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

An Interactive Qualifying Project Report Proposal submitted to
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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)
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.
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.

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.

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1 Introduction

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 could redefine the telecommunications industry and the societal and economic structures. Artificial intelligence (AI) is integral to this technological revolution, ushering in a new era of intelligent connectivity and seamless interaction. Amidst this innovation landscape, Taiwan emerges as a major player, known for its technological development, manufacturing prowess, and strategic foresight. 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 will explore 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 allows for fostering 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, and Artificial Intelligence (AI) 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 team is working with TIER's Research Division 1 team in collaboration with the Metal Industries Research and Design Center and Auray Technologies to anticipate the hurdles for 6G in Taiwan. The team hopes to satisfy this goal by ultimately providing TIER with a paper outlining a path to 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 back up the initial findings and research the team laid out a set of interviews and surveys in the methods section. By using these methods, the team hopes to satisfy the research objectives:

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

The team hopes this research can provide TIER with valuable insights into the future of 6G in Taiwan. Hopefully Taiwan will have a successful 6G implementation, leading to the advancement of decent work and economic growth, development in industry, innovation and infrastructure, and reduced inequalities.

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

2 Background

2.1 Background Overview

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 next 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.

2.1.1 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 market with 38.91%, 25.9%, and 24.02% market shares, respectively, and leads in 5G and 6G developments (Communications Market Report, 2022). They provide advanced mobile communication services and, more importantly, directing 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 applications in 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, is attributing to the decline in revenue in past years (see Figure 1). The number of subscriptions remained relatively unchanged at around 29 million subscribers from 2012 to 2020 (Communications Market Report, 2022).

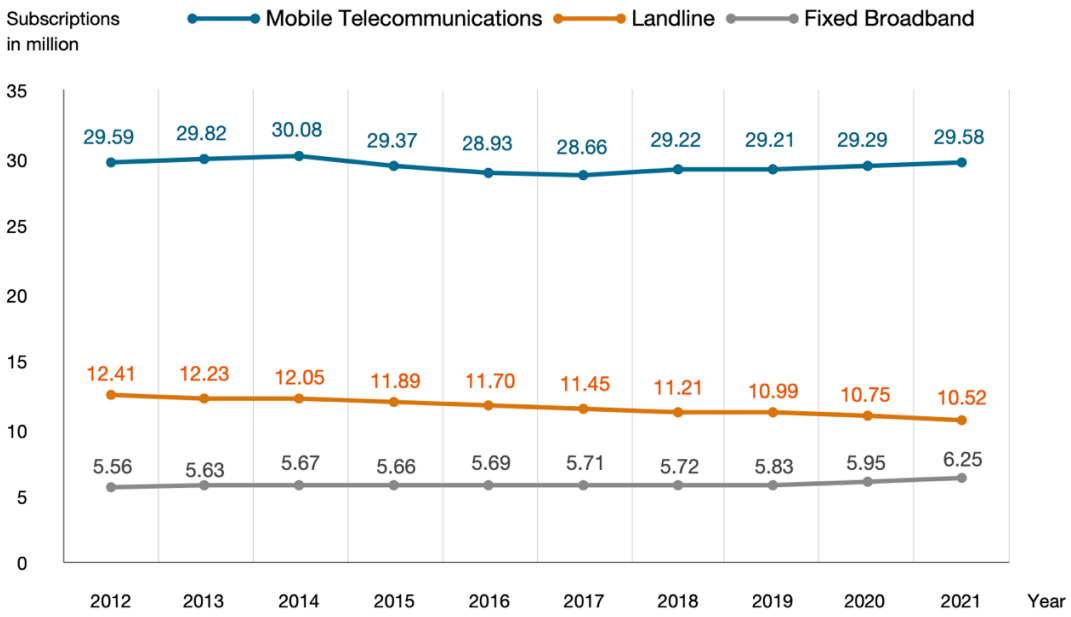

Figure 1: Number of Telecom Users in Taiwan (Communications Market Report, 2022)

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 5G users increasing, and the relatively expensive 5G charges accounted for a higher proportion of the plans (Communications Market Report, 2022).

The growth in the industry highlights the viability 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 in its infancy, 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 2). Other reasons for users ranged from incentives and promotional upgrades to just wanting to experience new technology (Communications Market Report, 2022). The growing acceptance of 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.

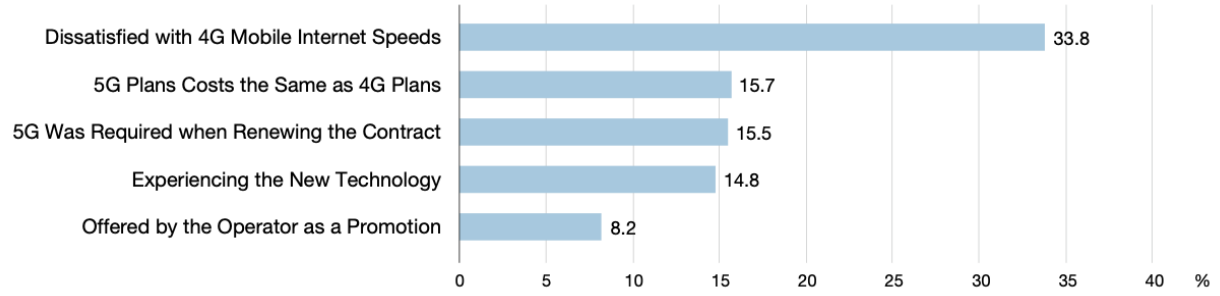

Figure 2: Top 5 Reasons for Switching to 5G in Taiwan (Communications Market Report, 2023)

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 the 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 composed of 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 insights 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), Powerchip

Technology, and Vanguard International Semiconductor Corporation (VIS), with global market shares of 56.7%, 7.7%, 2.4%, and 1.5% respectively (see Figure 3). The combined output from these four Taiwanese companies accounts for 68% of the world's semiconductor market (Sacks, 2023).

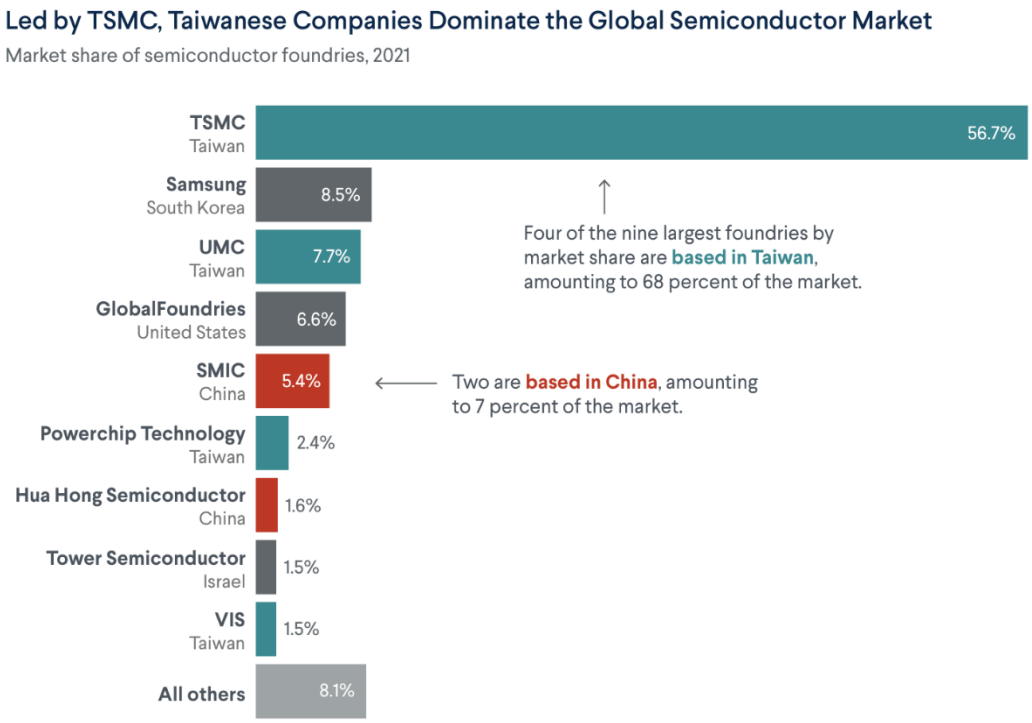

Figure 3: Largest Taiwan Semiconductor Companies (Sacks, 2023)

TSMC shipped two million 5nm technology wafers, used in devices including 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. 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 and AI 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 the 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. Meanwhile, the Concentration Hypothesis proposes that the economic acceleration is traced to the computer manufacturing industry. Regardless of which hypothesis is more valid, the overall impact of the internet on productivity 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 online shopping 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 4 (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).

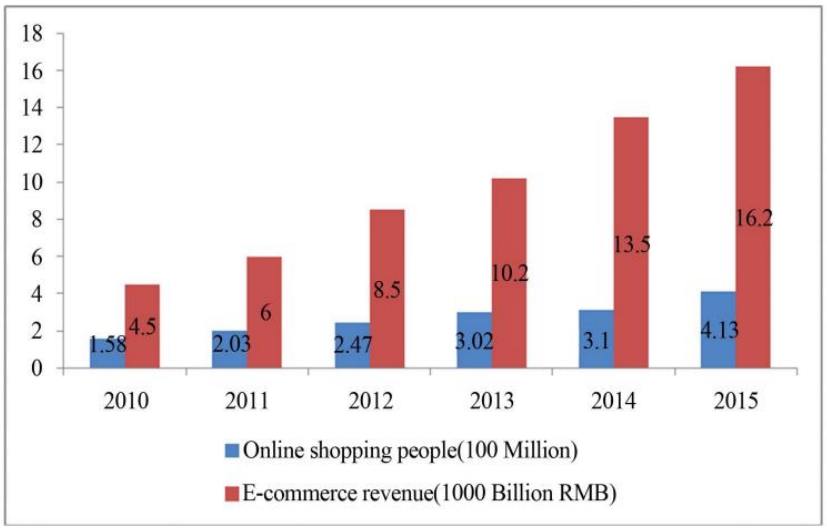

Figure 4: Chinese E-commerce revenue and people shopping online vs year. RMB is China's currency (Zhao et al., 2016, 6).

Seeing these statistics makes the correlation between internet usage and economic prosperity clear. The study 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 been able to verify 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 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 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 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 being 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. Ultimately this can lead to situations where people have limited access to the internet for hardware, software, or infrastructure 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 these efforts made for 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. 5G technology provides significantly faster data speeds, lower latency, and increased network capacity, which are essential for supporting emerging technologies like 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 5) (Communications Market Report, 2022).

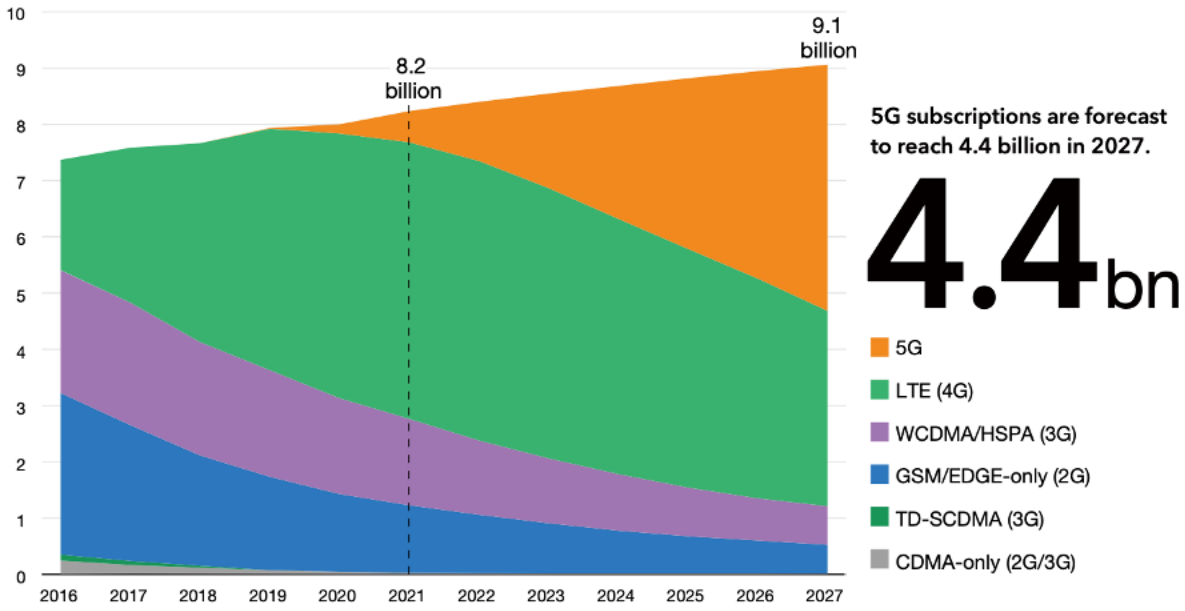

Figure 5: Global Users of Mobile Communications (Communications Market Report, 2022)

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 6).

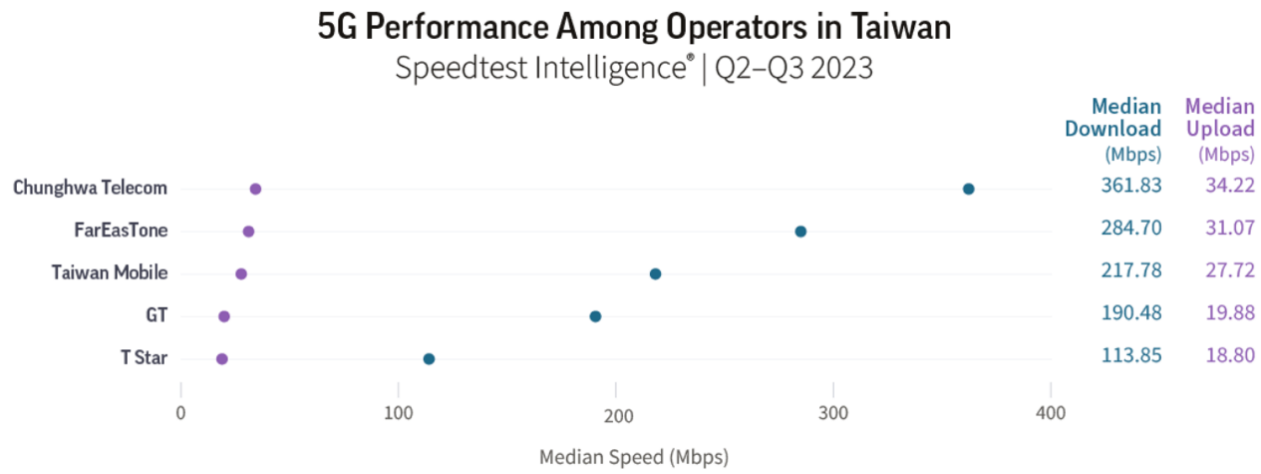

Figure 6: 5G Performance Among Operators in Taiwan (Johan, 2023)

Furthermore, Chunghwa Telecom also leads in 5G coverage, reaching 97.6% of locations in Taiwan with 5G coverage (see Figure 7); FarEasTone and Taiwan Mobile are close behind, having 88.9% and 85.6% coverage, respectively (Johan, 2023).

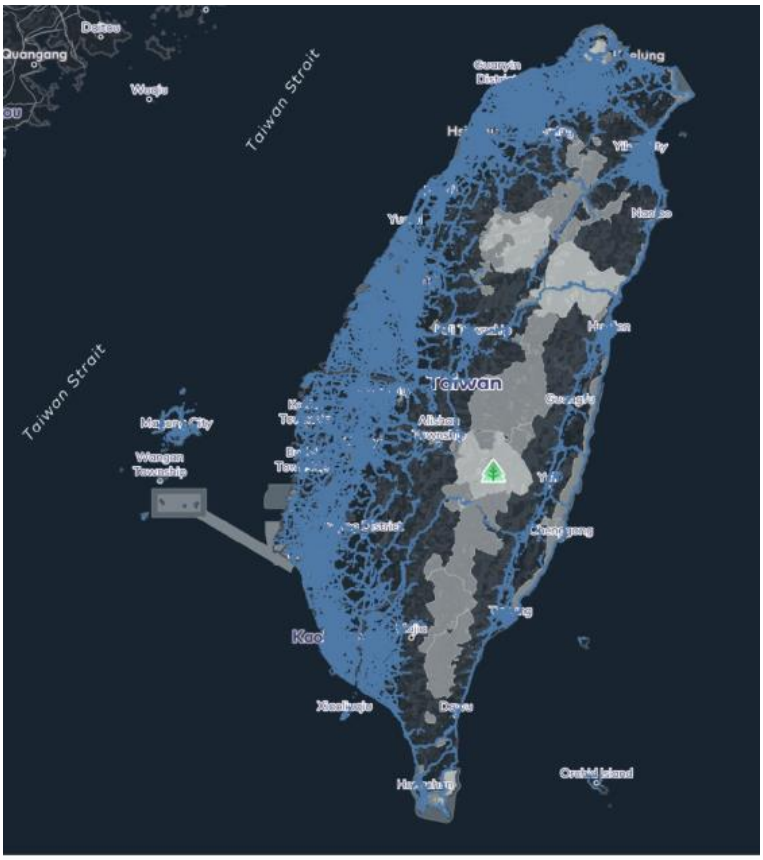

Figure 7: Chunghwa 5G Network in Taiwan (Johan, 2023)

Taiwan’s recent performance and development in 5G are 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, have 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, there have been numerous challenges with millimeter-wave deployment, 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 individuals and communities with limited access to 5G technology are left behind in the rapidly evolving digital landscape. As 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 poses 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 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, 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 threaten 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 conceptualization and initial 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 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 estimated 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 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*, 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 the initial phases of research and development being extended through the early 2020s (*Europe launches the second phase of its 6G Research and Innovation Programme*, 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 8.

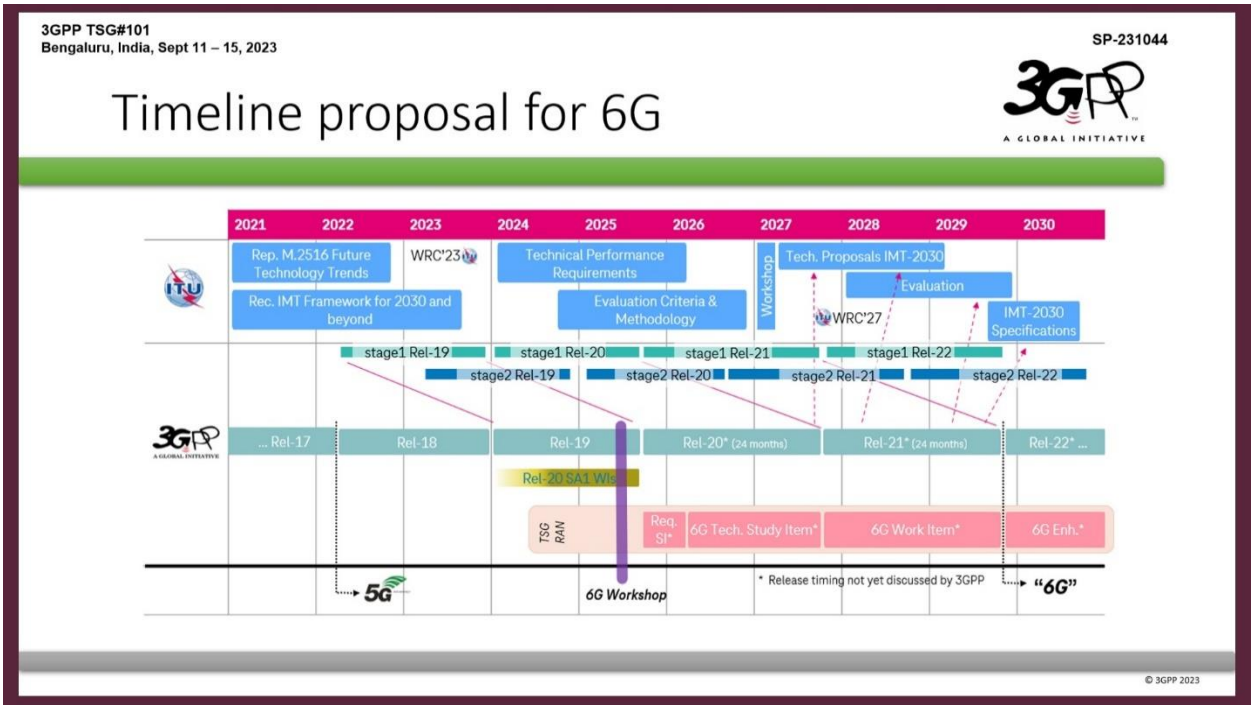

Figure 8 Timeline proposal for 6G (Free 5G Training [@5Gtraining], 2023)

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 are multifaceted, leveraging its strengths in semiconductor technology, telecommunications infrastructure, and international collaboration. Taiwanese companies and research institutions dominate the forefront of developing the

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) in parallel 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 end of 2023 report that the company's total revenue for the year was NT$2,161.74 billion (TSMC, 2024). As for the global connections between Taiwan and the rest of the world in the development of 6G, the Alliance for Telecommunications Industry Solutions formed the “Next G Alliance” in 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 has worked closely with Taiwan and has been 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.

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 the research space. On the global scale the nation has made numerous alliances with countries and industries to utilize various resources to maximize progress in an efficient and collaborative manner. 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. An IT company known as the Thales Group described that the 6G technical specifications will be defined in 2025, eventually leading to the first 6G specification in 3GPP releasing by 2028, with 2030 being the end goal of the deployment for commercial use (see Figure 8). 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 this experiment being done 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 there is a focus on the equality of access globally, spreading the benefits of social and economic growth to more people.

2.5 Summary

After exploring Taiwan's telecommunications landscape, it's evident that the sector is undergoing significant transformation, the rapid advancements in 5G technology, the foundational role of semiconductor companies, the broad socio-economic impacts of internet access, and the early stages of research into 6G technology. 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 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.

3 Methods

3.1 Methods Overview

The methodology chapter delves into the approaches, methods, and procedures, which helps the team 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. Using a mixed methods approach, the methodology aims to provide a comprehensive review of the current landscape and future projections. The 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, quantitative, and mixed methods and fits the needs and requirements of the project. The last section expands upon the methodological choices, such as expert interviews and surveys, explaining their rationale and ethical considerations while simultaneously acknowledging the challenges and limitations inherent in the timeframe and demographic considerations. By utilizing these methodological strategies and reflections, the project allows the team to anticipate some of the hurdles for 6G in Taiwan.

3.2 Research Questions

As stated in the *Introduction*, the team have 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 focus on the social impacts of telecommunications, and the technical aspects of 5G and 6G. Ultimately these topics lay 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. To investigate the public perception of AI and its applications in 6G.

To satisfy these objectives, the team plan on using three methods:

1. Interviews with industry experts on 5G adoption and development.
2. Surveys with people in Taiwan on data usage and preferences.
3. Surveys with people in Taiwan on their understanding and views on AI and its applications in 6G.

Our methods will all work together to satisfy these objectives, which should lead to the desired outcome – evaluating the expected hurdles in implementing 6G in Taiwan. All this information is condensed graphically in Figure 9.The first two methods will work towards investigating the technical aspects relevant to Taiwan. Interviews with experts in Taiwan and the United States will provide information about the technical side of the industry and development, and a survey about data usage and preferences will provide technical information about the consumer side of the industry. A second survey will provide information on AI and its applications in 6G. Together these methods will yield a broad dataset to answer the objectives and ultimately enabling the team to evaluate the hurdles in 6G implementation relevant to Taiwan's industries and society.

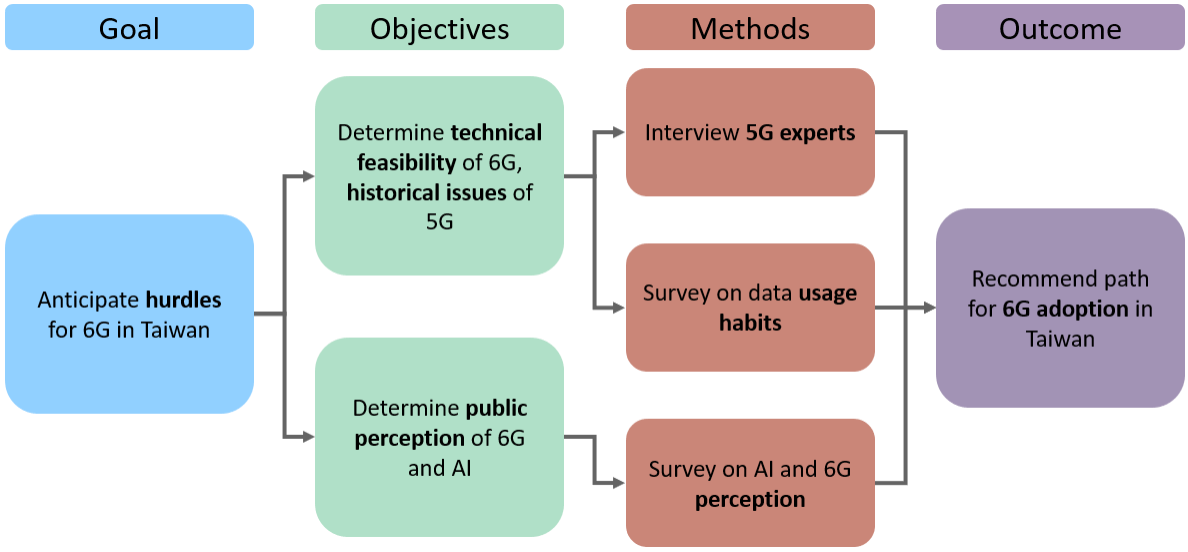

Figure 9: Methods Diagram, showing the goal, objectives, methods, and outcome

3.3 Research Design Approach

While designing a research strategy, it is valuable to consider different research design approaches, as this will guide and form the basis of investigation. To conduct successful and efficient research, the team must first evaluate the advantages and disadvantages of qualitative, quantitative, and mixed methods methodologies. This will guide 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 being limited to the bounds of the 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 will allow 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.

3.4 Methods Rationale

The choice to conduct semi-structured interviews with industry experts on 5G technology was motivated by the objective to gather detailed insights into the technical and operational challenges during the rollout of 5G in Taiwan. These experts, directly involved in the development, deployment, and troubleshooting of 5G networks, offer essential knowledge that can illuminate potential challenges and successes relevant to the transition to 6G. The interview will be structured in a manner that allows experts to answer some of the research questions while also having numerous opportunities to share their own thoughts and opinions on the matter. The interview questions designed encompass a range of experiences, focusing on involvement with 5G development, identification of roadblocks, ongoing issues, and views on 6G

development. The method for identifying interview participants involves utilizing connections in the WPI (Worcester Polytechnic Institute) ECE department and snowball sampling with knowledgeable individuals working in TIER (Creswell & Creswell 2018). This qualitative method facilitates a thorough exploration of the complexities in telecommunications advancements.

To augment the qualitative insights from expert interviews, the team chose surveys targeting Taiwan's general population to identify data usage patterns, preferences, and public perceptions of AI and its applications in 6G technology. This quantitative strategy allows for data collection from a broad demographic, providing 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; they can be sent to a large quantity of people for a generalized understanding of the population's views on these issues. With the percentage of the population who fill out sent surveys coming to around 30%, the team will triple the survey size to combat this hurdle (Church, 1993).

By combining in-depth perspectives from expert interviews with extensive statistical data from surveys, the objective is a nuanced understanding of Taiwan's telecommunications landscape. This mixed-methods approach enables an exploration of 6G's technical feasibility, public perceptions of AI and 6G, and the historical context of 5G's challenges and achievements. In analyzing the data, the team plans to use inductive coding for qualitative data from open-ended survey responses and interview transcripts (Creswell & Creswell 2018). The data will be systematically categorized and coded, adhering to a system the team will create after gathering more data, identifying recurring themes and trends that will inform the final deliverable.

Throughout the research, adherence to ethical guidelines is a priority. From securing IRB approval to respecting participant privacy and anonymity, the team is dedicated to conducting the study with integrity and sensitivity to cultural norms. This ethical commitment ensures the research's credibility and safeguards the interests and well-being of all stakeholders.

3.5 Ethics

Before starting any research, it is critical to go through the proper channels to get approval. The project involves obtaining approval from the Institutional Review Board (IRB) to ensure the methods meet ethical standards. Additionally, it is essential that the research ultimately benefit participants and contributes positively to society (Creswell & Creswell, 2018). The background chapter highlights the benefits of advancing telecommunications access (see Section 2).

During the research process, obtaining permission from subjects and transparently disclosing the study's purpose upholds ethical principles (Creswell & Creswell, 2018). Disclaimers that the team will use in the methods section with this information can be seen in *Appendix A.1 Interview disclaimer* and *Appendix B.1: Survey Disclaimer*. Additionally, the team will acknowledge the importance of respecting cultural norms and will conduct research to understand expectations for surveys in Taiwan, ensuring that the methodologies align with local customs and practices. The team will do this by working with their sponsor, TIER, in Tiawan before sending out the survey. Some local customs include a heightened respect for seniority, face-saving, and respecting other's time (*Taiwan - Culture, Traditions, Festivals | Britannica*, n.d.). The project team accounted for these local customs 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 persist in the analysis and distribution of findings (Creswell & Creswell, 2018). The team will analyze the data ethically, with careful consideration given to maintaining the privacy and anonymity of participants. Additionally, TIER being a think tank and not a company allows this research to focus more on social aspects of 6G, and avoids the ethical issues introduced by seeking a outcome from the research (Popovic & Huecker, 2024). 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.

3.6 Challenges

To properly prepare and conduct the methods effectively the team must identify the various challenges and limitations coincidental with the methods. An initial hurdle the team will face is finding relevant sources to interview and survey, such as experts and individuals willing to participate. The team aims to interview four groups of experts (two from U.S, two from Taiwan), as this would allow further insight into the development of 5G in both the US and Taiwan as well as their understanding of the 6G standard. However, getting a hold of these groups and individuals may prove to be quite difficult. The first step is to identify valuable contacts and to attempt to establish a connection. In the professional world many hindrances may arise. For instance, there could be conflicting or busy schedules between parties, a lack of interest in an interview, or attempts of contact may not connect. The best place to start is with the sponsor TIER, as they are a great initial resource for the project and may have experts on 5G that are willing to interview and even provide other contacts that would allow for networking and snowballing of interviews. Another aspect of the methods that may prove to be a challenge is identifying an appropriate demographic for the surveys. Knowing and understanding the targeted demographic for the survey questions will allow the team to clarify any biases during the surveying process. There will be inevitable bias for most cases, and there is expected to be different types of biases as responses are from numerous sources. An example of a specific type of bias is when doing in-person surveys and interviews can be affected by locational bias, as people in the city are more technologically savvy than those populating more rural areas. Online surveys also bring up different biases based off the responding groups. To mitigate the

influence of bias on the research the team will keep it in mind when selecting samples and will take the time to understand the types of bias's that will affect responses.

A limitation that is going to be a constant factor is the overall time restraint, having only seven weeks in Taiwan. Keeping this in mind ensures that a pace and steady flow of research and work is established to stay on track whilst abroad. Given the limited time in Taiwan there is a sense of urgency to conduct the methods properly and to follow a timeline to produce the greatest results (see Figure 10). As the challenges and limitations of the project become clear, the next steps are to move on and create a plan of action for when the project begins in Taiwan.

3.7 Next Steps

Following the arrival of the group comes the contact with the sponsor TIER for initial greetings and to connect and begin discussion of the project and share ideas. As meetings with the sponsor continue over the weeks abroad, the teams will work with them to finalize a timeline with sufficient time to perform the methods and analyze the results. Having TIER as a resource will aid in contacting experts on the subject for both the surveys and interviews. The team will practice performing surveys and interviews so that the methods will be carried out smoothly. The team will compile all the data from the methods to allow for depth analyzation of the results. The next step after conducting the methods, research, and compiling data is to assemble

everything into a final paper and presentation to complete the course and project.

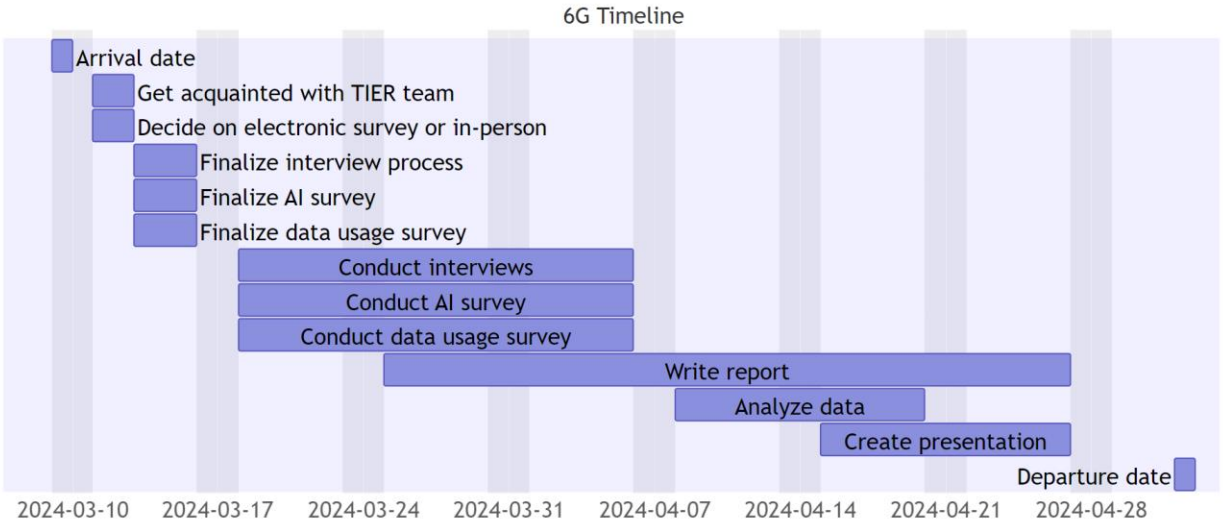

Figure 10 is a Gantt chart designed to depict the predicted timeline for the project conducted in Taiwan to give a visual to the allocation of time and resources.

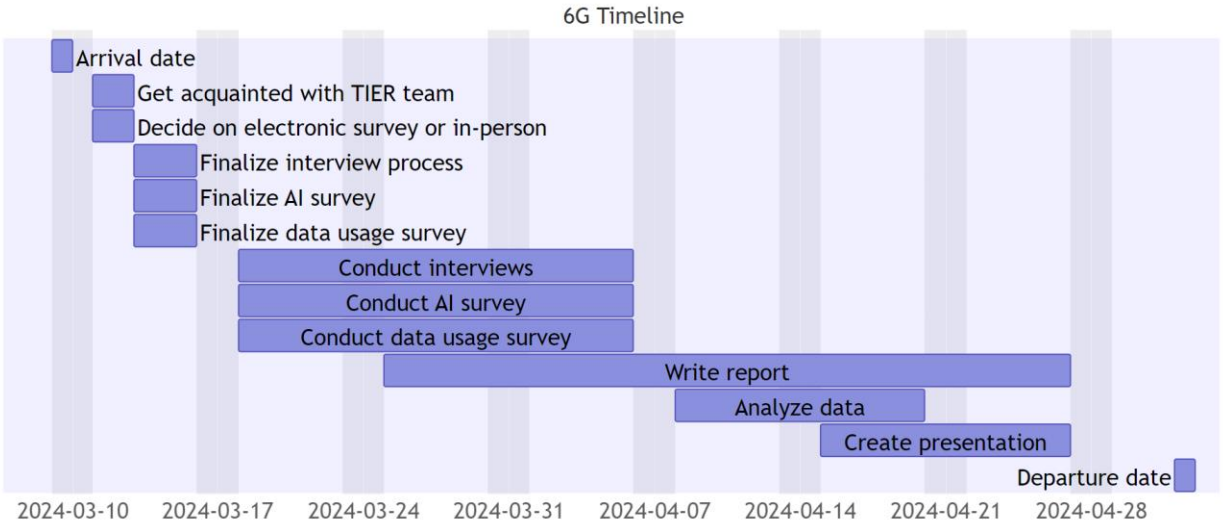

Figure 10: Gantt chart for Taiwan.

References

6G networks explained: Everything you need to know | Computer Weekly. (n.d.). ComputerWeekly.Com. Retrieved February 6, 2024, from https://www.computerweekly.com/feature/6G-networks-explained-everything-you-need-to-know

Abdel Hakeem, S. A., Hussein, H. H., & Kim, H. (2022). Vision and research directions of 6G technologies and applications. *Journal of King Saud University - Computer and Information Sciences*, *34*(6, Part A), 2419–2442. https://doi.org/10.1016/j.jksuci.2022.03.019

Carroll, T. (n.d.). *New 6G Networks Are in the Works. Can They Destroy Dead Zones for Good?* Scientific American. Retrieved February 7, 2024, from https://www.scientificamerican.com/article/new-6g-networks-are-in-the-works-can-they-destroy-dead-zones-for-good/

Chen, J. (2020, April 7). *The U.S.-China technology war has spread from 5G to 6G, and potential key technologies for next-generation communications will become a first-level war zone* [文字]. Department of Industrial Technology; 經濟部產業技術司. https://www.moea.gov.tw/MNS/doit/industrytech/IndustryTech.aspx?menu_id=13545&it_id=421

China sends "world's first 6G" test satellite into orbit. (n.d.). Retrieved February 7, 2024, from https://www.bbc.com/news/av/world-asia-china-54852131

Communications Market Report. (2022, December). Yaw-Shyang Chen (Chairperson of NCC). https://www.ncc.gov.tw/english/news_detail.aspx?site_content_sn=392&is_history=0&pages=0&sn_f=5689

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*.

Dictionary.com | Meanings & Definitions of English Words. (n.d.). Retrieved February 23, 2024, from https://www.dictionary.com/

Dohler, M., Mahmoodi, T., Lema, M. A., Condoluci, M., Sardis, F., Antonakoglou, K., & Aghvami, H. (2017). Internet of skills, where robotics meets AI, 5G and the Tactile Internet. *2017 European Conference on Networks and Communications (EuCNC)*, 1–5. https://doi.org/10.1109/EuCNC.2017.7980645

Europe launches the second phase of its 6G Research and Innovation Programme | Shaping Europe's digital future. (2022, December 15). https://digital-strategy.ec.europa.eu/en/news/europe-launches-second-phase-its-6g-research-and-innovation-programme

Free 5G Training [@5Gtraining]. (2023, October 9). *Proposal for a realistic 6G timeline presented by Johannes Achter, Deutsche Telekom at 3GPP TSG#101, Bengaluru, India, Sept 11 – 15, 2023 as part of SP-231044* [Tweet]. Twitter. https://twitter.com/5Gtraining/status/1711408590362153334

Huang, S.-C., & Cox, J. L. (2016). Establishing a social entrepreneurial system to bridge the digital divide for the poor: A case study for Taiwan. *Universal Access in the Information Society*, *15*(2), 219–236. https://doi.org/10.1007/s10209-014-0379-7

Internet of Things—Taiwan | Statista Market Forecast. (n.d.). Statista. Retrieved February 13, 2024, from https://www.statista.com/outlook/tmo/internet-of-things/taiwan

Welcome to ITU-R. (2024). ITU; ITU. https://www.itu.int:443/en/ITU-R/information/Pages/default.aspx

Johan, A. (2023, November 20). *The State of Taiwan's 5G Network With Telecom Mergers On the Horizon | Ookla®*. Ookla - Providing Network Intelligence to Enable Modern Connectivity. https://www.ookla.com/articles/taiwan-5g-performance-mergers-q3-2023

Koziol, M. (2023, May 6). *5G Networks Are Performing Worse. What's Going On? - IEEE Spectrum*. https://spectrum.ieee.org/5g-rollout-disappointments

Liang, T.-H. (2011). Association between Use of Internet Services and Quality of Life in Taiwan. *Journal of Data Science*, *9*. https://doi.org/10.6339/JDS.201101_09(1).0007

Lukasiak, L., & Jakubowski, A. (2010, January). *History of Semiconductors.pdf*. Https://Djena.Engineering.Cornell.Edu/Hws/History_of_semiconductors.Pdf. https://djena.engineering.cornell.edu/hws/history_of_semiconductors.pdf

Merriam-Webster: America's Most Trusted Dictionary. (n.d.). Retrieved February 23, 2024, from https://www.merriam-webster.com/

MS/RF - Taiwan Semiconductor Manufacturing Company Limited. (2010, 2024). Taiwan Semiconductor Manufacturing Company. http://www.tsmc.com/english/dedicatedFoundry/technology/specialty/msrf

Overview of Risks Introduced by 5G Adoption in the United States | CISA. (2020, December 17). U.S. Department of Homeland Security. https://www.cisa.gov/resources-tools/resources/overview-risks-introduced-5g-adoption-united-states

Sacks, D. (2023, July 6). *Will China's Reliance on Taiwanese Chips Prevent a War?* Council on Foreign Relations. https://www.cfr.org/blog/will-chinas-reliance-taiwanese-chips-prevent-war

Sperling, E. (2023, June 21). *Preparing For 5G Millimeter Wave And 6G*. Semiconductor Engineering. https://semiengineering.com/preparing-for-5g-millimeter-wave-6g-and-the-edge/

Taiwan Institute of Economic Research. (2007). Taiwan Institute of Economic Research. https://english.tier.org.tw/

Taiwan—NextGen Telecom Services. (2024, January 10). International Trade Administration. https://www.trade.gov/country-commercial-guides/taiwan-nextgen-telecom-services

The Chinese surveillance state proves that the idea of privacy is more "malleable" than you'd expect. (n.d.). MIT Technology Review. Retrieved February 16, 2024, from

https://www.technologyreview.com/2022/10/10/1060982/china-pandemic-cameras-surveillance-state-book/

The Internet and the New Economy. (2000). Brookings. https://www.brookings.edu/articles/the-internet-and-the-new-economy/

The Social and Cultural Impacts of Telecommunication Engineering. (n.d.). Utilities One. Retrieved February 12, 2024, from https://utilitiesone.com/the-social-and-cultural-impacts-of-telecommunication-engineering

TSMC - CUSTOMER NEWSLETTER. (2022, July). Taiwan Semiconductor Manufacturing Company. https://pr.tsmc.com/static/campaign/2022july/tsmc_eu/EU_Special_Edition.html

TSMC December 2023 Revenue Report. (2024, January 10). Taiwan Semiconductor Manufacturing Company Limited. http://pr.tsmc.com/english/news/3098

What's the latest on 6G? Standards, Features, Timeline. (2023, September 7). https://www.thalesgroup.com/en/worldwide/digital-identity-and-security/magazine/whats-latest-6g-standards-features-use-cases-and

When Is 6G Coming, and What Does It Mean for 5G and 4G LTE? (n.d.). Retrieved February 7, 2024, from https://www.digi.com/blog/post/when-is-6g-coming-what-does-it-mean-for-5g-4g

Zhao, Z., Xiong, W., & Fang, J. (2016). Impact of Internet plus to China Economy Development. *Modern Economy*, *07*(09), Article 09. https://doi.org/10.4236/me.2016.79096

Appendix A: 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

1. What company does your experience with telecommunications come from?
2. What is your job title?
3. What is your background with telecommunications and 5G?
4. How has 5G contributed to urban development?
5. What measures can be taken to ensure equitable access to 5G technology, especially in rural and underserved areas?
6. How has 5G technology affected the digital divide, both within countries and globally?
7. Were there any roadblocks in the 5G development or rollout, do they persist?
8. Looking back on the early stages of 5G, what measures would you take to avoid the struggles during the development/rollout period?
9. What was the public perception to the 5G rollout like? Do you expect a similar response for 6G?

10. Are there any ongoing struggles with 5G? Speeds, connections, reliability, rollout?
11. Beyond current applications, what future innovations do you foresee being enabled by 5G technology?
12. How do you foresee 6G affecting the average person?
13. Is there anything you want to add that we have not covered yet?

Appendix B: General Public Survey Questions

Appendix B.1: Survey Disclaimer

Hello, we are third year engineering students from the US studying at Worcester Polytechnic Institute in Massachusetts. We are carrying out a project to identify the benefits and hurdles of implementing 6G in Taiwan (the successor to 5G cellular technology). 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.

Appendix B.2: 5G Usage Survey

1. Do you live in an urban or rural area?
    a. Urban, rural.
2. Do you have a smart phone?
    a. Yes, no. *If no, skip the next 2 questions.*
3. What phone carrier do you have?
    a. Chunghwa Telecom, FarEasTone, Taiwan Mobile, other. *If other, please specify.*
4. What type of mobile data connection do you use most frequently?
    a. 5G, 4G LTE, 4G, 3G, other. *If other, please specify.*
5. How frequently do you access the internet?
    a. Multiple times every hour, hourly, daily, weekly, other. *If other, please specify.*
6. How do you usually access the internet at home (home WIFI, hotspots, cellular)?
    a. Home WIFI, hotspots, cellular, other. *If other, please specify.*
7. How do you usually access the internet in public (public WIFI, hotspots, cellular)?

    a. Public WIFI, hotspots, cellular, other. *If other, please specify.*

8. What do you mostly use your cellular data for?
    a. Communication, entertainment, shopping, research, work, other. *If other, please specify.*
9. How often do you have issues connecting to the internet (slow, dropping, freezing, etc.)?
    a. hourly, daily, weekly, monthly, other. *If other, please specify.*

Appendix B.3: AI and 6G Opinions Survey

1. How familiar are you with the concept of 5G technology?
    a. Very familiar, familiar, neutral, unfamiliar, very unfamiliar. *If very unaware, skip the next question.*
2. How do you feel 5G technology has improved your quality of life?
    a. Beneficial, marginally beneficial, neutral, marginally detrimental, detrimental
3. How familiar are you with the concept of 6G technology?
    a. Very familiar, familiar, neutral, unfamiliar, very unfamiliar. *If very unaware, skip the next question.*
4. What are your thoughts on the potential benefits and drawbacks of adopting 6G.
    a. *Free response*
5. How familiar are you with AI technology?
    a. Very familiar, familiar, neutral, unfamiliar, very unfamiliar. *If very unaware, skip the next question.*
6. What are your thoughts on the applications of AI?
    a. *Free response*
7. How much have you heard about AI integration in telecommunications, can you describe what you know?

    a. *Free response*

8. What are your thoughts on the benefits and drawbacks/concerns about AI integration in telecommunications?
    a. *Free response*