time even like LTE is sufficient, one of the big things with 5G, and kind of one of the big reasons its important is because it has capability of carrying

much higher subscriber based. So if you put up a 5G cell tower, in a dense area like an urban environment, and maybe you have temporary 5G performance for convention centers or concert venues and stuff like that, you can connect a lot more users and they can maintain a high level of quality service, because of that larger ability to carry users. So, that's kind of the big thing with 5G that the average person would see, obviously, you know 5G while deployed out to the field, it is constantly undergoing updates and changes, I think the, I don't know if its out yet or if it's the next revision 18 or 19, is the next kind of standard expecting to come out, and that's starting to focus more on stuff like IoT, and device to device and vehicle, so there are, despite it kind of seeming like its been deployed and its out, there are aspects of it that are constantly developing, because going from 5G to 6G isn't, you know, we stopped at 5G and we start with this new thing that is now 6G, at some point you basically go, we have enough new features and we have enough major features that might break backwards compatibility and end up in a new version, but a lot of the developments happening in 5G right now are things that will inform 6G.

Jameson: Yeah, that's great, because we had an interview with a Cisco employee who's on the board of direct for 3GPP, and he said pretty much exactly what you said. Still building up 5G, very much so, and our sponsor came to us asking about 6G, and here we are, weeks later, and we're pretty much hearing that 5G is still continuously being advanced. So I'm glad you mentioned that point as well.

Joe: Yeah, I mean generally with these kinds of things I think the rule of thumb that a lot of people in the industry say is every ten years is roughly when you get the new, the next version. You know 5G is only really, 4 years old, 2020 was around when it really started becoming, especially in America, when it really became ubiquitous, and so I wouldn't really 6G rollouts to be common until close to the 2030's. You know it obviously depends area to area, you know for

the 5G rollout especially, a lot of Eastern Asian countries like Taiwan and stuff like that they were a bit ahead of the curve rather than America and Western Europe with these kinds of deployments for various reasons that maybe you've seen, you can look into, but, I think the idea there is that, you know, just because we've deployed 5G doesn't meant that we have to stop updating it. I mentioned IoT for example, IoT is becoming a very big thing, 5G at its basic standard didn't have much support for IoT because it is primarily the cell carrier model where you have a central tower that everyone connects to directly, which doesn't work great for IoT because a lot of the time you want to establish these more kind of mesh style networks where you have devices connecting to devices, that's something that the newer standard or new revisions of 5G are working on, is that device to device which extends to vehicle as well, where you know, instead of having one central node that does all the management, you have this distributed network, which for our application ties back to security applications. If you deploy a network that has that cell tower that does all the management, that's a very weak center point, that if you were able to knock that node out, you'd cripple the entire network. So you know, looking at how can we make it more agile so that if a single node was down, the network isn't super impacted. Maybe it has to do some reorganization, but it still is in operation.

Jameson: Yeah so you're saying that IoT is going to be a bigger part of 5G moving forward rather than till 6G?

Joe: Yeah I think that, the way it stands, there isn't really any reason to wait till 6G to do IoT, you know it might not be, you might not be able to find off the shelf IoT devices that do 6G, or that family of standards until 6G, but the framework for how do we set up these topologies of these networks, that stuff that's all going into the network right now, you know, and there are other interested parties in that style of networking that not just IoT, we have vehicle fleets, or

you know other sort of, networks where you want to have the devices that the client devices directly communicating, that's the same kind of idea.

Jameson: Yeah, and we wanted to ask you about the future of 5G and you definitely elaborated on that, so I think rather than forward, we'll ask a little bit about the history of 5G instead. Do you have any, cause how long have you been working with WPI? On this?

Joe: My experience with 5G, between the research position I have now and my grad studies and MQP, it's been about 4 years, so my history with 5G isn't as deep as some of the other industry professionals that you've talked with, but I've seen some changes made to it but nothing super drastic.

Aaron: Mmhm.

Jameson: But you've definitely seen more development than the average person has.

Joe: Yeah

Jameson: Right. And, a more technical question, can you describe the aspects of the 5G system that you believe are the most important. Or at least what they should focus on moving forward.

Joe: I mean, I think obviously Machine Learning and AI are always going to kind of be this new hotness, everyone is using it, I think there are obviously many applications where it's not applicable but with a lot of the aspects of 5G it definitely is. From the security stuff we already talked about but there's also a higher level of if we start getting into these device to device

networks where you're not relying on a star topology where everything connects to one central point, instead of you're creating this kind of mesh, you can use AI there for establishing how these links work. I've done some research, where, if you have this mesh system, you know, a lot of the time it's very reactive. So if a link goes down, or there's poor communication in one aspect, it waits until that communication gets really bad to make adjustments to fix itself. So we've looked at machine learning aided routing schemes where it can kind of try to predict if a set of nodes is gonna go bad, or most nodes may go bad, preemptively start switching traffic to not only speed up recovery, but also try to save those links, so that instead of flooding them until they break, loosen up on them, so they can recover a little bit, and then maybe start sending traffic back to it. So that's a big thing. Obviously, with AI, you can manage how users are allocated in the spectrum more going on between time and frequency, which if you can be more agile with that and more densely packed users, that gives you a better, you know, number of users that can connect at a time, lower latencies, higher throughputs, kind of all that stuff that gets tied together.

Jameson: Yeah. And we've tried, we've been tying AI and ML into our IQP. And because when people hear AI and machine learning, they, the first thing their mind goes to is the security and privacy risks. So we're going to talk about that, more with our sponsor and draw conclusions from that, and try to talk about kind of how it's actually more of a positive thing and how they can attempt to shape public perception. Because like everything you just said, it's for the benefit of the system.

Joe: Yeah, and I mean, I think a lot of the time you have the public, you know, you have this black box, that isn't AI, where you said you put data into it, and then it makes decisions, and because of how complicated they can be, it's hard to know why it made that decision. And so what we've seen a lot with some of our sponsors, and DOD especially is there's this concept

that they've been introducing, that they're referring to as Explainable AI, which certain aspects of it are interesting, because it's this idea of, you can make this model that you can feed data into and could spit out, you know, decisions and stuff like that. But you still need to make sure that while you're developing it, you have the ability to understand why it's making those decisions. So whether that's, you know, kind of monitoring points inside the model to see, like partial decision making along the path or other, you know, maybe a more simple model that kind of emulates the behavior of the complicated model. These are a lot of things that we do know, we do think about so that we're not just saying, oh, yeah, we're gonna say, you know, we have this network, that's critical communication for emergency response. And we're just gonna give it to this black box and hope that it doesn't all of a sudden randomly start spitting out bad data or something.

Jameson: Yeah. That's a, that's a great point. Aaron, I think you wanted to ask about IoT.

Aaron: Yeah. So how does IoT impact your work? Or how does it fit into like what you're doing? I guess.

Joe: So our lab specifically isn't as focused on IoT, Professor Islam at school, relatively new, a professor, a lot of her work is focusing on IoT. And the big thing with IoT is, these are all very power constrained and usually compute constrained devices. You know, obviously, your cell phone, you've got a big battery, big processor and to do a lot of calculations, but with an IoT device, if it's something as small as like a sensor or a light bulb, or you know, these smaller applications, you can't really just throw on the same type of 5G chip you use for like a cell phone or something? Because it's unconstrained. So I know a lot of her work is, you know, how can we optimize these communication systems to draw less power? You know, not require those computation? AI involved Machine Learning involved? Is there, well, how can we strip these

models down to still perform on the smaller chips that have these constraints? So that's, you know, the big thing with IoT that I've seen, you know, kind of in passing at least is, you know, how do we make this 5G system more effective, so that it can run on these smaller devices, you know, at a smaller range without you know, because if you have less power to trade with, you know, from a pure physics standpoint, you're transmitting less power, that's less range, you know, you're more susceptible to noise in the air, all of that stuff. So how can we maybe, you know, improve the system to be able to handle those things? You know, is it as simple as we need to just optimize the transmit power so that we're using less power in other places so we can transmit? Is it, you know, do we put Machine Learning on the receiver so that we have a system that's better suited to filter out noise ideas like that all the time? Or what I've heard at least.

Jameson: Yeah, so it sounds like AI and Machine Learning and IoT are going to have a pretty symbiotic relationship moving forward. If they don't already.

Joe: I would say that with a lot of different aspects of communication, you know, it's, some of it might stick, some of it might not stick. But the big focus is how can we use this new tool to optimize basically every aspect of the communication system?

Jameson: Oh yeah, definitely.

Aaron: Yep. So I guess, so a big I guess, the big focus on IoT and AI would be just optimization one and then security, improve security right?

Joe: Yup.

Aaron: And then moving on, I guess, has your group ever discussed anything about like 6G, or like the upcoming 5G.

Joe: We're so the work we're doing, it's not, we don't really refer to it as like, this will be part of 6G. It's not, you know, we're not coming up with massive new ideas for 6G. A lot of the work we're doing if it were to be incorporated into aspects of 6G, it would be you know, when they update 5G to 6G, it's, you know, this new stuff, we put in that becomes part of the pivotal cornerstone of 6G. So we're definitely doing emerging research on 5G and kind of DOD circling and future G systems. But it's not as explicit as to say, alright, this is an idea for 6G, we're going to work on this for 6G, I think it's kind of a bit more low key than that, it's, you know, we're looking at, you know, using multiple antennas to do better directionality, we're looking at using Machine Learning to do security, we're looking at ways to model this better. And so a lot of these systems won't really be 6G specific until they are 6G specific, if that makes sense.

Jameson: Yeah, so it seems. I was gonna say, so that was like a more of an explicit answer. But if we could, like, twist it, had the you or you and your group ever, just kind of like spit ball and think about 6G in a different way? Like, what, what do you guys talk about if you were to ever talk about 6G, if you guys ever do talk about 6G?

Joe: I mean, a lot of the work, because a lot of the people here are doing research directly guided by, you know, sponsoring groups. And it's not really we're not, we don't have as much freedom to do kind of 6G as like some of the more kind of governing bodies of the standard do. But I mean, we do look at you know, there are papers that get published that we read that have, you know, kind of idea crafting the 6G that we look into. I don't think from from at least what I've seen, I don't think 6G is going to be this massive new revolutionary system, you know, it's going to be built on the foundation of 5G. Just like 5G was built on the foundation of 4G LTE. I think a

lot of the, if you're in the field and you're working with this, specifically, you'll be able to pick apart the differences between the two. But for your average person and people that aren't as experienced with specifically wireless cellular communication, a lot of it will kind of seem the same. It'll just be you know, better and faster and, you know, work better and kind of these big ideas. Like I said, I think 6G is mostly going to be, I guess one specific thing that I can bring up that might be dense is the actual operational frequency bands that it operates in. There is a, and maybe you've seen this in your research, spectrum and specifically in this instance is very expensive and we don't have a lot of it and um it is limited resource obviously. The current way that it works is there are these incumbent groups that have rights to certain swaths of spectrum that they have had for a while. They operate in those but as we start adding these more advanced systems we run into issues where we need to do more effective and dynamic spectrum sharing. The big example we always talk about when telling people about spectrum sharing is the radio altimeters on aircraft, the FCC for a while basically had this large, large band spectrum dedicated to the FAA for the devices the airplanes use to determine how far off the ground they are. And then what happened was because they had such a big swath of spectrum and they didn't really have to worry about any other signals nearby, the radio altimeters weren't designed to be super tight and stay within super constraints, they kind of spread out a bit. And so what happened was at some point the FCC sold and opened up rights to certain spectral bands that were close to these radio altimeters for stuff like 5G. There were issues of you know you have these 5G systems interfering with these radio altimeters near airports, so if you have a 5G signal in that space where a radio altimeter is, noise floors change, the airplanes can't tell as well the distances they are from the ground. And so try to figure out how you can more effectively operate in harmony with all of these systems that are interfering with them. Is it just be more efficient with the spectrum you're already allocated, do you take some away from other groups? I know another one of the big discussions is some of the frequency bands is that some of the frequency bands that are being eyeballed for 6G and future

G deployments are currently used a lot in radio-astronomy, um so a lot of radio-astronomers are afraid that if 5G signals start being propagated in those bands they won't be able to pick up electromagnetic spectrum from celestial bodies to do their research. So a lot of it is how do we share this with all of the other disciplines, and how do we effectively use it without crippling one system or the other.

Aaron: Mmhm.

Jameson: Yeah, that's definitely tricky. Are those spectral bands a private sector thing? Is that why it is so expensive?

Joe: It depends. So, for example WIFI is 2.4 and 5 GHz. That is a band known as the ISM band, which basically the FCC rules for these ISM bands is these are for scientific research and public stuff, so there aren't jamming in those bands, you can kind of do whatever you want in them. You have bands like 900MHz that are very locked down because those are used for radar applications for example, and if you transmit in those bands for longer than a short burst somebody might notice, they'll file a complaint, you'll get a cease and desist. And so a lot of the bands that 5G uses, you know groups like T-Mobile, Version. They own swaths of that spectrum and it belongs to them and maybe they rent it out to people, maybe they do other stuff with it, but it belongs to them. So we can't just say "alright version we are taking that away from you to use this other purpose" because they paid so much for it. Back in 2021 the FCC sold part of the 60GHz band. They opened up part of the 60GHz band and they sold another part of it for it was probably millions of dollars to some group. This stuff is so expensive because there is so little of it, and everyone wants to own bands of it so they don't have to worry about sharing, they can just do what they want in their band.

Jameson: So do you think 6G is going to be using a more expensive and higher grade [band]?

Joe: The trend we've seen is that the higher the frequency, everything is always moving up in frequency, because the higher the frequency the more data you can send per second. The trade of there is range, if you have a higher frequency your signals don't penetrate things like walls and buildings and trees. I've worked with stuff in the millimeter waveband which is 70 GHz. This can do really fast communication. The radios we are using, it's not 5G but there are millimeter wave 5G implementations. These are radios that are designed for like inter-campus back call links. If the main campus [WPI] and gateway weren't connected by fiber you could use these radios, point them at each other over a couple of miles, and get 10Gb/s though them wirelessly. The radios are expensive, but it is a lot cheaper than having to dig up the ground, put fiber in, keep it repaired. The problem is when you get into these 70GHz bands you start seeing issues even when it rains, the signals can't properly transmit through rain. So it starts raining and all of a sudden you drop off, lose connectivity and through put. We can't go too high with it, so we can't just keep going up and up and up, but at the same time we want to keep going up because that means faster throughput.

Jameson: Yup, that's definitely a great input. And I think we just had; I think we have 1 last question. It can be a little bit less specific; it is more about 6G and IoT.

Aaron: How do you see 6G and IoT interacting with each other. Do you think is just going to build upon 5G and what's been happening?

Joe: It's hard to say, because IoT networks operate very differently than traditional 5G and 6G network, or what will be 6G networks, because of the fact that, you know, if I'm in my house, and I have, you know, a full smart home, now, I could have hundreds of devices in that small area,

which is good for 5G 6G applications, like I said, because we can connect more subscribers. But the problem is, you know, these like to operate as a mesh. So like, you know, my light switch will talk to my microwave to talk to the fridge to talk to like the main server. And so I think in order for 6G and IoT to really work together, there are a lot of questions that need to be solved. And because the current IoT, wireless communication central in the US operate very differently, you know, there isn't, we can't rely on a single central authority to be our authentication server, we can't rely on that single device, because like I said, IoT devices, low power range, if my master server is in one side of my house, and then some IoT devices on the other side of the house, they can't have a direct connection. So what the current systems do is they use that hopping I mentioned where you know, one device to send it to another and kind of bouncing along this chain till they make it 6G doesn't have that capability, or 5G, excuse me, it doesn't have that capability yet. The closest thing we have is some research into vehicles talking to other vehicles. But you know. There's a lot of questions of you know, the way the authentication and connection process for 5G works, relies on that central server, it relies on a certain part of the physical data frame where we say this part of the spectrum in time is special, because you don't have to be authenticated to use it, you can just kind of randomly blast into it, and then the power will get back to you or tell you where you should actually start transmitting. So I do think there are some kind of major hurdles to connect the two. But it does seem like there is a focus on it because of how useful it would be. And obviously, the more things that get standardized, the better. You know, instead of having five different ways these devices connected, if we say they all use 6G, then you get a bit more consumer choice. You don't have to look at you know, does this LG device and this Samsung device work together. They both use the standard being only one.

Jameson: Yeah, and you mentioned previously idea crafting and also just now hurdles. We saw a lot of that in our research over the past few months. Part of what we wanted to find out from

our research, I guess was these specific hurdles and connecting that with IoT and then definitely with AI and Machine Learning. So you definitely touched on a lot specific topics that we really want to focus on in our paper and our research and our findings. And so, one half of our methods for the IQP is interviews. And the other half is surveys, surveying the public of Taiwan. And it's pretty much formatted so we asked about their current perception of 5G, AI. Then we give a hypothetical 6G use case. And it sounded kind of similar to something you mentioned in this interview, which was, so the train station, the train system here is really like a big part of a lot of people's lives, especially around Taipei. So a hypothetical we made was connecting 6g and IoT to something in their daily life. And in this case, it was their train system. So we said, hypothetically, 6G, and IoT could connect to use facial recognition to make it easier to board these trains, automatically bill you, and we kind of wanted to gain and gauge public concern about this. Things they were concerned about, but also did they think would benefit them? And so that was certainly something we were looking at.

Joe: That's interesting. Yeah, I definitely think that you'll get people with strong opinions, because there's, I think, you know, you guys have talked a lot about the public's opinions on the security of the systems. But the other part of it in something that we've seen is perception of the technology itself. So as I mentioned, as we get into these higher frequency bands, we start to see concerns with people thinking that, you know, that are possible health effects, things like that, you know, you say, Oh, we're putting out you know, 30 GHz 5G tower, you know, down the street from your house, people might get concerned. And I mean, you know, working with the system, obviously, we know that, you know, it is radiation, because anything that has electromagnetics still has radiation, but crucially, it's non ionizing, so it doesn't actually have those health effects or something like solar arrays do. But it's really a hard concept to get across, because the easiest thing to look at is, you know, bigger frequency, you know, higher oscillation rate, you know, that's that can be a, you don’t understand exactly what it is. And you

just know that it means that, you know, there's more of this radiation happening, it can be a concern. And, you know, we've seen, and a lot of the time, people will say, Oh, you know, it's just people out in like rural areas a lot of the time. But we've seen the same thing in New York City, especially where companies are putting these towers in New York. And because 5G is so high frequency, they need to put more of the towers in, they need to be closer, they can't just stick them up on the roofs of buildings. Some of them are on like streetlights and stuff like that. So there is a lot of concern with that aspect of it, too, that we've seen.

Jameson: Yeah, I mean, I know, I don't know about you, Aaron, but even I saw some public concern of when 5G was initially rolling out and when those towers were being put up. So I can imagine that the same trends will be seen with 6G, especially if, like you said, the more powerful the, I'd imagine the lower the radius. That might mean more towers in 6G, unless something changes. So we might see that same trend again.

Aaron: Yeah, so um, I think in a previous interview, they talked about satellites, using satellites to replace maybe the towers for connection. Do you think that's, like, viable or?

Joe: In some applications, yes, obviously, Starlink is a big thing right now that everyones talking about, you know, bring broadband to rural areas, because we don't need to put towers down, we don't put fiber down, we can just send satellites in space and just have them do it remotely. The problem is, you can only get so fast to satellites, because just the speed of light is the speed of light. I know, I think it's geostationary orbit to get the signal off to a geostationary satellite, and then back down is at a minimum 500 milliseconds half a second, which, you know, half a second to some people seems really fast, but that is forever in the communication world. You know, a lot of especially when, you know, the connection between the two of us from, you know, Worcester to Taiwan, or the opposite side of the world, that's probably less than a 10th of

a second, just because of how fast you've made these undersea cables and the fiber. So you know, you can send these satellites up into space, you know, maybe you pull them a bit closer than geostationary if they're not geostationary, then you need to do what Starlink does and have kind of this full mesh of them to fully encircle the Earth, which you know, is a valid and possible solution. But then you start running into what I talked about with you know, we need to cooperate and be collaborative with other researchers. So if we start filling this kind of settle, it's gonna go back to astronomers and stuff like that all of a sudden, you can't see past the satellites, because they're so bright and kind of their emissions are so strong compared to these bodies that are do light years away. So I think it's, it's a balancing act, as always, you know, maybe we can do some satellite stuff, but I think it is a constant discussion that needs to happen between not just, you know, communication with 5G researchers, but also other research fields.

Jameson: Yeah, it's funny, you mentioned Starlink, because our last, our previous interview was with a woman who was an MIT graduate who's working directly on Starlink. And she was talking about using satellites, helping get connections to rural areas. And the big part of our paper is, you know, social stuff. So we talked about reducing the digital divide, which I definitely think that using satellites has helped that. But like you said, there's definitely an impact on speed. There's a difference between, like the connection we have right now, versus the connection from a satellite to back down to earth. Do you think there's going to be, you mentioned a balancing act? Do you think there's going to be more of a focus on something synonymous with Starlink? And for 6G, or future 5G applications? Or do you think we're going to focus more on ground to ground?

Joe: Um, it's hard to say just because like we mentioned, there's, it's when you're, you're looking at rural areas, especially. One of the first projects I worked on here was a rural

deployment project. It wasn't 5G, specifically, it was, does millimeter wave radio, as I mentioned, and that was kind of some general consumer equipment for the kind of last leg of the connection. But you know, that system worked well enough, people were happy with it, because it was just it was better than what they had before. But, you know, we had those issues with poor weather, you know, obviously, keeping, when you're in a rural area, wind is a big concern, you know, the Midwest is Tornado Alley, it's massive tornadoes. And so even a small wind storm, if these radios aren't properly secured, when they get to such high frequencies, and also to long distances, that such an like narrow beam of spectral energy that even if they are like a degree off alignment, over that big of a distance, and you could, you know, half a mile off at the receiving end. So even a little bit of wind could cause problems. So I think there are use cases in which satellite is good and works. I think another big aspect is figuring out exactly what we need for broadband. You know, obviously, the FCC still defines a broadband connection as 25 megabit down five megabit up, and then some latency requirement. And you know, with COVID never been going remote, we found that that's just not enough for most use cases. But then, you know, you have companies that they want to have the big advertising numbers and say, Oh, we can do 500 megabit, you can do gigabit. But what I found in my research personally, is a lot of times you don't need such big numbers, people always want the biggest the fastest. But when I was trying to do some optimization for a constraint network, even with artificial constraints on that rural network in Missouri, I still couldn't constrain it enough to a point where I could do sufficient enough measurements of the concerning network and kind of these smart allocation schemes, just because, you know, it's a town of 30 households, you know, they're all connected, they get a gigabit back to the main trunk, but they're not all using it at the same time, different people have different schedules, you know, and maybe, maybe if everyone was streaming, you know, the new TV show at the same time, every night, we push that connection. But, you know, that's not what we saw. So I do think it's a question of, you know, what is sufficient, you know, maybe we can make these 6G systems that can do, you know, super high

speeds, but that doesn't mean we need to put them everywhere. You know, when 5G was first rolling out, the first mode that got rolled out was called non standalone, it was basically it was 4G LTE systems with some 5G aspects tacked on. And so doing hybrid systems like that is also another valid way of delivering to these requirements that is cost effective, because you're not deploying the new hotness everywhere. It's not wasteful, you know, you're not putting out these, you know, towers that are gonna get 5% utilization at most. So I think there are uses for all of these different methodologies in different places, and it's just a question of, you know, figuring out which ones work best where, you know, satellite would never work in New York City just because there's so many people. But at the same time, there's no reason to put, you know, a 6G tower in the middle of a town of 50 people out in the middle of Kansas or wherever.

Jameson: Alright yeah. So you're saying definitely, it's not going to be either or, either satellite or ground to ground, it's going to be whatever is most efficient and allocates the most appropriate resources depending on like, like you said, rural versus urban and suburban. And we are definitely getting some of that traction from the interviews we're doing is seeing that proper allocation. I think that's honestly it for the questions. I don't really have any other questions. Do you Aaron?

Aaron: No.

Joe: It was great talking to you guys. I'm glad I could help out. I did see your email about headshot. I will send that to you at some point, over the next couple of days.

Jameson: Great. Thank you.

Joe: But yeah, I think that's it.

Jameson: Thank you very much for your time, have a good day.

Aaron: Thank you, have a good one.

Appendix H: Interview with Aurelius Transcript

The team conducted this interview in a separate manner than the other expert interviews. The sponsor TIER sent Aurelius the file containing the interview questions, in which he typed out his responses in mandarin. Victor from TIER then translated the responses into English and sent the document back to the team. Listed below are the interview questions and Aurelius's responses.

The file was received Friday April 19th at 6:16AM EST.

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1. What companies does your experience with telecommunications come from?

   MediaTek Inc.(聯發科技)、WISTRON NEWEB CORPORATION(啟碁科技)

2. What is your job title?

Assistant Manager

3. What is your background with telecommunications and 5G?

   Research and development of 5G, low-power chips. (研究開發 5G、低功耗晶片)

4. How has 5G contributed to urban development?

   While the rollout of 5G technology may not have an immediately discernible impact on urban life for consumers, its true potential lies in its evolution towards the concept of the Internet of Things (IoT). This shift emphasizes the interconnectivity of devices and the burgeoning importance of machine-to-machine communication. Particularly noteworthy is the significant enhancement in efficiency seen in smart factories, where the optimization of processes through 5G connectivity leads to tangible improvements in productivity. Thus, although the benefits of 5G may not be readily apparent on the surface, its transition towards facilitating the seamless connection of devices heralds a transformative era, especially in the realm of industrial operations. (其實 5G 對城市幫助有限，消費者感受不出，主要是 5G 開始偏向萬物連網的概念，物和物的連結變得很重要，尤其是智慧工廠的效能提升)

5. Who can take measures to ensure equitable access to 5G technology, especially in rural and underserved areas, and what measures can they take?

   In my opinion, Government can take several measures to ensure equitable access including funding allocation, regulatory, promote public-private partnerships, support digital literacy programs. (網路上很多資訊，現在美國的基建計畫，關鍵字 BEAD、ORPC、BABA)

6. How has 5G technology affected the digital divide, both within countries and globally?

   The widespread adoption of 5G technology has the potential to exacerbate the digital divide due to several factors:

   (1) High infrastructure deployment costs: The high cost of deploying 5G networks in rural and underserved areas may lead to these regions being prioritized lower for access to this technology.

   (2) Digital literacy disparities: The use of 5G technology may introduce new technological challenges, putting individuals without the ability or opportunities to learn how to use these new technologies at a disadvantage.

7. Looking back on the early stages of 5G, what measures would you take to avoid the struggles during the development/rollout period?

   I would suggest the following points to avoid the struggles.

   (1) Global standards: Ensure all stakeholders (equipment manufacturers, network operators, etc.) agree on harmonized specifications early in the development process.

   (2) Backward compatibility: Develop 5G technology that integrates seamlessly with existing 4G infrastructure, reducing the need for complete network overhauls and minimizing disruption for users.

8. What was the public perception to the 5G rollout like? Do you expect a similar response for 6G?

   I think the public perception is positive to the 5G rollout since 5G provides faster speeds and lower latency, which also provides enhanced gaming experiences. Yes, I expect a similar response for 6G.

9. How do you foresee 6G affecting the IoT space?

   Massive connectivity, AI and machine learning integration (edge AI) and Ambient IoT.

10. How do you foresee 6G affecting the average person in your country?

    It won’t have an impact in the short term until

11. What are some of the potential commercial values that could come with 6G technology?

    In my opinion, Holographic communication would be one of the most exciting things.

12. Is there anything you want to add that we have not discussed yet?

    None(無)

Appendix I: Interview with Bob Everson Transcript

The Interview began Thursday April 32rd at 8:00PM EST.

Bryce: All right, so I'm starting off a really just, uh, what company does your experience with tell me you could help me.

Bryce: Telecommunications come your job title.

Bob Everson: Uh, Cisco, um, you know, I work with. I work with all sorts of different players in the industry from, you know, equipment vendors that we work out. A lot of partners we work with as well that make equipment make software. We work with telco operators all around the world work with enterprise and government, and sort of the end user community as well, which is really what. 6 success is reliant on really is is kind of the end user's. So, once we get, so I kind of work across the whole ecosystem.

Bryce: So, how do you think 5G has contributed to urban development?

Bob Everson: You know, it's, it's a good question. Um. So, there's not a variety I'm going to give you sort of an indirect answer to that. 1. um. You know, 5, G5, g, technology brings a lot of, um, a lot of interesting capabilities to network operators and people who run those networks. It's been a little bit the chain. I'm sure you guys are setting this. You you hopefully you've come across this as well, the implementation and adoption of it has been somewhat limited globally. And it, it's been a bit of a struggle because. If you if you look back. Over the generations, you know, 3, g, which was. Certainly before your time, but that was just, you know, can we get a.

Can we get a data connection on a phone, you know, something, something like this? Right? You know, can we get a data connection that you can actually use on a phone? And then was and once you could. Then everybody's like, oh, well, I need that. And so they would adopt it and then 4 g came out and it was all about can we get a broadband data connection to the phone, which increase the capabilities quite a bit? And everybody wanted to adopt it. And then when 5g came out. I think the assumption was that we were going to sort of follow the same path and everybody was just going to suck it up. In reality, what's happened is that for the average user. Yeah, I mean, you do the speed test, or you might be able to download something quicker. You get to light it for 5g light on your phone and you say, hey, I've got 5 connectivity, but it's not markedly differentiated. And so we figured out with 5g and I'm getting, I'm getting to the answer to your question. I promise. You know, what we found with 5 new technology is it requires a lot more than just the new radio technology to to be useful. And, and and so what it requires is new spectrum to be allocated globally for 4 or 5g spectrum, which is. Pretty far down the path now there's still some countries that are lagging a little bit there, but it's pretty far down the path. You need radios, obviously to support the 5 year link and support the power and all the different all the different aspects of that. In some cases you need a new mobile core. Hopefully you guys have gotten into that a bit and sort of. Function to the mobile core, so you can do this thing called NSA non standalone you can use the old core, but if you really want to get 5g, you have to put in a new core. And so there's all this. All this infrastructure has to be implemented and then you need new devices, you need specific user equipment that can harness the capabilities of this 5g network and those are starting to come along. But but it's still it's still lagging a little bit. So, when you look at it. Globally, there's some markets that are pretty far ahead. A lot of markets are sort of holding back on it somewhat still. And it's because of the complexity of all that coming together. When you look at urban development. You know, there's 2 aspects 1 is just the value of having good quality broadband, mobile connectivity for urban, you know, to attract people to an urban area. And just to have that, you know, that layer of connectivity and

income in places where that has been. I think there there have been some values that have been shown. I'm not. Super close to all that, or I can pull it all the data off the top of my head, but it does it does help. It has helped there, there's hotspots of, you know, like events and things like that or 5g. I mean, if you look at the Super Bowl, and, you know, like big marquee events like that, it's, it's driven, you know, people to come together and leverage this. Overall, 5g and Urban Development, I think it's still coming, though like, the big the big benefit for for 5g and Urban development is still coming in a lot of markets. Again, a place like Taiwan where you are obviously there too small country. Very well contained also very, technically innovative, so you see, a lot of technology adoption there, but then you go to some of the European countries, even or you go to a place like India or or you go to, you know, a lot of other China. China's, you know, way out ahead. On as well, just because of the way they can make things happen there. Um, but overall urban development I would say is still, you know, kind of a work in progress.

Bryce: Actually, that's really well into the next question of who can take measures to ensure equitable access to 5 years technology, especially in rural and underserved areas. And what measures can people take.

Bob Everson: You know, it starts with, it starts with the government or the, the. The body that allocates spectrum, right? Which is typically, you know, some sort of a government entity there and so it starts with that, um. And I do think there's a responsibility as well to make sure, you know, operators are deploying. You know, broadly, um, but, uh. Big part of it is driving the use for it, you know, I mean, Y, you know, so fix wireless access is actually a great driver for getting. 5g, connectivity, which, which helps the phones, but also helps provide Internet access in those rural underserved communities, and it helps drive the business case for operators to invest more in those areas. So, you can always have government incentives, and you should talk to somebody in our government affairs group. For for kind of their view on that my view is yeah,

there's there's government incentives that can be taken there. There's. You know, sort of not restrictions, but conditions that can come along with, you know, with spectrum allocation. We see some countries do that, but ultimately too, you want a healthy business. And and because that's what really drives sustaining. You know, investment and innovation and I think a lot of that is about exploring, you know. Okay, fix wireless access as a viable alternative because a lot of times Robin access is covering those kind of communities as well. So I think that's a good addition in addition to, you know, obviously smartphones and things like that. Okay.

Bryce: Uh, you mentioned something about rural areas and, uh, connection.

Bryce: And kind of within the question of how does 5g, technology affect the digital divide, or how has it affect the digital divide? Um, and.

Bryce: That is both within countries and globally.

Bob Everson: Hitting me with the with the philosophical questions here, I thought we were going to talk technology. So on the on the, on the digital divide, um. I don't know anything about it. Yeah, no, I mean, I'm just kind of thinking thinking out loud here, but I would argue that. I don't know that we've seen the I mean, I've kind of go back to my 1st. It's my 1st, discussion around it's not widely deployed in the U. S. we have a, we have a globally with T mobile as a not globally. T mobile has a nationwide 5g network you know, the other operators 80 T Verizon have 5g widely deployed. I mean, certainly, it's providing. Some level, they would say it's providing better profit and access. In in those areas globally. I don't I don't really see the big impact of the digital divide yet, because in a lot of those areas, there's still, there's still, in some cases, they're still. But, but, you know, like, they're, they're trying to get to 4 g and maybe 5 or something. I just I haven't seen 5. do you have a huge impact yet?

Bryce: So, quick pause really quickly so we can actually give you a little background of what we're doing. So we are doing a like an international, broad program and everyone's given a project.

Bryce: And our project was investigating the social implications of and Taiwan. So, this project is, we went out and

we surveyed a bunch of people in the public, um, on their opinions of solar technology, 5, new technology, and then potential 6g technology in the future. And then on the other other side, we're interviewed.

Bryce: A bunch of us experts to get their opinions to then write this big report and give to the Taiwanese Institute of economic T. I. E. R

Owen: They focus on academic research.

Bob Everson: I should know.

Bryce: That, but.

Bob Everson: Yeah, so it's we're going to.

Bryce: All this data together, and then give our suggestions to this, uh.

Bryce: Economic company or a research company it's going to, um.

Bryce: Help advise the government when they're rolling out 16 country, which is kind of.

Bryce: Um, but our side of the project is all of the social aspects, um, which.

Bryce: Being engineering students is something that I feel like we're not very used to. Um, so that is, uh, kind of where these questions are going to be going. So I think we have well.

Owen: But that sounds questions are a bit more tactical. Yeah.

Bob Everson: I know that's cool. I mean, it is important to consider these things even if, even if you're even if you're going to be an engineer, I've always found. It's good to understand a, sometimes engineers, you get an engineering role, and you're so focused on I need to build this product or even, like, I need to build this feature for this product and understanding the broader context of where it fits in what some of the implications are like the whole thing I was talking about on the ecosystem people build radios. They don't realize that that. Doesn't get used unless it has a, and spectrum and all these things out there and all that stuff comes together. So that's interesting. Yeah, that's a good background though. I'll be curious to see what you what you find out. You're, you're in a good market for leading technologies. I said earlier timeline is somewhat of a bubble with the innovation.

Bryce: So, looking back at the early stages of 5, new technology, uh, what measures would you take to avoid the struggles during the development period slash rollout.

Bob Everson: I would recommend that we take more of a of an outside in approach with truly understanding the applications and what. Problems it's going to solve and in driving the prioritization of development around that, versus kind of what happened, which was. Everybody

said, oh, yeah, this is going to be for businesses and industries and they're going to have all these great features and then they came out and they said we have 5g. don't you want to use it? And and they didn't do a great job. I mean, we, as overall as an industry, I think didn't do a great job of being really in touch with. Okay, these are the actual problems that the customers need to solve and what the use cases are. And how that actually maps into the technology, and into the prioritization of what's accomplished in there.

Bryce: You mentioned, businesses have more of a cautious approach to the broader, um.

Bryce: What did the public perception of 5G look like to and do you expect a similar response from 6G.

Bob Everson: It depends, you know, there's a bunch of ridiculous sort of conspiracy stuff around 5g. that I'm sure you guys have seen that put that aside but but. If you if you look at overall, public perception, I think was initially. Hey, you know, I want this I want my, I want the 5. you like to. And I'm not sure I'm paying for you right now, but I wanted to show by on my iPhone, or I wanted to show, you know, 5g on my, my smartphone because it's going to be better. And in developed in wealthy economies, you know, people invested in new files for that and have to have the latest. Once the once, sort of the novelty of having 5g were off again, a lot of people were still they're still struggling somewhat to understand what the differentiation is there with. Businesses are very much. You know, I always tell people and I speak on this a lot, you know, businesses are not in the 5g business. They're in the, you know, whatever, whatever business I'm in. That's the problem. You know, I'm in manufacturing, I'm an insurance run, you know, whatever the bank medical all that. In fact, she's just another 1. Fire, even though it's wireless, it's just another network connectivity mechanism right? It's a means of connecting back to the network. And if the characteristics are the best for a particular use case that they have. Then

they'll invest in it if they're not then they're not going to, you know, they're not going to. Waste a lot of money playing with the latest technology, because that's not what they're incentive for. And I think that's where we are on 5. g now, is a business is saying, okay, prove it. I want to see this. I want to see it, you know, doing what I needed to do better than better than my other alternatives. And, you know, that, that goes back to the whole ecosystem thing that I talked about earlier.

Bryce: So you mentioned businesses and what they're going to be using it for.

Bryce: How do you see 6g affecting the IoT space?

Bob Everson: 6G ok, so we're changing over to 6g now. Um. I think 6g brings some, some could bring some novel new capabilities. Obviously, new spectrum bands. More of an centric approach. Um, you know, I would look for some more intelligence around just kind of the way, you know, we'd be able to if you think about I mean, basically, you know, if you really think about is everything, but a person on the end of, of a wireless connection. So, it could be. You know, it could be my Alexa box, it could be the temperature sensor that I have out on the boat, or it could be the car, you know, and everything in between. And so the impact of 6g is going to vary, depending on on, you know, the problem that you're trying to solve for. Um, I personally see 6g as hopefully as, like, an incremental step on top of 5g versus a completely new generation. I think I think this. Notion of it's completely new and you need to kind of almost throw out everything from the past or whatever. Was there in the past is just going to be part of the legacy network. I don't think it works for 6g. I don't think the economics work. I think all the changes that operators have had to make. For the 5g. G. or are making for 5g. Whether it's on the, you know, on the, the software side service, based architecture, all the, you know, the core all of that. 6g should be new technologies that are on the top of it that make 4 better coverage,

more intelligence. I think we're going to see more automation of the overall network experience. So. You know, like automated, fully automated site survey where I can just. You know, take my vision is, you know, I want to this thing's got it up. It's got enough sensors in it to where actually, if you video that you can capture all the data off of it, you could actually get a good idea of inside of the building. You do an automated site survey you can do automated ran planning, you could do self optimizing network once you put the radios in, they automatically adjust to each other. I think that. Life cycle is going to be automated for so many years. Radio planning radio operations. Everything was. Like, very small handful of people who are the experts. And if some of these big operators needed to change something, they had to go back to a few people and, or the small group I think, with 6g that's going to be 1 of the biggest things is we're going to get to just. Total lifecycle, automation of the full system. Which will certainly provide benefits and then there'll be some of the spectrum brands. Not too sure about terahertz spectrum. You guys you guys been studying, setting that in your classes. Like, the viability of the spectrum a little bit we're both robotics engineers. Um. Yeah oh, that's cool. Yeah, I want to talk some more about that. We'll have another call sometime. I want to hear what you guys. We're picking there yeah, you know, stuff like that, you know you know, you get back to. What problem are you trying to solve for what what do you, you know, is that a, is that a. Autonomous robot, or is it a. Hpv, is it a guide vehicle or is it a fully autonomous. Supposed to be fully autonomous system there, they have different network requirements, you know, with the bandwidth latency all that all goes back to. What's probably trying to solve for? That's what we have to get back to.

Bryce: Um, so we kind of talked about space and then, do you foresee 6g affecting the average person in the US or.

Bob Everson: Having some time in the future yeah, I mean, I don't I again, I don't know that aside from. Um, the need for something new to make things happen, because sometimes you

just need something new to to drive, you know, whether it's an upgrade cycle or people to align around something. I think 5g's got a long runway. For the consumer space. For sure, and again, I my belief, my hope, and in talking to talking to some of the operators around as well, they don't want to see a completely new generation here. They want to see, you know, incremental. Like, there's some cool stuff that's being worked on in 6g. let's let's bring that in, but not. Sure, everything.

Bryce: You, and then final question before we have our open ended question, that is like, the final final question. Um, what are some potential commercial values that could come with 6g technology?

Bob Everson: Commercial values, I mean, yeah, I mean, commercial, it's all about. It's all, it's all about the use case and, you know, the problems we can solve for. It's, um. It would be hard to sitting where we are right now. It would be really I'm gonna have to talk about some cool like robotics or something. You know, I can talk about things like that. I think. Um, what we need to do is we need to stay focused there on, um. Growing because we're still in a theoretical world with 6g. we're still somewhat in the theoretical world with hygiene. So the way this works is 5g continues down this path. Uh, and then we're thinking about and and what now, what capabilities will be in, um. We've got to be focusing on differentiation, stretching things forward without, without breaking on. I. Yeah, I mean, I, I, I'd be like making up. You know, use cases, like my joke 1 that I always say when I. I get up on stages, remote haptic, drone surgery. Uh, you know, because everybody wants to go for these, like, crazy, you know, sort of sort of use cases that. Yeah, but like, that's a corner case. That's. If that's even if that's even a plausible and desirable a use case, it's definitely a corner case. It's about making this mainstream I mean, that's that's the thing that I think is really important with. Um, 5g, and as we looked at 6g is 1 of the things that are going to be. Most broadly applicable, so all the automation stuff in the

network, broadly applicable new spectrum bands to solve new problems, or just to solve the fact that we're running out of spectrum in better ways to optimize the existing spectrum that we have and get greater structural efficiency. Really? Broadly. Applicable when you start drilling down into some of the more specific things um. Yeah, show me the show me the business case.

Bryce: And that leads the final thing of, is there anything that you would want to add that we have discussed yet? Um, I feel like we.

Bryce: A lot of social questions, if you technical questions, but I feel like you have a lot more expertise that we haven't really asked. And do you have anything that you really want to add.

Bryce: Hello.

Bob Everson: I mean, we've touched a lot of a lot of a lot of different aspects. My, my, my guidance on this in this 6g in general is. And I've said it already kind of is. We need to solve 5g still and 5g, adoption and 5g applicability before we get too far down the 6g path we need to be constantly looking for. Right I'm all for innovation and looking forward. But we really do need to still roll up our sleeves on solving for 5g, adoption and 5g, solving big problems before we get too far down the next shiny object path with 6g. Mean operators missed. The last thing I'll say is, I mean, if you guys are setting, social and economic, social, economic affects and all that, you probably had some insight into the state of the business of operators globally. They're not super healthy businesses right now on hold. And, um, so there's sort of this. Flushing out in the industry as well, that needs to happen for them to have money to invest in 6g. so, we need to it goes back to my, you know, when we were talking about kind of, you need a healthy business we've got to get to a healthy, you know, we got to figure out the right healthy business model before before, um. Stephen becomes a real consideration, I think

Bryce: So, I felt that answer questions here.

Bryce: You said everything that we really wanted to hear, um, regarding, um, and the conclusions that you've drawn kind of parallel with a lot of the points that we've made in our paper. Um, which I think is really awesome. Thank you so much. Um.

Bryce: We're going to take a transcript of this interview, and you'll have your own natural section in this favor analyzing this interview, which is going to be.

Bryce: Uh, kind of cool, but cool. Thank you. Thank you so much. Thank you for giving us your time. And, uh, yeah, I think that's that's all on my part. Do you have anything done.

Owen: Now, thank you for thanks for your time. Thanks to the interview. Yeah.

Bob Everson: No, that's cool. So when when are you guys done there in Taiwan?

Bryce: Actually, our 1st, version of our final draft is due at noon today right? Is it at noon? So yeah. Um, oh, yeah, we went.

Bob Everson: Figure out. I'm sorry about that. Yeah.

Owen: You'll make it into the 2nd version of this in a little bit sooner. If I know.

Bob Everson: There was a deadline for is.

Bryce: Find out where we have a lot, we have everything else done that we finished. So is there a lot of.

Bob Everson: You go back, you're there through what semester break or something, and then you go back home. Yeah.

Bryce: We're here for another week. Um, and then, okay, then we go home I'm flying home to Japan and going back to the US. So.

Bob Everson: Yeah.

Bryce: That's cool. Yeah.

Bob Everson: I'd love to hear more about what you guys are up to, maybe after you get through this paper and stuff like that. I'd love to hear more about about what you're setting and kind of I want to hear. I want to hear from your side now and ask you some questions about what you guys are seeing out there and what you're doing.

Bryce: Yeah.

Bob Everson: Cool. Thanks guys. Good luck on your paper. I'll let you get to get to it.

Bob Everson: And any, anything else just ping me I'm happy to happy to chat with you.

Bryce: You so much I appreciate it. Thank you.

Bob Everson: All right cheers guys.