ANNEXES A-1

FUTURE COMMUNICATIONS AND INTERNET-OF-THINGS

CONTENTS

1 INTRODUCTION & OVERVIEW - SPEEDING INTO THE FUTURE: COMMUNICATIONS AND INTERNET-OF-THINGS

A bright future. A global city. Powered by Communications and Internet-of-Things

This report covers Future Communications and Internet-of-Things (IoT) technologies. These technologies are empowering a digital future via establishing a connected world and enabling technology innovation and emerging technologies adoption. By providing access to high-speed networks and enabling ambient connectivity across devices, people and businesses, these technologies have enabled the transformation of enterprises into digital businesses and the creation of value by facilitating new business models, new products and solutions. As these technologies evolve, they are expected to support a greater variety of use cases and thus, fuel further innovation.

Communication technologies generally comprise wireless and wired communication technologies. Wired communications should be considered not just from consumers' perspectives but also as a backbone and core exchanges across various networks including wireless networks. Hence, they need to be of high capacity and few magnitudes faster than wireless.

Of all emerging technologies, IoT is intrinsically intertwined with communication technology, as communication is an integral part of its information value loop [a] [1] that enables significant value creation. This explains why this report explores the capabilities and opportunities related to communications and IoT technologies together.

These technologies are also increasingly facilitating access to emerging technology solutions and allowing the adoption of Cloud Native solutions. Along with the supporting data centres and submarine cables, these communication technologies are expected to be central to the physical and digital infrastructure required as a foundation to the Digital Economy Framework to support and enable Singapore's vision of becoming the Services 4.0 hub [2]. Services 4.0 is defined as a response to social and economic shifts accelerated by emerging tech to capture opportunities by designing services which are end-to-end, frictionless, anticipatory and empathic to customer needs. Communication technologies provide a foundation to ubiquitous connectivity and Data Tsunami, emerging technology adoption and enable the offering of Cloud Native solutions [b]. Thus, communication technologies enable the building of a Services 4.0 (defined as the evolution of services enabled by the confluence of emerging technologies and servitisation of products) ecosystem.

This report is not meant to be a comprehensive list and study of all communication and IoT technologies, but rather a collaborative effort by the public and private sectors to highlight some key present and upcoming technologies that the industry can adopt to remain relevant in this era of disruption and to participate in the Services 4.0 technology ecosystem.

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a Deloitte Information Value Loop indicates 5 stages for IoT – Create, Communicate, Aggregate, Analyse, & Act

b Cloud-native is an approach to designing the components of software systems to optimise for distributed, cloud-based deployments and run applications that fully exploit the benefits of the cloud computing model.

2 MARKET STUDY OF FUTURE COMMUNICATIONS & INTERNET-OF-THINGS

2.1 Global Trends

As mentioned earlier, communications technologies such as 5G, optic fibre, submarine cables, and data centres, make up the digital and physical infrastructure that are the crucial foundations to creating an ecosystem that enables Services 4.0.

Three key global paradigms have emerged that are increasingly relevant to support technology and business innovation and are paramount to building a Services 4.0 ecosystem - ubiquitous connectivity and access to data leading to a Data Tsunami, emerging technologies adoption and offering of Cloud Native solutions. In Services 4.0, significant value creation comes from the use of emerging technologies, offered as part of the Cloud Native technology ecosystem, to unlock value from data generated and captured. Communication technologies are key foundations to each of these paradigms.

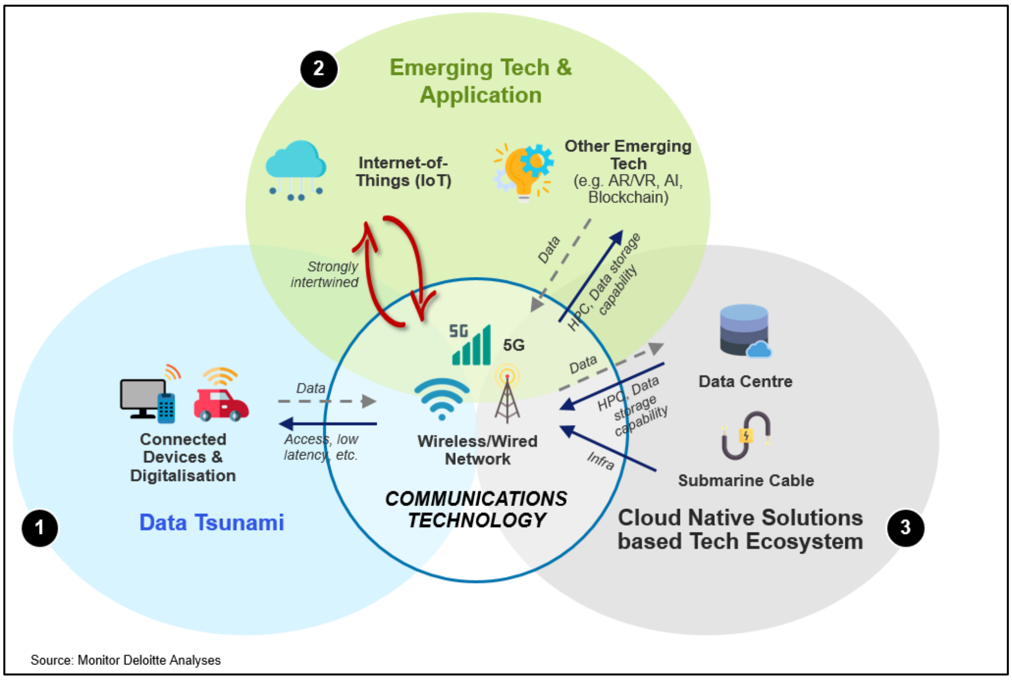


Exhibit 1: Three paradigms of Services 4.0 enabled by Communication Technology

Wireless technologies such as 3G, 4G and Wi-Fi supported by optical fibre, submarine cables and other wired technologies have enabled the rapid, inexpensive and seamless connectivity between people and businesses leading to an explosion of data. 5G and IoT are expected to further fuel this data explosion through the proliferation of devices supported, leading to a “Data Tsunami”.

Communication technologies such as 5G are key enablers for the adoption of emerging technologies. These emerging technologies such as Augmented and Virtual Reality (AR/VR), Artificial Intelligence (AI) and blockchain are highly dependent on data and connectivity enabled through 5G and other communication technologies and place specific demands such as high capacity, low latency on them. Greater convergence of these emerging technologies are also expected with IoT facilitated through the use of 5G and other communication technologies.

Cloud Native solutions are becoming increasingly important for rapid innovation. High-bandwidth connectivity enabled through Backbone Architecture technologies such as optical fibre and virtualised routers and switches (SDN solutions) used in submarine cables and data centres have been crucial enablers for cloud computing. Thus, these are expected to be foundational to this new paradigm of Cloud Native solutions that enable the leveraging of cloud computing and creating of a new technology ecosystem.

This chapter explores in more detail the ways communications technology is the foundation of: 1) Data Tsunami, 2) emerging technologies and the applications, and 3) Cloud Native solutions based technology ecosystem.

2.1.1 Communications Technology is the Foundation of Data Tsunami

We are moving to an always-connected world: as consumers, as businesses, and as society-at-large. Connectivity is pervasive in how we work, how we commute, how we live. This has been constantly evolving and is expected to continue to change. With this ubiquitous connectivity, consumers and businesses are increasingly demonstrating a growing demand for instant access to information, leading to a rising importance of data with a concept of 'Data Tsunami' to the world.

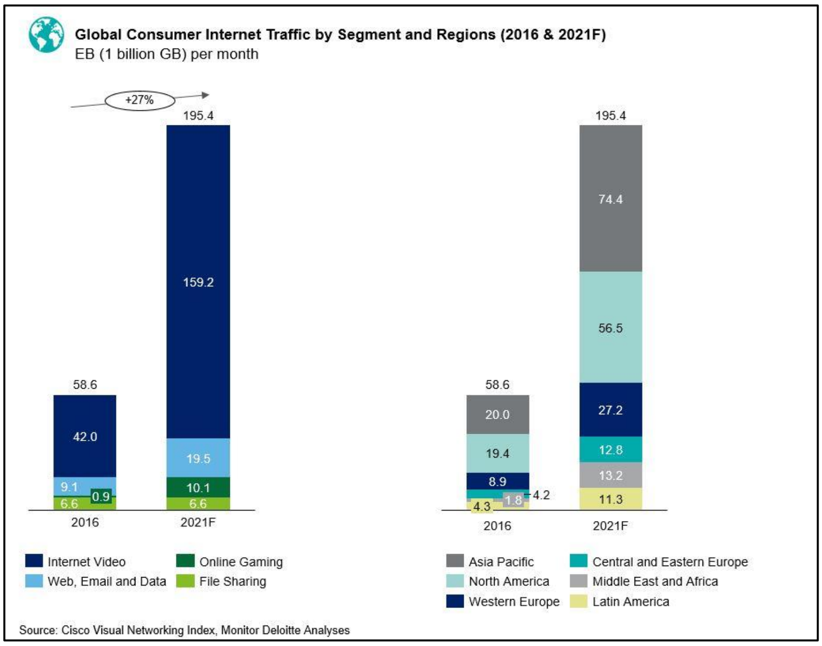


Exhibit 2: Global Consumer Internet Traffic per Month

In an update to a 2016 peer-reviewed study, a Swedish researcher Anders Andrae mentioned [3] that "We have a tsunami of data approaching. Everything that can be is being digitalised. 5G is coming, IP traffic is much higher than estimated, and all cars and machines, robots and artificial intelligence are being digitalised, producing huge amounts of data which is stored in data centres." It is estimated that the number of IoT connected devices will reach 30 billion by 2020 and 75 billion devices by 2025 [4]. This will lead to increasing amount of data created, stored, archived and transmitted, which will require large amount of internet consumption (Exhibit 2).

Total global internet traffic (both consumer and business internet traffic) is expected to reach 236 EB per month by 2021 with a 26% CAGR from 2016 to 2021 [5]. In APAC, the total internet traffic is estimated to reach 90 EB per month in 2021 with a 29% CAGR from 2016 to 2021 [5]. In Singapore, total internet traffic is forecasted to reach 0.7 EB per month in 2021[6] with a 30% CAGR between 2016 and 2021. Consumer internet traffic is a key contributor to total traffic at ~82% of total internet traffic.

Global consumer internet traffic is expected to reach 195 EB per month by 2021 with a 27% CAGR from 2016 to 2021 [5]. In APAC, total consumer internet traffic is forecasted to reach 75 EB per month in 2021 [5] with a 30% CAGR between 2016 and 2021. Please refer to Exhibit 2 for more details. In 2021, APAC is expected to account for 38% of the global consumer traffic and hence presents a significant opportunity for Singapore to capitalise on. In Singapore, total consumer internet traffic is forecasted to reach 0.58 EB per month in 2021 [6] with a 30% CAGR between 2016 and 2021.

Among different applications, internet video is expected to be the most significant driver for the growth of consumer internet traffic accounting for ~84% of the overall Global consumer Internet traffic in 2021, increasing from 75% in 2016 [5]. The internet video market will in turn be driven by the AR/VR technology. AR/ VR has already shown promising growth at ~80% CAGR from 2016 to 2018. The estimated consumer internet traffic as a result of AR/VR is expected to be 14.33 EB per month [7] [8] [9] [10] indicating a 20 times increase with an 81% CAGR from 2016 to 2021 [11].

The Data Tsunami shows no sign of abating. The Tsunami is characterised by the 5Vs – Volume, Velocity, Variety, Veracity and Value. Communication technologies will continue to remain foundational to support this growth and generate value to people, businesses and economies.

2.1.2 Communications Technology is the Foundation of Emerging Technologies and the Applications

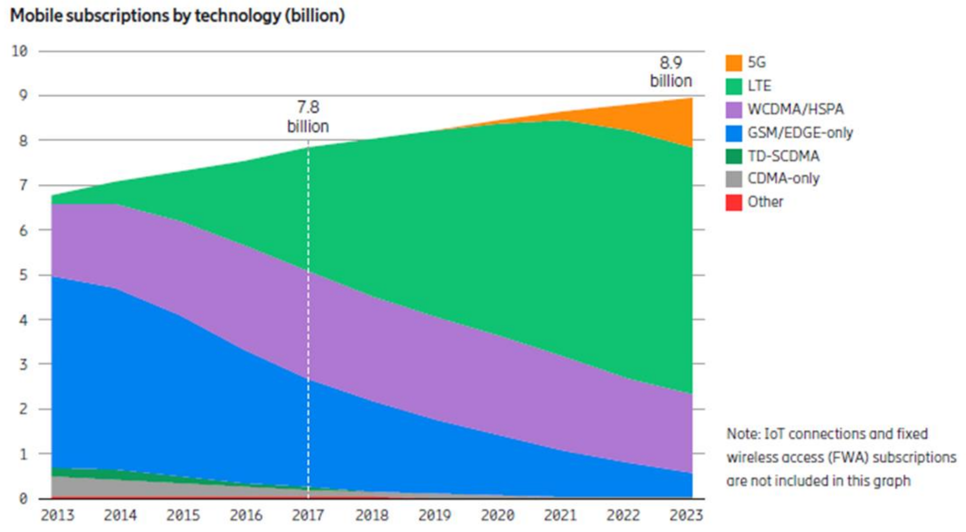
Please refer to:

- **Other technology reports** for deep-dive into each of the technologies discussed in this sub-chapter

2.1.2.1 Rise of 5G as an Enabler

Technology has been a key enabler and communications technologies, in particular, have been pervasive more than ever. As communications technologies continue to evolve, they will revolutionise and influence our daily lives. The world and increasing number of innovations will go wireless (Please refer to 3.3.1). With the global mobile data traffic expected to grow eight times to 8.9 billion by the end of 2023 [12], there is a need for a more efficient technology, higher data rates and spectrum utilisation. (Exhibit 3).

As the next-generation mobile network, 5G has been accelerating in terms of their standardisation. The first 5G New Radio (NR) standard was finalised in December 2017 and completed in June 2018. The first commercial 5G networks and devices based on the 3GPP standards are expected to be introduced in 2018. In terms of subscription, 5G is also expected to grow rapidly, with over 1 billion subscriptions, accounting for 12% of all mobile subscriptions and 20% of all mobile data traffic.



Source: Ericsson Mobility Report June 2018

Exhibit 3: Mobile subscription projections by 2023

With enhanced mobile broadband and connectivity, 5G network will be a major enabling technology for growing industry digitalisation and innovation. It creates and enhances industry use cases such as autonomous driving, remote robotic surgery and augmented reality (AR) support for field maintenance and repair. 5G can also enable new capabilities with its data rates up to 100 times faster, network latency lowered by a factor of five, mobile data volumes 1,000 times greater than today's, and battery life of remote cellular devices stretched to 10 years or more. These capabilities include:

a) **Precise remote control:** 5G will enable a quick reaction time required for operating machinery using haptic control, which connects the remote operator to the machine's environment. For example, a doctor could "feel" his patient's body in a distant operating room to avoid slicing through a vein, improving precision of a remote machine operator.

b) **Near-instantaneous communication:** 5G will shorten the reaction time of self-driving cars, reducing its braking distance to just an inch (2.54 cm) from about 4.6 feet (1.4 m) with 4G, reducing the risk of collisions and accidents [CTIA, 2016].

c) **Lower latency:** The low latency of 5G will allow factories to shift their robots' "intelligence" to the cloud. This can lower the cost for individual robots, while expanding the ability to control many robots at once, enabling better coordination between robots.

d) **Seamless connectivity:** 5G will vastly multiply the number of devices that a network can handle but decrease energy requirements, spurring widespread growth of IoT. Deploying a large network of sensors, such as vehicle sensors, is becoming more practical, with greater network capacity and longer battery life for the devices.

e) **Agile networks:** Network slicing [c] will enable operators to provide networks on an as-a-service basis to meet the various needs of industrial use cases. Speed, capacity, and latency will be dialled up or down in network "slices" to meet specific demands, whether it be managing a large group of sensors (high capacity) or controlling a remote robot (low latency).

[c] Powerful virtualisation capability that will enable flexibility as it allows multiple logical networks to be created on top of a common shared physical infrastructure.

Leveraging on these capabilities, industries can create new products and services to grow their markets, increase productivity and efficiency to reduce costs, or increase safety and security to reduce risk. Based on Ericsson and Arthur D. Little's study on the business potential, the total revenue for 5G-enabled industry digitalisation revenue for ICT players is estimated to reach US$1,307 billion in 2026. (Exhibit 4).

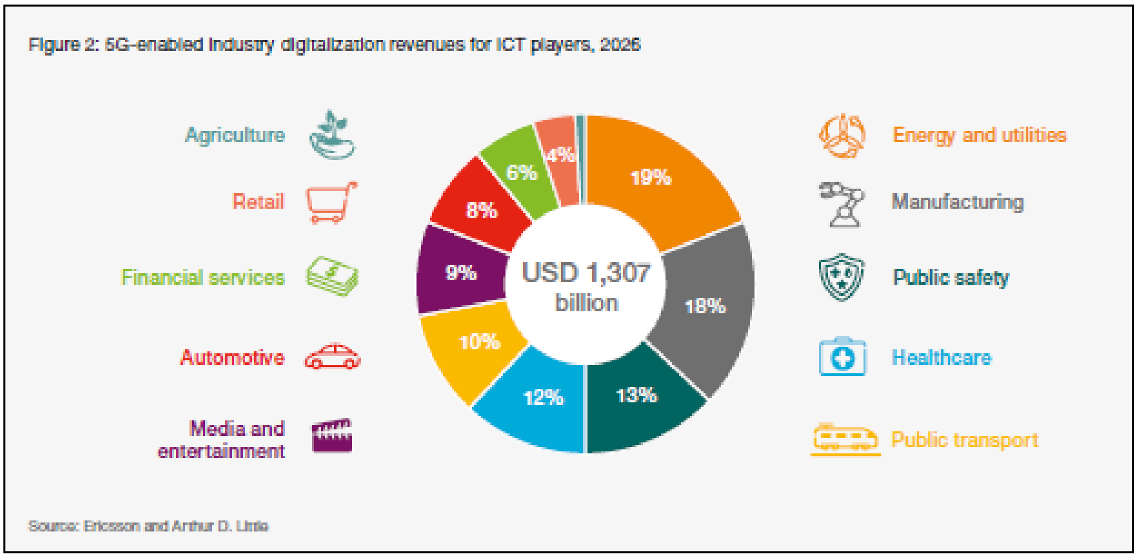


Exhibit 4: 5G-enabled industry digitalisation revenues for ICT players

2.1.2.2 Rise of the Internet-of-Things (IoT) Enabled by Communications Technology

Please refer to:

- **Chapter 3.3** for use cases of Future Communications and Internet-of-Things
- **Chapter 2.3** where the opportunities of IoT has been discussed in greater detail

The Internet-of-Things (IoT) is a key technology pillar which is seen as the "third wave of Internet development" by Steve Case in his book, The Third Wave: An Entrepreneur's Vision of the Future" [13] and a potential game changer for the industry. The global IoT market is projected to grow to US$1.5 trillion. (Refer to Chapter 2.3.1) The number of cellular IoT connections is also expected to rapidly grow, reaching US$3.5 billion in 2023 with an annual growth rate of 30% [12].

IoT is transforming people's lives both at home and in businesses and its applications are increasingly gaining traction. New waves of businesses will arise from those who expands the bandwidth capability to those who will analyse the realm of data and create new IoT applications. (Refer to Chapter 3.3.2) IoT-enabled devices can also bring a new value to businesses. They can automatically collect and share data without human intervention, transforming a normal product into a 'smart device'. According to the IoT Information Value Loop, data is captured by sensors in IoT-enabled devices, enabling the creating of information from several variables such as temperature, location and user behaviour. This information is communicated and aggregated over a network, enabled by internet technologies, and is analysed at the edge or in a data centre to generate insights. These insights may be used to make decisions or communicated back to the devices for automated actions, helping business to increase the level of productivity and efficiency. Advanced communications technologies and massive storage capacities are requisites to IoT in order to connect billions of devices with large bandwidth and low latency as well as store the vast amount of data created by those devices (Refer to Chapter 2.1.1). Cloud computing becomes important, not only for its storage capabilities, but also for high computing power closer to the edge to process data quickly (Refer to Chapter 2.1.3).

2.1.2.3 Other Emerging Technologies enabled by Communications Technology

There is a wide range of new applications that are commonly discussed for future network evolution, from improved service provisioning and delivery such as OTT [d], 4K/8K, 3D/ 360 videos, to other emerging technologies such as Augmented and Virtual Reality (AR/VR), Artificial Intelligence (AI) and blockchain. Similar to 5G and IoT, emerging technologies are also largely enabled by digital information, requiring a high level of connectivity and data processing. The communications network will serve as a critical infrastructure for emerging technologies as they typically require higher bandwidth, greater capacity, security, and lower latency. In addition, Cloud Native solutions based technology ecosystem will be another key enabling infrastructure to provide an easy and affordable access to high computational power and to enable seamless data storage and sharing (Refer to Chapter 2.1.3)

AR and VR pose high connectivity requirements: high capacity, low latency, and uniform experience at a low cost [14]. This is necessary to ensure a fully immersive, high mobility, seamless experience to users. Given that 5G will be able to support higher capacity and lower latency, it is expected to be a key enabler for AR/VR and facilitate widespread adoption of the same. In fact, six 5G testbed projects were recently launched by the UK government as part of its Digital Strategy [15] with a total grant size of US$35 million in 2018, and 5G Smart Tourism is one of the six projects [15]. The focus is on delivering enhanced visual experiences for tourists using vision technologies, including AR/VR enabled by enhanced 5G network, in major attractions in Bath and Bristol, including the Roman Baths and Millennium Square. This goes to show how paramount 5G is to AR/VR.

AI refers to an intelligent machine that works like “human” and delivers tasks. AI systems are typically built using a database of knowledge, and requires high connectivity to process the data and run algorithms online. Advanced communications technologies such as 5G can transmit more data at higher speed. For example, 5G can deliver 10 gigabits of data per second, which is 10 times faster than LTE. “The ability to access additional information quicker through 5G networks will help AI-enabled devices understand their environment and the context in which they operate” said Bob Rogers, chief data scientist for analytics and AI in Intel’s Data Centre Group. [16] Advanced communications technologies can enhance AI-machines to be “smarter”. High computing and data storage are also crucial for the advancement of AI. Advanced AI is expected to increasingly intertwine with High-Performance Computing (HPC) in the future due to its requirement for increasing amount of data and level of precision performance required [17].

Blockchain is a type of a distributed ledger with data stored in an encrypted format. There are three key elements to blockchain infrastructure; which are communication, processing and storage. As blockchain is distributed across and managed by peer-to-peer networks, communications technology is necessary to establish communication. Increasing bandwidth with advancement of communications technologies have also enabled and improved seamless network connection. For processing and storage, hyperscale computing and storage network are also increasingly becoming important for seamless decentralised processing and data storage. For example, the global Bitcoin network was estimated to require a computing power of 64 exaFLOPS [e] in 2013, which is over 250 times [18] the

[d] Over-the-top (OTT) refers to the service (e.g. audio/video streaming) or application that is provided over the Internet and bypasses the traditional distribution providers such as telecommunication providers, Pay-Tv providers.
[e] 10^{18} floating point operations per second (FLOP - a measure of computer performance in terms of number of calculations per second).

combined speed of the top 500 supercomputers [f]. This can be enabled by a Cloud Native solutions based technology ecosystem (Refer to Chapter 2.1.3 for more details).

2.1.3 Communications Technologies are the Foundation of a Cloud Native Solutions based Technology Ecosystem

Services 4.0 is heavily dependent on emerging technologies. If access to technology is restricted, the impact of Services 4.0 cannot be realised. However, the current technology system with its monolith IT nature is not suited to accelerate emerging technologies. As such, a new technology ecosystem that is based on Cloud Native solutions needs to be introduced. The Cloud Native approach to building and running applications takes advantage of the cloud computing delivery model. (For a detailed discussion on monolithic systems and Cloud Native technologies, kindly refer to the Services and Digital Economy Technology Roadmap.)

Why cloud computing?

In a 2018 survey, 71% of enterprises plan to grow their public cloud spend by more than 20% [19]. 57% of enterprises already have a central cloud team or centre of excellence, of which 69% are focused on moving applications to cloud. The global move to cloud computing is evident.

Cloud computing will bring ample advantages to cloud businesses [20]:

1. **Rapid implementation**: Less time is required for an application to get up and running on cloud-based systems.
2. **Affordability**: Cloud's pay-per-use model and limited upfront capital investment lowers the barriers for smaller-sized and medium-sized businesses to adopt cloud applications.
3. **Agility**: Companies can quickly develop and deploy cloud applications to meet changing customer needs, which in turn enables greater innovation.
4. **Scalability**: Cloud provides a flexible platform which enable companies to scale up or scale down the cloud applications as required, without the hassle of managing infrastructure and manpower needs.
5. **Accessibility**: Cloud computing provides a high degree of abstraction, making it easy for businesses or developers to use without needing to understand the underlying technology.

The advantages of cloud computing extend to emerging technologies as well, whereby emerging technologies will be developed and deployed in a cloud environment. In addition to those already mentioned, cloud computing will offer easy and affordable access to high computational power, which is required by most emerging technologies. Overall, leveraging cloud computing, a Cloud Native technology ecosystem allows adoption of emerging technologies in a low-cost, rapid, agile, and scalable manner. This will democratise emerging technologies, ushering in a wave of emerging technologies and solutions for citizens and businesses, subsequently enabling the realisation of Services 4.0 in Singapore.

For cloud computing, communications technologies and in particular, backbone architecture technologies such as optical fibre and virtualised routers and switches (SDN solutions), data centres and submarine cables are key enablers. The wide range of cloud computing services, including storage, applications, processing power, and emerging technologies, are housed in and delivered via data centres. In 2017, Google, Amazon and Microsoft's cloud businesses helped more than double the spending on data centres [21]. Just recently, Google announced plans for their third data centre in Singapore to keep up with demand for their Google Cloud Platform [22]. As cloud computing services are not constrained geographically, submarine cables are important to allow international data transfer.

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[f] Supercomputers refer to High-Performance Computing (HPC) that functions at/around currently highest performance rate.

As shown, it is important for Singapore to invest in these technologies. Ensuring better connectivity by investing in these technologies is likely to make Singapore more attractive for more of the major players to build their hubs here. Therefore, this is likely to enable Singapore to gain a bigger share of the regional cloud computing market.

2.1.3.1 Data Centres

Data Centres (DCs) are one of the backbones of today's interconnected world as majority of internet activities are processed, stored and shared through data centres. Modern enterprises leverages on online services, that are hosted in DCs, which provides business productivity tools, business processes and continuity functions, such as online office suite, Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM). Digital services are similarly developed and delivered to the consumers and businesses through DCs, which hosted these services, such as e-Commerce, shared economy services (such as ride sharing, bicycles sharing, accommodation sharing), even entertainment such as music, movies and TV are all delivered from DCs.

With advancements in technology, more businesses are adopting data analytics, machine learning and IoT to collect, analyse and process data. Driven by Internet-of-Things, the total amount of data created by any device will reach 847 ZB per year by 2021, a significant increase from 218 ZB per year in 2016 [23]. In Chapter 2.1.2.2, we have explored how communications technologies is integral to IoT. Hence, IoT will have a significant impact on the demand for computing and storage resources that are hosted in DCs. Other emerging technologies, such as AR, VR, AI and blockchain will also drive the demand for DC and SC, and correspondingly the demand for future wired and wireless technologies. Please refer to Chapter 2.1.2.3 for an understanding of communications technologies as key enablers of these emerging technologies.

2.1.3.2 Submarine Cables

Submarine cables (SC) total bandwidth is expected to double every two years globally to meet the increasing flow of data. In 2017, there were new SC projects in every ocean including the Arctic with more than 70,000 kilometres of cables laid and 400 Tbps of design capacity [24]. Currently, nearly all planned SC projects would be equipped with 100G (100Gbps/ wavelength) technology. For example, the recently installed Australia Singapore Cable (ASC), a 4,600km cable connecting Perth, Australia and Singapore via Indonesia is Asia's first 40 Tbps (100G). The global submarine cables total potential capacity (lit and unlit) is estimated to reach 6,330 Tbps by 2022 [25], CAGR of 28% over the 2017 to 2022 forecast period. The Intra-Asia SC capacity is expected to reach 1,550 Tbps by 2022 [25], achieving a CAGR of 21% over the 2017 to 2022 forecast period.

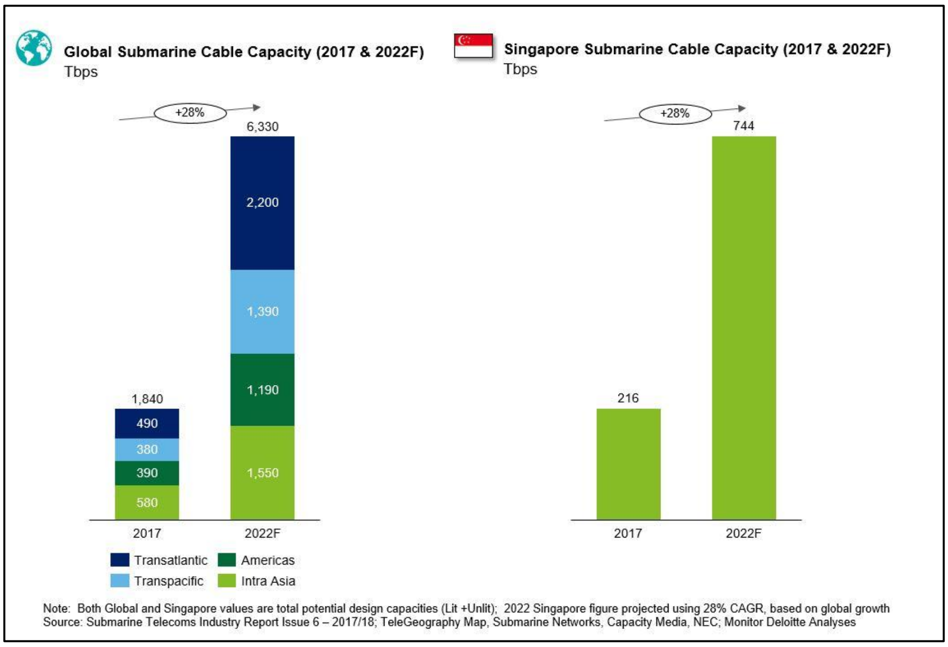


Exhibit 5: Global & Singapore Submarine Cable Capacity (Tbps)

Data Centres and Submarine Cables in Singapore

As shown in Exhibit 5, the total potential (lit and unlit) submarine cable capacity in Singapore in 2017 was 216 Tbps, and is poised to expand to 744 Tbps in 2022 [26]. Due to its strategic location, many international submarine cables land in Singapore, making it one of the top submarine cables hubs globally [27]. Since Singapore is connected to countries in every continent, it is an attractive destination for regional submarine cables built and thus making it the connectivity gateway to SEA region. Aside from the Australia Singapore Cable, Japan's NEC Corporation has recently signed an agreement to build a high-performance submarine cable connecting Singapore, Hong Kong, and the U.S. [28]. They are also building a cable for the Southeast Asia-Japan 2 consortium (SJC2), connecting Southeast and North Asia, with Singapore as one of the eleven landing stations [29].

The connectivity gateway status drives growth in data centres [30]. Singapore hosts 54% of the data centre capacities in SEA regions [31], and is the fourth largest internet data centre market in APAC [32] . Leading cloud providers such as Microsoft Azure and Amazon AWS have established their data centres in Singapore to serve the SEA region. Facebook is building their $1 billion first purpose-built data centre in Singapore.

Evidently, as a connectivity gateway and data centre hub, Singapore is in an advantageous position to push for a Cloud Native technology ecosystem. In addition, Singapore is known to be a business hub and entry point to the Asia Pacific market. In fact, Singapore's share of the global trade in digitally-delivered services almost doubled between 2005 and 2015, from 3.5% to 6.5% [33]. With its DC/ SC infrastructure and access to regional demand market, Singapore can attract ICM providers and developers to make Singapore their cloud computing hub for providing cloud computing solutions. It is then crucial for Singapore's DC and SC infrastructure to continue supporting its businesses, and the region's capacity needs.

In this chapter, we have discussed in detail how communication technologies, both wired and wireless provide a foundation to ubiquitous connectivity and Data Tsunami, emerging technology adoption and enable the offering of Cloud Native solutions. Thus, these technologies are integral to the creation of a Services 4.0 ecosystem.

These communications technologies have evolved significantly in the last two decades and are expected to continue to evolve further. Standards for several of these technologies like 5G are still being finalised. As these technologies evolve and find greater adoption, they are expected to transform the world as we know and enable a digital future. Thus, we will categorise all these communication technologies into an all-encompassing technology area – Future Communications. This technology area will encompass Network Infrastructure (Wireless, Fixed Access, Backbone and other network), Software and Services. In the next chapter, we will address the market potential of these technologies.

2.2 Future Communications Market Potential

In the last chapter, we discussed the potential of the communications technology to enable connectivity and data access and emerging technology adoption in detail. In this chapter, we will look at the market potential of these technologies classified under the Future Communications technology area that include - Network Infrastructure (Wireless, Fixed Access, Backbone and Other Network), Software and Services.

Under this chapter, there are two further sub chapters –

a) **Global and Regional Market potential**: that will provide an overview of the market size and growth of these technologies classified under Future Communications in 3 regions - Global, APAC and ASEAN and some of the key drivers that affect the growth of these technologies and

b) **Singapore Market potential:** that will provide an overview of the market size and growth of these technologies classified under Future Communications and some of the key drivers enabling this growth in Singapore.

2.2.1 Global and Regional Market Potential

In this chapter, we will explore the global and regional (APAC and ASEAN), the market size and growth of the various technologies classified under the Future Communications technology area along with some key drivers for each of the different technologies that have played a part in enabling this growth.

2.2.1.1 Market Size

In this chapter, the market size and growth of technologies classified under the Future Communications across the different elements – Network Infrastructure, Software and Services in the 3 different regions will be shared. Network Infrastructure will be further broken down into Wireless, Fixed Access, Backbone Arch and Other Networks.

Global Future Communications Market Size

The global Future Communications market size [g] is estimated to be US$188 billion in 2022 [34], achieving a CAGR of 3% over the 2017 to 2022 forecast period. Please refer to Exhibit 6 for more details.

[g] Future Communications market size is calculated as the spending on the different technology categories – Network Infrastructure (Wireless, Fixed Access, Backbone Architecture, and Other Network), Software and Services by CSPs.

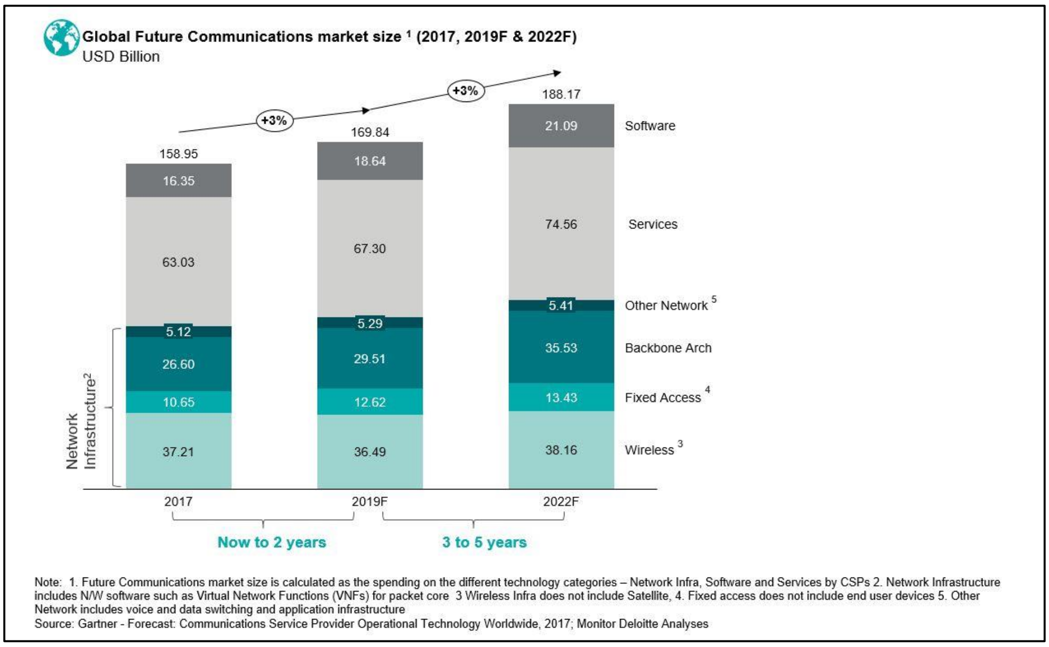


Exhibit 6: Estimated Global Future Communications Market Size

APAC Future Communications Market Size

The APAC [h] Future Communications market size is estimated to be US$67.7 billion in 2022 [34], achieving a CAGR of 3% over the 2017 to 2022 forecast period. Please refer to Exhibit 7 for more details.

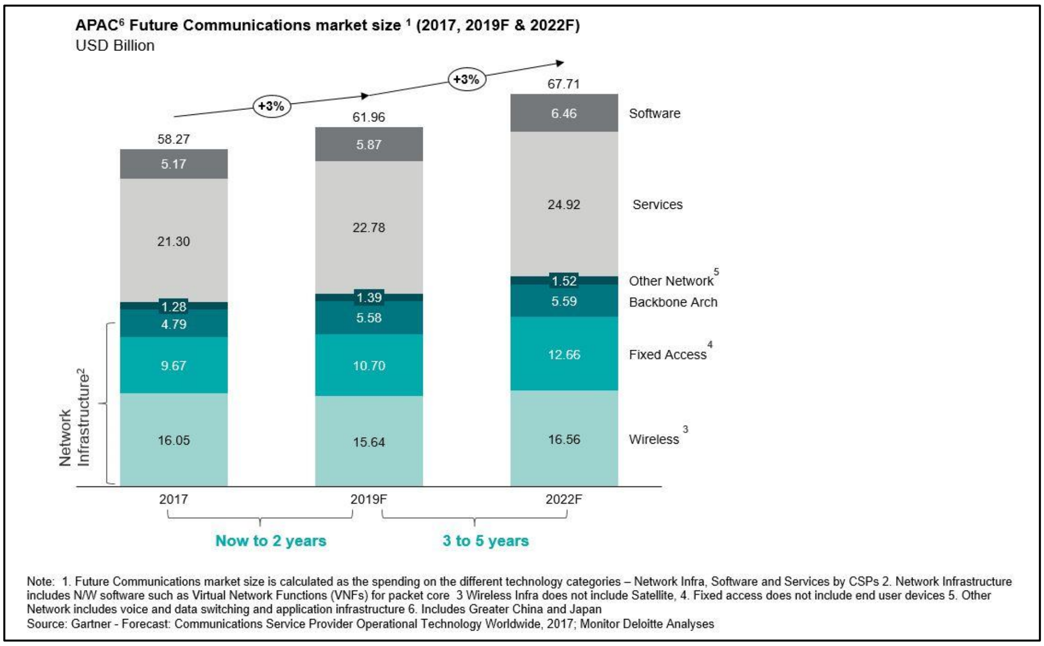


Exhibit 7: Estimated APAC Future Communications Market Size

h APAC also includes Greater China and Japan

ASEAN Future Communications Market Size

The ASEAN (includes all countries except Singapore) Future Communications market size is estimated to be US$7.19 billion in 2022 [34] [35] [36], achieving a CAGR of 1% over the 2017 to 2022 forecast period. Please refer to Exhibit 8 for more details.

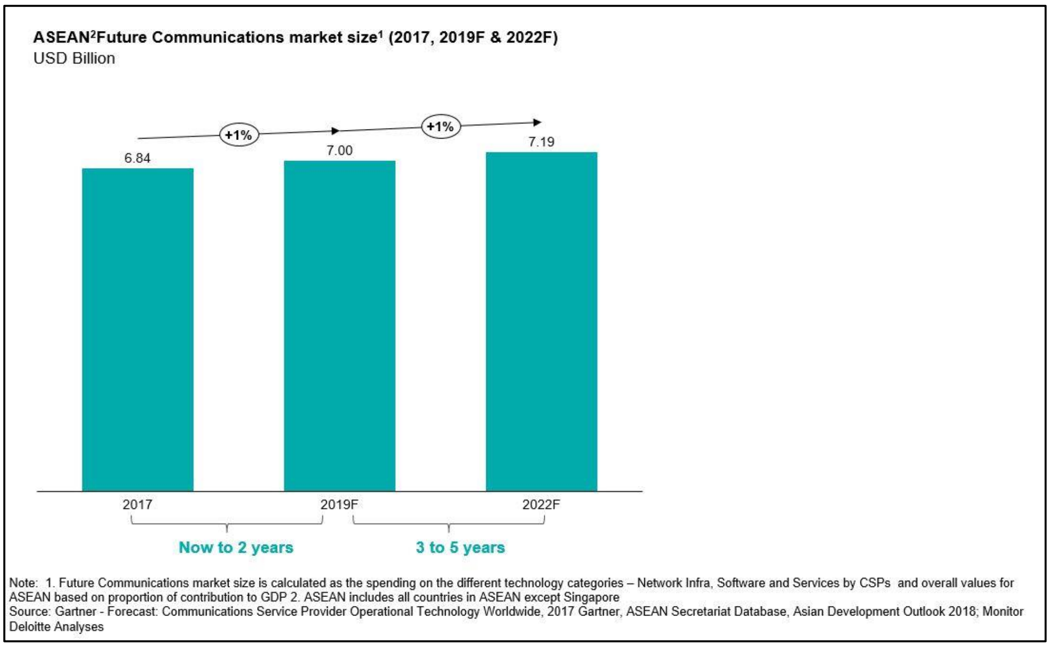


Exhibit 8: Estimated ASEAN Future Communications Market Size

2.2.1.2 Key Drivers of Growth

In this chapter, we will define the different elements across the network – Network Infrastructure, Software and Services and discuss the key drivers that affect these elements.

Network Infrastructure

Network infrastructure refers dedicated network components, which includes networking software, such as virtual network functions (VNFs) for packet core elements and other network components, but excludes operational software and services:

a) Wireless infrastructure (5G, Long Term Evolution (LTE)/4G, 3G, 2G, small cells (including Wi-Fi) and mobile core)

b) Fixed access (fibre, Digital Subscriber Line (DSL) and other broadband)

c) Backbone architecture (service provider routers and switches and optical transport)

d) Other network (encompassing voice and data switching, and application infrastructure)

Key Drivers

Market size and spending across different infrastructure elements have been driven by multiple factors such as the services expected to be supported, efficiency gains, etc. Thus, there are different drivers across the four types of infrastructure elements.

a) **Wireless infrastructure** market size has been declining from 2017 to 2019 due to the reduced spending on 2G and 3G Radio Access Networks (RANs) as operators considered upgrades to 4G and is expected to grow from 2019 to 2022 driven by network upgrades and investments in efficiency measures.

    i. Wireless network upgrades to be able to tap into new revenue opportunities have been and are expected to be key drivers for investments. Investments in 5G are already underway and are expected to grow given that it is a key enabler for different applications. However, globally, countries are in different stages of maturity with respect to 3G/4G adoption. Countries such as Japan, South Korea, and US have led the early migration to 4G, other developed countries in the Middle East and Eastern Europe are primarily on 3G while developing markets in Asia and Africa still operate primarily 2G networks [37]. This is likely to have significant impact on investments in 5G.

    ii. Cost and efficiency measures have also been and are expected to be key drivers for investments. Small cells are an inexpensive solution for filling coverage gaps, increasing capacity and enabling 5G. Thus, investments in small cells have been growing and are expected to grow further. Investments in Network Function Virtualisation (NFV) have increased and are expected to increase further due to the reduced CAPEX and OPEX and greater service offering scalability enabled. Operators in emerging markets such as India and Latin America - have been exploring mobile network infrastructure sharing deals (these nearly tripled between 2010 and 2015 [38]) to reduce investments in wireless infrastructure. Such deals are highly likely to proliferate with adoption of 5G [39] due to the number of small cells required to support the high frequency bands. Due to the high frequencies bands in 5G, coverage range will be small and thus, many small cells will be required and multiple providers are likely to collaborate for financial reasons.

b) **Fixed access** market size is growing from 2017 to 2019 and is expected to grow further to 2022 and beyond driven by investments in FTTx (deep fibre), fixed wireless for 4G and some G.fast deployments.

    i. There have been significant investments made in FTTx in many developed nations (e.g. UAE, Singapore, South Korea and China) and technology has driven the cost of offering FTTx down to a point where many consumers and enterprises are increasingly looking to opt for these service to increase penetration [40]. The penetration of FTTx is expected to grow further as demand for high speed broadband access grows. As wireless capacity demands increase under 4G/5G, it is an imperative for telecommunication providers to backfill their networks with FTTx solutions (e.g. fibre to the base station) in order to keep abreast of the wireless bandwidth demands.

    ii. Fixed wireless access has seen investments grow due to being the only viable alternative for rural access where there are limited opportunities for other fixed access technologies to be offered. This is expected to continue to grow further as this becomes another enabler for 5G (5G networks are expected to use a combination of fixed and wireless access).

    iii. DSL, while relevant globally, is not relevant to Singapore - Growth has been flat due to increasing global investments in FTTx. Limited adoption of G.fast [41] that enables leveraging existing copper infrastructure is expected to drive some growth.

c) **Backbone architecture** market size has grown from 2017 to 2019 and is expected to continue to grow to 2022 driven by significant investments in optical fibre backhaul and virtualised switches and routers.

   i. Optical fibre has increasingly become the backhaul of choice as technology continues to evolve to be able to support the exponential growth in bandwidth requirements. In order to be able to support 5G [42], larger capacity and higher speed optical fibre technologies such as Gigabit Passive Optical Network (GPON) deployments are currently being deployed and thus, investments in these and future optical fibre technologies are expected to grow.

   ii. Spending on hardware for virtualised switches and routers has grown and is expected to grow as operators gain significant CAPEX and flexibility advantages from standardised and virtual hardware such as white box and bright box routers and switches.

d) **Other network** market size has seen limited growth from 2017 to 2019. This is due to some investments in media gateways and decline in investments in voice and data switching as networks move towards a combined packet core in Long-term Evolution (LTE). Other network market size is expected to grow slightly to 2022 due to further investments in media gateways and Content Delivery Networks (CDNs) expected to support video and other immersive/interactive services such as AR/VR.

Software

Market size for Software is driven by spending on software related to managing customers, offering software products and services and that spent on networks. (This also includes spend for new licenses, updates and subscriptions, as well as technical support and software maintenance). These typically includes the following:

a) **Application software** encompasses business services implementation, such as customer care, products and revenue management (includes BSS systems); and

b) **Infrastructure software** includes software required to plan, provision, activate and manage resources, and to fulfil and assure their networks and services to their customers (includes OSSs/network management).

<u>Key Drivers</u>

Market size of infrastructure software has been driven by and is likely to continue to be driven by the spending on infrastructure upgrades from 2G, 3G towards 4G and 5G and towards advanced wired technologies. Also, infrastructure is increasingly becoming more centralised and controlled by software as evidenced by Software Defined Networking (SDN) [43] architectures are being piloted and deployed by operators globally.

Services

Market size for Services is driven by spending on the following:

a) **Infrastructure services** include services provided to telecom operators by businesses related to the operations of the underlying infrastructure and includes designing, building, operating and supporting networks such as network planning and design, network integration and testing, etc., and assure their networks and services to their customers includes workforce management and service management.

b) **Application services** include services provided to telecom operators by businesses related to designing, building and operating and supporting IT solutions, assets including data processing and hosting in data centres.

Key Drivers

Spending across services has been driven by both infrastructure and application services. In infrastructure services, network planning and optimisation has been the key driver as operators and solution providers upgrade their networks and try to optimise existing networks to be able to get maximum capacity and coverage. Within application services, Information Technology (IT) applications development and data centre hosting services have been and are expected to be key drivers as cloud computing based flexible consumption models and services become more widespread.

2.2.2 Singapore Market Potential

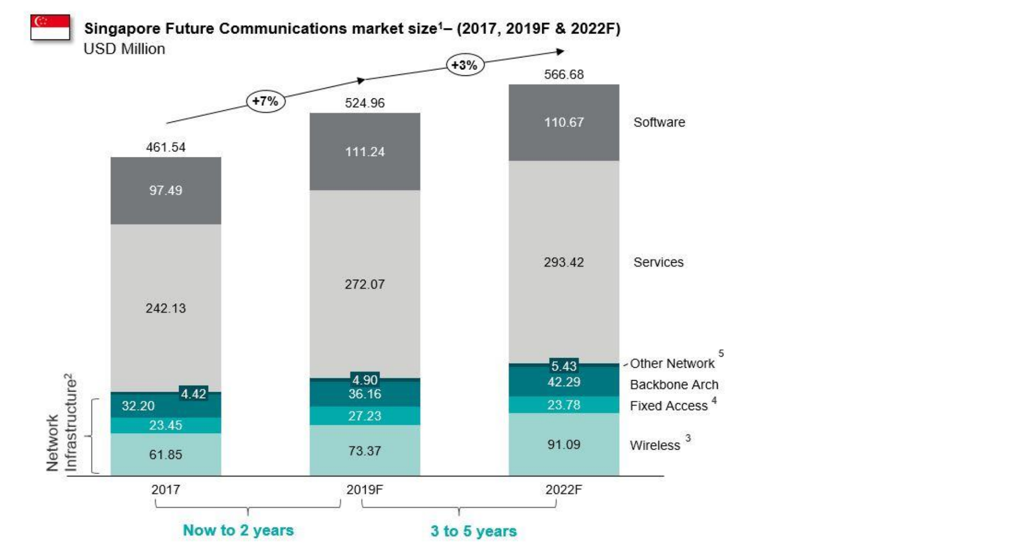
In this chapter, we will provide an overview of the market size and growth of the technologies classified under Future Communications in Singapore and some of the key drivers that affect the growth of these.

While the overall global Future Communications market size has grown by 3% [34] CAGR from 2017 to 2019, the equivalent value in Singapore has grown at 7% [34] CAGR from 2017 to 2019. This has been primarily due to the increased investments by the Singapore telecom operators across infrastructure (primarily 4G), services and software when compared to other operators globally.

However, the Future Communications market size in Singapore is expected to grow in line with the global growth – 3% CAGR [34] from 2019 to 2022. Given their advanced state, it is expected that Singapore telecom operators are likely to invest in 5G and other service and software in line with global operators.

2.2.2.1 Market Size

The Future Communications market size in Singapore is estimated to be US$567 million in 2022 [34], achieving a CAGR of 4% over the 2017 to 2022 forecast period. Please refer to Exhibit 9 for details of the size and growth across the different network elements.



Note: 1. Future Communications market size is calculated as the spending on the different technology categories – Network Infra, Software and Services by CSPs 2. Network Infrastructure includes N/W software such as Virtual Network Functions (VNFs) for packet core 2. Wireless Infra does not include Satellite, 3. Fixed access does not include end user devices 4. Other Network includes voice and data switching and application infrastructure
Source: Gartner - Forecast: Communications Service Provider Operational Technology Worldwide, 2017; Monitor Deloitte Analyses

Exhibit 9: Estimated Singapore Future Communications Market Size

2.2.2.2 Key Drivers of Growth

In this chapter, we will discuss the key drivers that affect the market size and growth for different network elements – Network Infrastructure (Wireless, Fixed Access, Backbone and Other network), Software and Services in Singapore.

Network Infrastructure

Market size and spending on different infrastructure elements have been driven by multiple factors such as the services that are to be supported and efficiency gains, etc. Thus, there are different drivers across the four types of infrastructure elements.

a) **Wireless infrastructure** - Spending has been increasing as operators in Singapore continue to invest significantly in 4G. This is expected to increase significantly driven by investments in 5G and Small cells.

   i. Since 2011, telecom operators in Singapore have been offering 4G services. They are all now looking to offer 5G solutions as pilots are underway – Singtel [44] with Ericsson and M1 with Huawei and Nokia. Thus, spending on 5G is likely to be the crucial driver in wireless infrastructure spending.

   ii. From 2017, all operators in Singapore have been adopting small cells as they view small cells as a less expensive option to spectrum to be able to boost capacity and coverage. This spending and investment is likely to grow further as 5G networks proliferate.

b) **Fixed access** spending has primarily driven by FTTH deployments in Singapore

   i. The government launched its Next Generation National Broadband Network (NGNBN) in 2009 and the rollout is now complete. Thus, operators have been taking significant strides towards investing in FTTH solutions. Singapore has thus very high FTTH and FTTB penetration of 90% [45] and is very unique in that the solutions offered to residential users has higher bandwidth than those to commercial users. With such high penetration in the home market and slower growth in the commercial market, this market is expected to become saturated and thus has declining growth.

c) **Backbone architecture spending** is expected to continue to grow driven by significant investments in optical fibre backhaul and virtualised switches and routers.

   i. As part of the deployment of FTTx and 4G upgrades, operators have invested in significant optical fibre backhaul and this is expected to grow further to support the Smart Nation initiatives and 5G demands.

   ii. Spending on hardware for virtualised switches and routers has also grown in Singapore as telecom operators such as Singtel [46] look to leverage both a reduction in CAPEX and OPEX cost for themselves and a revenue generating option of offering of these services to enterprises and Small Medium Enterprises (SMEs).

d) **Other network** has had limited growth leading up to 2019 but is expected to grow further as operators look to invest in media gateways and CDNs to support the growing demand for video. Singtel joined Ericsson's Unified Delivery Network [47] to leverage these capabilities.

Software

Most of the telecom operators in Singapore have already invested in and operate up-to-date Operations Support System (OSS) and Business Support System (BSS) and significant investments made in cloud and service delivery platforms. There is expected to be limited growth in investments in these areas.

Services

Spending across services in Singapore has been primarily driven by infrastructure and application services. In infrastructure services, network planning and optimisation has been the key driver as operators both upgrade their networks and try to optimise existing networks to be able to get maximum capacity and coverage. In Singapore, investments in 4G and impending investments in 5G are expected to drive this further. According to BCG [48], existing 4G networks are forecast to reach capacity by 2021 and will necessarily rely on 5G technology to provide the additional capacity required in a cost effective manner. As Over-the-Top (OTT) players drive down traditional revenue, telecommunication providers have invested in infrastructure services such as network optimisation in order to be able to offer superior customer service with existing assets and provide a differentiated offering. With regard to application services, increased investments in Information and Communication Technologies (ICT), managed services and cloud services to offer these services for enterprise use have been and will continue to be key drivers for further growth. A Cloud Native Architecture is envisioned in order to realise Singapore's ambition to become a Hub for Services 4.0. Thus, this is expected to drive further spending in this space.

2.3 IoT Market Potential

As we have seen earlier, IoT is intrinsically intertwined with communication technology, as communication is an integral part of its information value loop that enables significant value creation. Among the emerging technologies, IoT is expected to generate significant value for both consumers and enterprises across several sectors enabled through Communication technology and primarily 5G.

In this chapter, we will look at the market potential of IoT. Under this chapter, there are two further sub chapters –

a) **Global and Regional Market potential:** that will provide an overview of the market size and growth of IoT in 3 regions - Global, APAC and ASEAN, some key drivers that affect the growth of IoT and some key sectors across the 3 regions where IoT has seen adoption.

b) **Singapore Market potential:** will provide an overview of the market size and growth of IoT in Singapore, some key drivers and sectors that affect the growth of IoT elements.

2.3.1 Global and Regional Market Potential

In this and the next chapter, we are going to present the global and regional (both APAC and ASEAN) market potential of IoT including estimated market sizes, key enablers for IoT adoption and some relevant sectors in which IoT has seen significant uptake.

2.3.1.1 Market Size & Growth

Global IoT market size

The Global IoT market size [i] is estimated to be US$1.5 trillion in 2022 [49], achieving a CAGR of 19% over the 2017 to 2022 forecast period. Please refer to Exhibit 10 for more details.

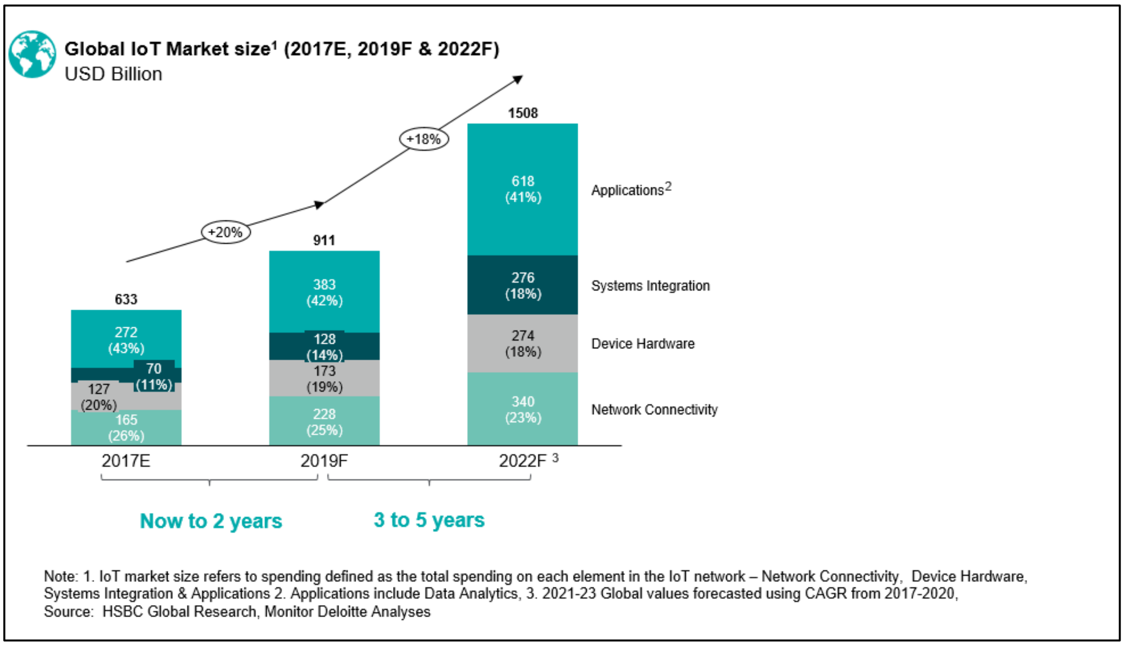


Exhibit 10: Estimated Global Market IoT Market Size

APAC IoT Market Size

Across all regions, APAC has the highest expected IoT market size in 2018 at US$312 billion [50] and is expected to continue to be the largest region with spend growing to US$516 billion in 2022, achieving a CAGR of 13% [50] over the 2018 to 2022 forecast period. China was the largest market in the world for IoT in 2018. Please refer to Exhibit 11 for more details on how APAC and China market size compare with other regions in 2018.

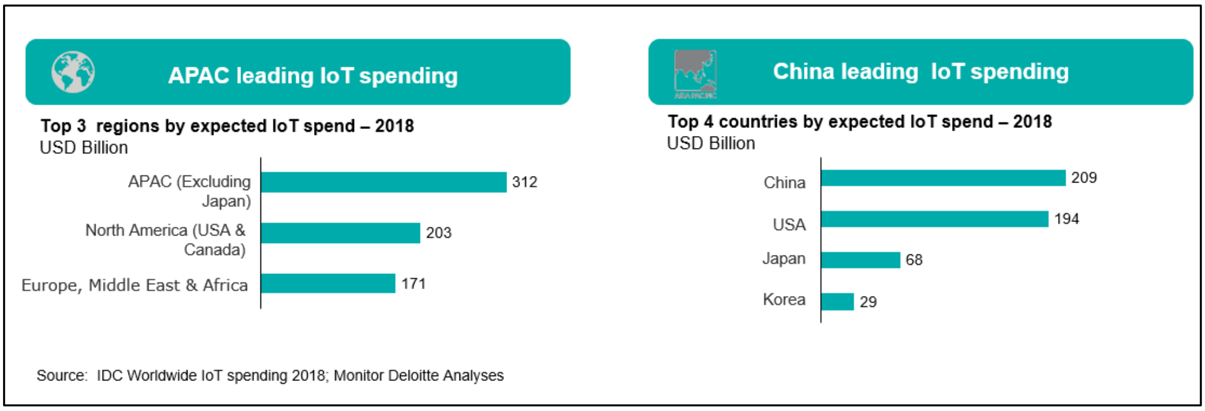


Exhibit 11: Top 3 regions and Top 4 countries by expected IoT spend in 2018

[i] Global IoT Market size defined as the total revenue generated from or end user spending on each element in the IOT network – Network Connectivity, Device Hardware, Systems Integration and Applications.

ASEAN IoT Market Size

Overall IoT adoption in ASEAN is expected to grow further as Governments continue their efforts to drive Smart Cities in the region and Industry 4.0 efforts proliferate. The overall market size for IoT for in ASEAN (all countries except Singapore) is expected to be US$4.6 billion [j] [35] [36] [51] in 2020 growing from a very small base of US$280 million in 2014. Please refer to Exhibit 12 more details on the expected IoT spending by the top 4 countries in ASEAN (excluding Singapore) in 2020.

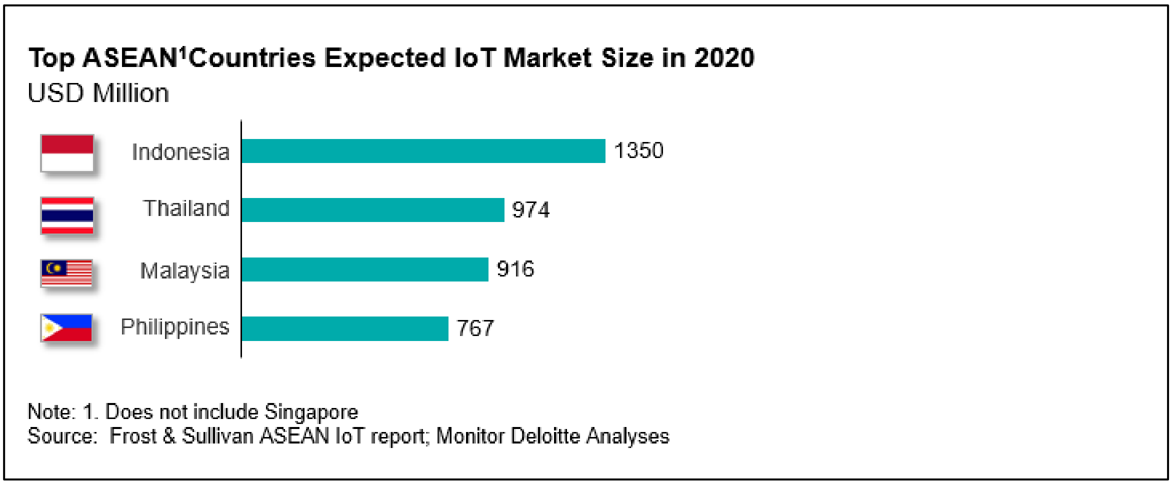


Exhibit 12: ASEAN Expected IOT Market size

2.3.1.2 Key Drivers of Growth Across the Different IoT Elements

In this chapter, we will discuss the key factors that play a part in driving growth across the different elements on the IoT network.

System Integration

This refers to the middleware that connects hardware and application layers and integrates different proprietary systems with one another and with other open systems.

Key Drivers

These are becoming increasingly standardised as pre-integrated solutions are being launched in the market as platforms. As platforms proliferate, many of the large players in the ecosystem have been looking to capture more value by launching platforms with "*horizontal capabilities*" supporting more functions across multiple layers – both network and application layers. In addition, smaller niche players are now launching platforms that are sectors specific with a view to differentiate themselves and compete with the broader platforms. Thus, the proliferation of both sectors specific and industry agnostic platforms are expected to drive further growth in systems integration.

Devices and Hardware

This refers to the components used in machines and devices such as sensors and circuits to collect information.

[j] ASEAN IoT market size estimated using proportion of GDP contribution of the top 4 countries excluding Singapore to IoT Spending

Key Drivers

The diminishing size and cost of sensors and devices and the increasing power efficiency are expected to be key drivers to the expected exponential growth of the number of endpoints or devices for IoT. On the other hand, the need for mission critical decision-making, enhanced security and reduction in bandwidth on the networks, *devices at the "edge"* – (either end devices or gateways) are becoming increasingly more *intelligent* with more computing power and functionality to be able to do more "analytics at the edge". Thus, spending on both devices and hardware are expected to continue to grow.

Network Connectivity

This refer to existing networking and emerging technologies and standards that enable connectivity among different IoT devices.

Key Drivers

Today, several networking technologies are currently being explored for use in IoT networks. As most networks, some key distinguishing characteristics include the following:

a) Medium – Wireless or Wired
b) Range – Personal Area Network, Local Area Network, Metropolitan Area Network, Wide Area Network
c) Power efficiency – Power efficient (Low power) vs Regular conventional power consumption
d) Speed/Data rate supported
e) Reliability
f) Latency
g) Ability to support mobility

Investments in networks that will exhibit the characteristics to address the specific needs of IoT networks are ongoing and are likely to enable greater IoT adoption. For IoT networks range, power efficiency and latency are critical factors. Existing and new network standards are being developed to enable greater interoperability. Increasingly, network providers are also working on developing highly power efficient networks such as Bluetooth Low energy for PAN, NB-IoT and LTE-M for cellular LPWAN and Sigfox, LORA for non-cellular LPWAN. 5G is expected to be a key enabler for cellular for IoT addressing low latency and mobility needs.

Investments in network connectivity are expected to continue to grow as telecom operators and other network providers look to invest in 5G, NB-IoT and other technologies in order to meet the specific needs of IoT networks. Thus, these technologies are critical enablers to being able to offer IoT solutions.

Applications

This include a broad range of software solutions and services including data, visualisation, security and analytics that can be enabled by using IoT networks.

Key Drivers

Driven by the growth in advanced data analytics tools and the increased value generated, *AI/Machine learning solutions* are increasingly becoming coupled with IoT. Given the challenge of data privacy and potential threat to security on IoT networks, *security solutions* are being launched. In addition, IoT platforms are increasingly offering more applications to become truly end-to-end platforms. These rising applications are expected to drive growth and contribute to large IoT market spending.

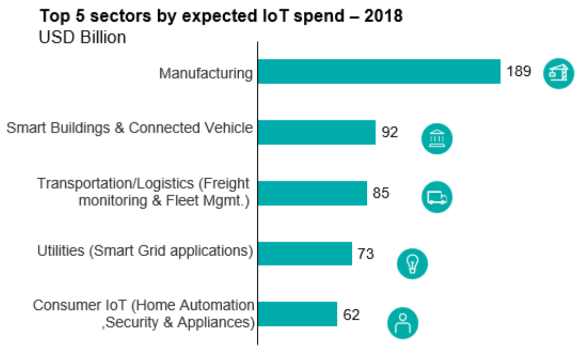
2.3.1.3 Sector View

Global Sector View

There have been traditionally two types of IoT applications – Industrial IoT and Consumer IoT.

Historically, global spending on the Internet-of-Things has been driven by the industrial sectors such as Manufacturing, Transportation and Logistics and Utilities [50] but increasingly IoT applications in sectors such as Home Automation, Security and Appliances (Consumer IoT), Insurance, and Healthcare are expected to grow faster [50]. Please refer to Exhibit 13 for more details.

Global market



Top 5 fastest growing sectors based on expected spend growth from 2017-22F

No.	Sector	CAGR (2017-22F)
1	Consumer IoT	19%
2	Insurance	17.5%
3	Healthcare	16.9%
4	Govt. spending (Smart Buildings & Connected Vehicles)	16.1%
5	Others	13%

Source: IDC Worldwide IoT spending 2018; Monitor Deloitte Analyses

Exhibit 13: Top 5 sectors by expected Global IoT spend in 2018 & Top 5 sectors by growth in expected spend

IoT in Manufacturing

Manufacturing is the largest sector by global expected spend – US$189 billion in 2018. IoT in manufacturing has been primarily driven by *Industry 4.0* to digitise and optimise manufacturing processes. Thus, the leading use of IoT in manufacturing [52] has primarily been used for operations (asset and process optimisation), production asset management (asset tracking), condition based monitoring and predictive maintenance.

IoT in Logistics and Supply Chain

On the industrial side, freight monitoring is the key application for IoT in logistics with almost two of thirds of all logistics spending and is expected to continue to be a key driver of IoT spend. Fleet management accounts for the remaining spend. IoT is expected to be a key enabler for Logistics 4.0 [53], the next generation of supply chain systems, especially with the use of "digital twins".

Digital twins in supply chains enables creating a mirror of processes and information in a business resulting in obtaining a view the business end-to-end processes [54], finding bottlenecks and improving performance. Digital twins enable improved asset tracking and provide enhanced real time insights into existing and projected inventory [55] to plan to meet changing customer demands.

Blockchain and IoT are also increasingly being tested in supply chains. When used with IoT, blockchain is expected to enable different stakeholders [56] in the supply chain to ensure traceability and reduce risk. Sharing a unique block chain across the entire supply chain will ensure that goods in the value chain are authenticated, thus preventing potential fraud.

IoT in Utilities

The use of IoT in utilities is driven by the investments in smart grid applications for gas, electricity and water. However, in some countries such as Germany, Energy 4.0 is a key national agenda for the Government. Thus, this revised Energy 4.0 agenda is expected to drive increased use of IoT in the utilities sector.

IoT in Smart buildings

This includes the IoT spending on smart infrastructure that will be applicable across sectors. Smart buildings include building automation, energy management, HVAC (Heating, ventilation and air conditioning), predictive maintenance (e.g. lifts monitoring), typically used in commercial applications in buildings. This also includes the public and private sectors funding on airport facilities automation, electric vehicle charging, and in-store contextual marketing (most likely to be used in the retail industry).

IoT in Connected Vehicles

Telematics is seeing adoption in Connected Vehicles for enabling the capture and sharing of key parameters and data. Going forward, telematics is expected to be fundamental to building Connected Vehicle solutions to be able to enhance user experience, capture insights and thus help unlock value.

Consumer IoT

Refers to the IoT spending on by the consumer within his home and including the Smart Home, security solutions and smart appliances. These typically consist of Home security alarm systems, Home monitoring, Health and Wellness Management, Home Automation and energy management systems. This category is expected to experience the highest growth of 19% CAGR from 2017. (Exhibit 14)

IoT in Services Industries such as Healthcare and Insurance

Previously, IoT has seen significant adoption in industrial applications with several benefits as described above. Similar benefits are now being captured by the adoption of IoT in service industries such as healthcare and insurance. Adoption of IoT in services has led to new business models, new services, enhancements, and greater efficiency. IoT in healthcare is typically used in telemedicine [57], clinical operations, medication management, connected imaging, inpatient monitoring and other applications. Key benefits of IoT in healthcare includes enhanced patient care, reduced costs, reduction in errors, improved patient experience, and improved patient outcomes along with better disease management. Driven by the need to reduce the rising cost of healthcare, an aging population around the world and the increasing use of security solutions (addressing key concerns of data privacy and regulation) in IoT, IoT in healthcare is expected to grow at 16% CAGR from 2017 to 2022 from a base of 110M [58] in 2017. Connected biometrics and wearables help health insurers track patient adherence to lifestyle and medical recommendations. Insurers, both globally and in Singapore, have adopted to offer “usage based” auto insurance to drivers [59].

APAC Sector View

Increased urbanisation leading to a greater focus for building Smart City infrastructure, greater penetration of next-gen industrial automation, focus on Industry 4.0 and significant investments in enabling digital infrastructure have been key drivers for the growth in APAC IOT. China will be the country with the largest IoT spending total in 2018 of US$209 billion [50] , driven by investments from manufacturing, utilities, and government. IoT spending in the U.S. will total US$194 billion in 2018 [50], led by manufacturing, transportation, and the consumer segment. Japan with US$68 billion and Korea US$29 billion are expected to be the third and fourth largest countries in 2018 [50], with IoT spending largely driven by the manufacturing industry. Please refer to Exhibit 14 for more details.

In Asia Pacific (excluding Japan), it is expected that manufacturing, transportation and utilities will continue to be significant as part of expected spend while Consumer IoT is also expected to a large part – all contributing to ~60% of expected spend in 2022. Please refer to Exhibit 14 for more details.

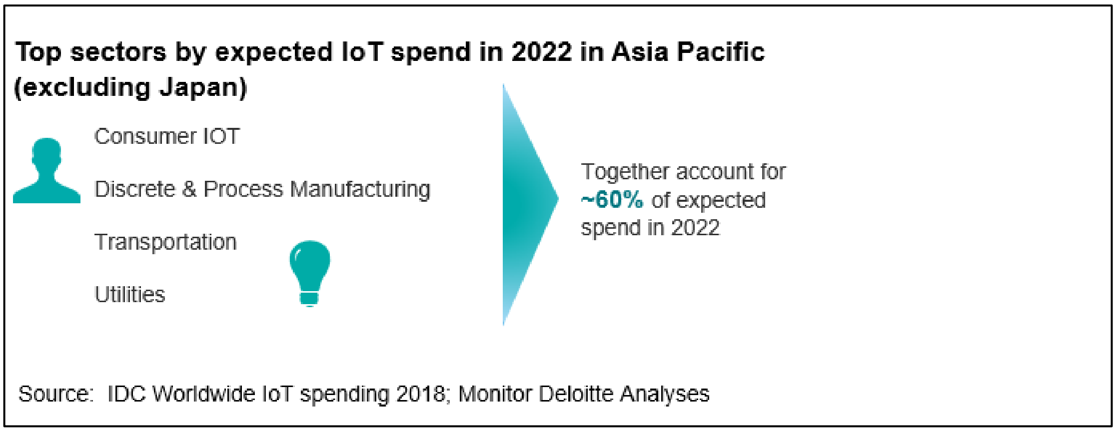


Exhibit 14: Top sectors in Asia Pacific (excluding Japan) in 2022

ASEAN Sector View

In ASEAN, countries are in different stages of IoT adoption. Some of the key private sectors include both industrial sectors such as manufacturing, logistics and energy as well as service sectors such as financial services, retail and healthcare. Smart Cities and other Smart initiatives by Governments are key drivers across ASEAN countries. Please refer to Exhibit 19 in Chapter 3.3.2 for more details of IoT use cases in different sectors across ASEAN.

2.3.2 Singapore Market Potential

The following chapters provides more details on Singapore IoT market size and outlines the specific drivers and actions by key stakeholders that have fuelled the growth of this market.

The IoT market size in Singapore market grew in line with the global market for IoT from 2017 to 2019 at 20% [60]. However, it is expected that the IoT market size in Singapore will grow faster at 20% [60] from 2019 to 2022, while the global market for IoT is expected to grow at 18% [49] in the same time. This is primarily expected due to the Smart Nation initiatives driven by the Government and the current Industry 4.0 drive in manufacturing and logistics sectors.

2.3.2.1 Market Size

The Singapore IoT market size [k] is estimated to be US$1.1 billion in 2022 [60], achieving a CAGR of 20% over the 2017 to 2022 forecast period. Please refer to Exhibit 15 for more details on this size and growth.

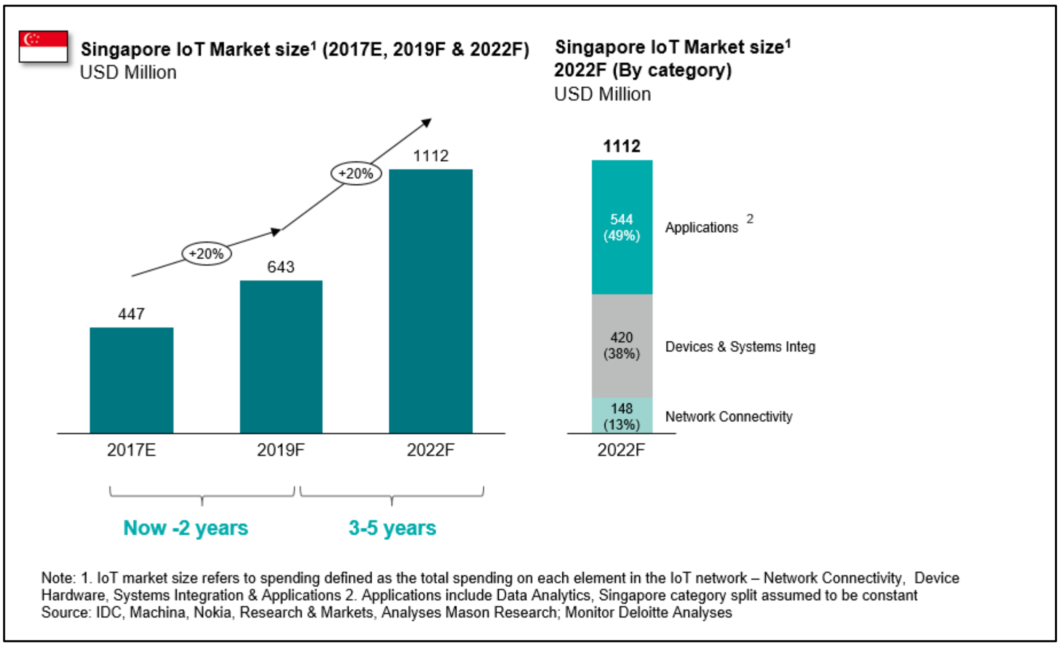


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Exhibit 15: Estimated IoT Market size for Singapore

2.3.2.2 Key Drivers and Sectors

Industry 4.0 has been a key enabler for significant investments in the manufacturing sector to drive technology adoption. There is strong focus on integration of sensors with machines and products to improve customer service, optimise asset utilisation and conduct predictive maintenance. According to IDC, Singapore leads the APeJ (Asia Pacific excluding Japan) nations in IoT readiness in the manufacturing sector due to factors such as Singapore's ease of doing business, cloud infrastructure, investment in IT and IoT, labour force productivity and use of robotics and automation in manufacturing processes.

The Smart Nation thrust by the Government has also been a key driver in driving adoption of IoT as the Government has been increasingly looking to launch initiatives that incorporate IoT as part of its strategy to digitise and enhance its public services [61]. In 2017, the Government Technology Agency (GovTech) announced the development of nationwide sensor network called the Smart Nation Sensor Platform that will include common infrastructure and services such as a data sharing gateway, as well as video and data analytics capabilities. GovTech is also expected to work with Land Transport Authority (LTA) to incorporate more IoT solutions.

Infrastructure - Singapore has significantly invested in fibre across the nation. Investments in low power networks specially geared to support IoT solutions such as the launch of the NB-IoT and Sigfox networks in Singapore is likely to play a large part in driving IoT adoption in Singapore. Mobile operators are also making investments in 5G solutions that are expected to be a key enabler for IoT applications.

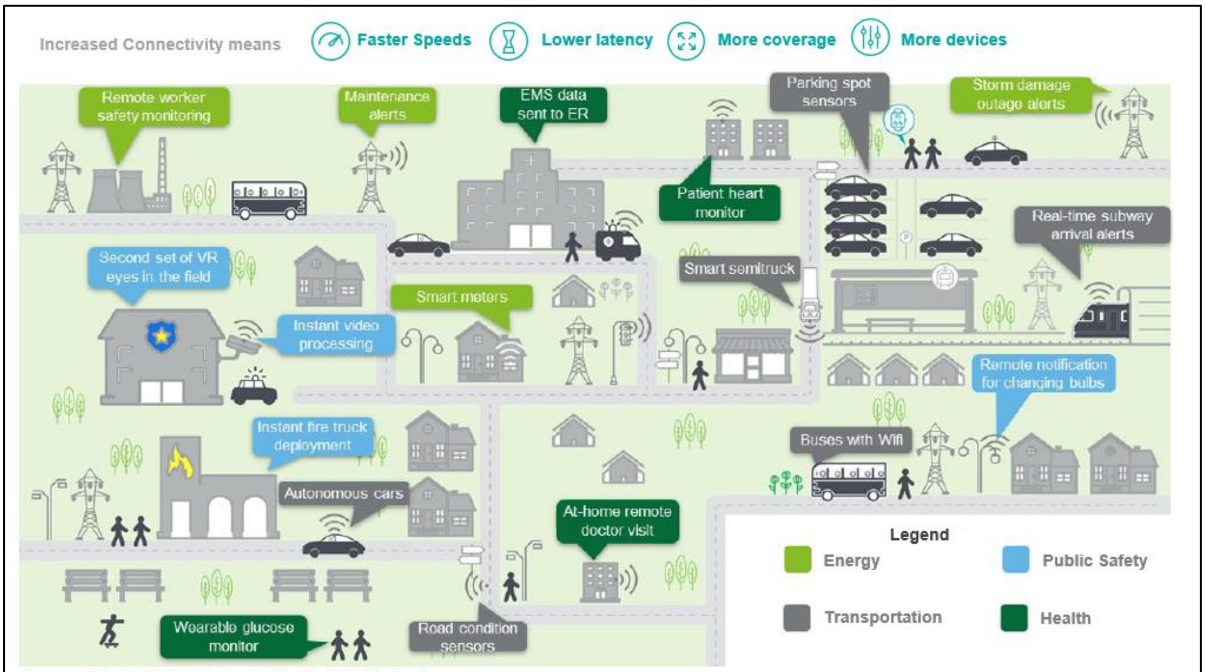
[k] Singapore IoT Market size defined as the total revenue generated from or end user spending on each element in the IoT network – Network Connectivity, Device Hardware, Systems Integration and Applications in Singapore.

2.4 Market Study Conclusion

Future of Communications enabling the Ecosystem of Connectivity

We have seen earlier how communications technologies under the Future of Communications are the foundation of ubiquitous connectivity and Data Tsunami, emerging technologies adoption and enabling the offering of Cloud Native solutions. Increasing connectivity and mobility have been transformational change agents by fuelling significant economic growth and innovation. By providing access to high-speed networks and enabling ambient connectivity across devices, people and businesses, these technologies have enabled the transformation of enterprises into digital businesses and the creation of value by facilitating new business models and new products and solutions.

With the key enablers of faster speeds, lower latency, more coverage and more devices support offered, 5G is expected to be the key catalyst in the "Eco-system of Connectivity". This 5G-enabled "Ecosystem of Connectivity" encompasses government and cities, consumers, objects and industries, etc., meeting all their needs and providing new avenues for revenue growth and innovation. This will lead to extensive economic development and job growth. Innovation enabled through seamless connectivity facilitated by 5G is likely to further overhaul economic and business policies and blur geographical and cultural borders. For example, several European countries have set up joint cross border 5G corridors that will enable testing of connected and automated mobility solutions and driverless vehicles [62]. Thus with 5G, there has been a key evolution from "just another wireless network" to a robust ecosystem that is expected to enable increased connectivity to drive innovation (Exhibit 16)



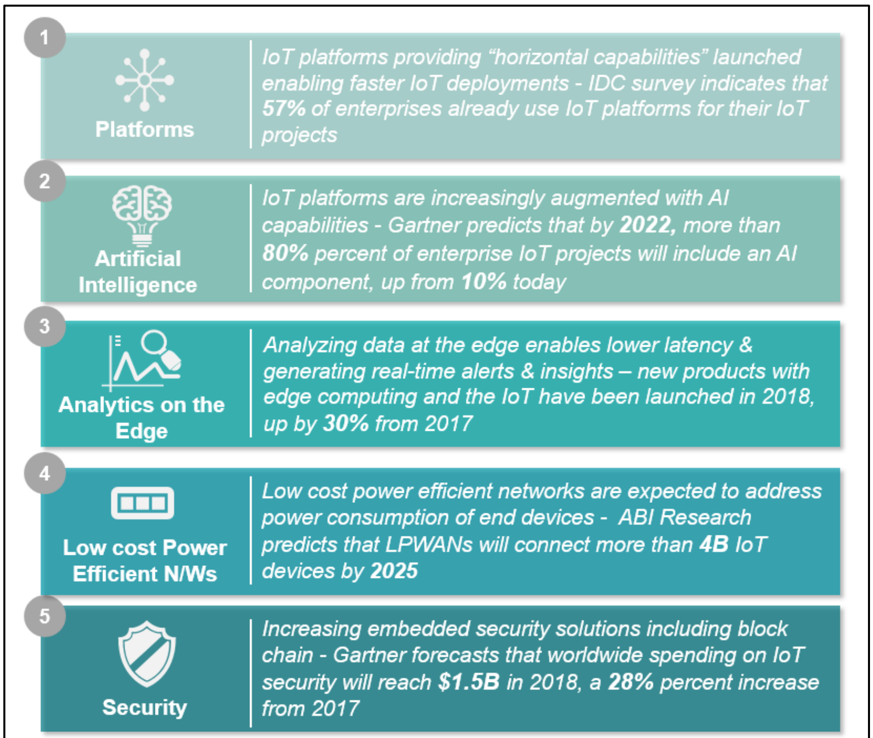
Source: Deloitte University Press; Monitor Deloitte Analyses

Exhibit 16: 5G & the Eco-system of Connectivity

Future Communications technologies are also key enablers for adoption of emerging technologies such as IoT, AR/VR, AI and blockchain. These emerging technologies place significant demands on the network and thus the benefits enabled through 5G are expected to facilitate access and enhance the value created by technologies. Among the emerging technologies, IoT is crucial to being able to enable this "Ecosystem of Connectivity" as it is intrinsically linked to communications technology. Thus, it will be important to understand what might be some key accelerators that will drive IoT adoption.

5 vectors for IoT

5 vectors [63] have been identified as critical factors that will accelerate the adoption of IoT and thus enable greater value creation in this “Ecosystem of Connectivity” enabled through 5G. Increasingly Platformisation, convergence of AI and blockchain and the proliferation of lower power networks and smart devices specially designed to meet the needs of IoT are among the key vectors identified. These have been described further in this chapter (Exhibit 17).



Source: Deloitte University Press, IDC, ABI Research, Gartner, Quid Inc; Monitor Deloitte Analyses

Exhibit 17: 5 Vectors driving adoption of IoT

a) **Proliferation of Platforms**: There is increasing proliferation of platforms as both large and small players are launching solutions that make it easier to integrate IoT hardware, networks, and applications. A survey from IDC indicates that 57% of enterprise use IoT platforms. However, this has led to multiple heterogeneous platforms that are not all interoperable. Efforts are being made to improve platform interoperability by projects such as the IoT European Platforms Initiative (IoT-EPI) [64].

b) **Artificial Intelligence:** Predictive analytics capabilities that derive insights and predict future outcomes though machine learning solutions are increasingly becoming a key to unlock greater value from IoT networks. Thus, there is increasing convergence of AI and IoT across sectors. This is also expected to have a positive network effect, driving further adoption of IoT.

c) **Analytics at the Edge:** For many applications of IoT, latency is critical and the processing time for information in the cloud and response time is too long to be meaningful. In addition, there are significant security concerns across sectors. Thus, the devices at the edge of the networks [65] (either end devices or IoT gateways) are increasingly becoming more intelligent with higher computing power and AI capabilities to do more “analytics at the edge”. This is expected to address specific industry needs.

d) **Lower Power Networks:** Most existing wireless networks typically have high power requirements for devices to transmit and receive data. This has been a key challenge for IoT networks, given the scale and the low cost nature of devices. There has been an inherent trade-off between range and power efficiency. This led to the development of network standards with lower power requirements specifically geared towards IoT networks, such as NB-IoT and Bluetooth Low Energy. With increasing standardisation and wide usage, more devices are likely to be built on these network standards, enabling greater scalability and positive network effects.

e) **Security:** Security has been one of the key barriers to the use of IoT networks. This is particularly in sectors like Healthcare, and Consumer applications [66], where privacy concerns are paramount [67]. A survey by Deloitte on Connected Home Devices indicated that more than 40% [68] of consumers were concerned about devices tracking their usage and other privacy concerns. Security solutions tailored for IoT networks are increasingly being deployed and embedded in the underlying hardware. Hence, alleviating security concerns is one of the most important drivers in both consumer and industrial IoT applications.

Future Communications and IoT are thus key foundational technologies for Services 4.0.

This “Ecosystem of connectivity” enabled through 5G will facilitate access to emerging technologies leading to enhanced innovation and value creation. The increasing convergence of emerging technologies and solutions is expected to further fuel this innovation and value creation through network effects.

We have seen that Future Communications technologies are key enablers for creating a Cloud Native technology ecosystem that leverages cloud computing.

In Services 4.0, significant value creation comes from the use of emerging technologies offered as part of the Cloud Native technology ecosystem will be key to unlocking value from data generated and captured. Future Communication technologies and IoT are expected to be central to the Physical and Digital Infrastructure required as a foundation to the Digital Economy Framework to support and enable Singapore’s vision of becoming the hub for Services 4.0.

3 TECHNOLOGY STUDY

3.1 Technology Adoption Readiness Map for Future Communications

The technology adoption readiness map intends to inform the stakeholders on which technologies are expected to become mainstream in the coming years globally. A consistent time frame has been used in the narrative across three buckets – now to 2 years (short-term), 3 to 5 years (mid-term) and beyond 5 years (long-term). Broadly,

- Technologies included in the now to 2 years timeframe are already or expected to be viable for adoption by majority of the industry players in the now to 2 years (short-term);
- Technologies included in the 3 to 5 years timeframe have shown evidence of promising use cases, is being provided and afforded by a handful of companies but still not viable for mass adoption; they are expected to be viable in the next 3 to 5 years (mid-term);
- Technologies included in the beyond 5 years timeframe are mostly in the R&D stage and remains unviable to the industry players; they are expected to be viable sometime beyond 5 years (long-term).

There are 5 broad technology areas identified for Future Communications that will be used as key categories to develop the technology readiness map. They are:

a) **Speed (Wireless):** High bitrate information delivery over a wireless air medium.

b) **Speed (Wired):** High bitrate information delivery over a wired medium.

c) **Latency (Wireless):** Low communication delay for data to get from one designated point to another over a wireless air medium.

d) **Low Packet Loss (Wireless):** High reliability of the network to be able to transfer information with limited loss over a wireless air medium.

e) **Power Efficiency (Wireless):** Low power consumption information delivery over a wireless air medium.

The following table reflects the industry's view of the likely evolution and mainstream adoption of Future Communications technologies.

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
SPEED (WIRELESS)		
MOBILITY • LTE Advanced/ Advanced Pro • LTE Enhanced License Assisted Access (eLAA) • LTE-WLAN Aggregation (LWA) • LTE WLAN Radio Level Integration with IPsec Tunnel (LWIP) • 5G eMBB (NSA) **NON-MOBILITY** • Fixed Wireless Access • 802.11ac Wave 1/ 2 (Wi-Fi 5) • Bluetooth 4.2/5 Basic Rate/ Enhanced Data Rate (BR/EDR) • 802.11ax (Wi-Fi 6) • 802.11 ad	**MOBILITY** • 5G eMBB (SA) NON-MOBILITY • 802.11 ay	**MOBILITY** • 5G eMBB enhancements NON-MOBILITY • Li-Fi
SPEED (WIRED)		
FTTx • G-PON • XG-PON (10G-PON) • XGS-PON • NG-PON2 (4 wavelengths) **TRANSMISSION** • 400G/ 800G WDM • 10/40/100 Gigabit Ethernet	**FTTx** • NG-PON2 (8 wavelengths) • 25G PON • DWDM **TRANSMISSION** • Multi-Terabit WDM	**FTTx** • 50G PON • NG-PON2+ (TWDM-PON, OFDM-PON) • XG(S)-PON+ **TRANSMISSION** • Optical OFDM (OFDM for optical) • 100G PON (100Gbps downstream) • WDM PON (Dedicated wavelength per user) • 200/400 Gb/s electrical interfaces
LATENCY (WIRELESS)		

• LTE Mission Critical (MC) services • Dedicated Short Range Communications (DSRC)	• LTE-V2X/C-V2X • 5G uRLLC	• 5G uRLLC enhancements
POWER EFFICIENCY (WIRELESS)		
WIDE AREA • LTE-M/ eMTC (Cat M1) • NB-IoT (Cat NB1) • LoRaWAN • Sigfox **SHORT RANGE** • Bluetooth 4.2/ 5 Low Energy (LE) • Z-Wave • Zigbee • Near field communication (NFC) **Low-power Wi-Fi**	**WIDE AREA** • LTE-M/eMTC (Cat M2) • NB-IoT (Cat NB2)	**WIDE AREA** • 5G mMTC
LOW PACKET LOSS (WIRELESS)		
	• 5G uRLLC	• 5G uRLLC enhancements

Table 1: Technology Adoption Readiness Map for Future Communications

3.2 Technology Adoption Readiness Map for Internet-of-Things (IoT)

There are 4 broad technology areas identified for IoT that will be used as key categories to develop the technology readiness map. These are capabilities that customers may demand or service providers could offer for IoT. They are:

a) **Platformisation:** Availability of pre-integrated technologies and standardised features/ solutions enabling interoperability, scalability, modularity and thus reducing time to market.

b) **Intelligence:** Support for AI and analytics capabilities and where these are located (increasingly at the network “edge”).

c) **Security:** Support for embedded security solutions for IoT (including authentication, network security, encryption, API security and security analytics amongst other).

d) **Mobility:** Support for wide-area coverage in instance where parts of the system are expected to change their location.

The following table reflects the industry’s view of the likely evolution and mainstream adoption of IoT technologies.

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
PLATFORMISATION		
• Message Queue Telemetry Transport (MQTT) • Constrained Application Protocol (CoAP) • Advanced Message Queuing Protocol • Data Distribution Service (DDS) • eSIM • Device Management- (OMA-DM, OMA-CP)	• IPv6, 6LoWPAN • Device Management - Open Mobile Alliance Lightweight Machine-to-Machine (OMA LWM2M)	• Enterprise taxonomy and ontology management
INTELLIGENCE		
• Speech recognition • Machine Learning (including Ensemble learning methods) • Natural language understanding • Predictive analytics • Video Surveillance	• Deep learning • Edge computing technologies (multi-access computing, fog computing, cloudlet, micro-data centre) • Natural language generation • Predictive analytics	• Cognitive computing • Deep reinforcement learning • Conversational user interfaces • Natural language processing • Prescriptive analytics
SECURITY		
• Application Security as a Service • Identity-proofing services • Disaster Recovery as a Service • IaaS container encryption • Tokenisation • End point protection – Identity & Access Management • FIDO Authentication protocol • IoT network security	• Secure processing unit • Trusted Environment • Software-defined security • Secure web gateways • Identity management as a service • Security analytics • Secure by design • Secure Web Gateway • Cloud-access security brokers • Cloud service brokerage	• Hardware Security • Blockchain • Digital security • Key management as a service

• IoT security for data encryption • IoT API security • IoT PKI & Digital certificates		
MOBILITY		
• LTE-M/eMTC (Cat M1) • NB-IoT (Cat NB1) • LoRaWAN • Sigfox	• LTE-M/eMTC (Cat M2) • NB-IoT (Cat NB2)	• 5G mMTC

Table 2: Technology Adoption Readiness Map for Internet-Of-Things

3.3 Use Cases

3.3.1 Future Communications

Communications is a key fundamental enabler of the digital economy that enables the growth and proliferation of IoT, Artificial Intelligence, Immersive Media and other future-ready technologies that industries use to gain competitive advantage. The exploding demand on bandwidth, connection density and latency requirements bring about significant implications for the ecosystem of wired and wireless technologies and its associated infrastructure. Here, we present a brief overview on key use cases enabled by some of the more notable communication technologies mentioned in the technology adoption readiness map.

3.3.1.1 High-Speed Wired Technologies

Wired communications form the backbone for high-speed interconnections between various networks all over the world. As more consumers and enterprises migrate to the cloud, demand for ultra-high-speed connectivity, in particular enterprises, will become more significant when leveraging cloud services such as site-to-site replication, data analytics and AI. Some use cases for high-speed wired technologies are:

a) Data centre interconnects (DCI) to achieve a low latency, high bandwidth, data centre fabric using leading optical transmission technologies; and

b) Wired networks to residential, commercial and other spaces as backhaul for edge computing deployments, wireless gateways and access points, ultra-high-definition end-points.

3.3.1.2 High-Speed Wireless Technologies (Non-mobility)

Non-mobility, high-speed wireless technologies are generally used in localised networks. Typically operating in license-exempt spectrum bands, these networks are usually cheaper, faster and more flexible to deploy. The success of the Wi-Fi standard and its associated branding is undisputed, with ubiquitous and pervasive deployments in residential, enterprises and commercial locations all over the world. Use cases for such wireless technologies include:

a) Ultra-high definition streaming applications;

b) AR, VR, MR streaming applications;

c) Instant replays during live matches;

d) Fixed wireless access networks;

e) High quality video conferencing;

f) Instant cloud access;

g) Large file transfers; and

h) Cloud computing.

3.3.1.3 High-Speed Wireless Technologies (Mobility)

Technologies like LTE and the upcoming 5G eMBB are high-speed wireless technologies that support mobility use cases required over a wide area. These are usually deployed using equipment in licensed spectrum bands that offers better reliability, resiliency and availability as compared to license-exempt technologies. Mobile use cases that could leverage on such high-speed wireless technologies are:

a) Ultra-high definition streaming applications;

b) AR, VR, MR streaming applications;

c) High quality live video sharing;

d) Instant cloud access;

e) Large file transfers; and

f) Cloud computing

3.3.1.4 Low Latency and High Reliability Wireless Technologies

An emerging focus area of wireless technologies (such as 5G uRLLC), these wireless technologies are optimised and designed to meet milliseconds and sub-milliseconds latency performance and extremely reliable communications. These are expected to address the requirements of mission-critical and near instant use cases, such as:

a) Industrial automation;

b) Remote and tele operations e.g. remote surgery, tele-driving;

c) Tactile internet;

d) Collision avoidance of automated guided/autonomous vehicle to vehicle, vehicle to infrastructure and vehicle to human;

e) Unmanned Aerial Vehicles/ Drones;

f) AR/VR/MR cloud applications;

g) Cloud and interactive gaming; and

h) Public safety e.g. emergency services

3.3.1.5 Power Efficient Wireless Technologies

Power efficient wireless technologies enable battery powered, low and infrequent data transmission devices to be connected. Short-range technologies such as Z-Wave, Bluetooth, and 802.15.4-based, solutions are usually deployed in a localised area like homes and offices, and use cases may range from:

a) Temperature and humidity sensors;

b) Door/windows sensors;

c) Motion sensors;

d) Light sensors;

e) Smoke detection sensors;

f) Alarms; and

g) Smart locks

Low power, wide-area technologies such as Sigfox, LoRaWAN and NB-IoT have been increasing in maturity in the recent years, thus bringing the aforementioned capabilities of power efficiency beyond localised areas. This allows low power, low bitrate devices to be connected at scale over a wide-area, which previously was difficult to achieve. The choice of technologies to use depends largely on the scenarios and use cases, taking into consideration key parameters such as scalability and compliance to international standards. Examples of use cases include:

a) Wearables;

b) Asset and fleet trackers;

c) Smart electricity, water and gas meters;

d) Waste management; and

e) Other battery-powered smart monitoring devices e.g. environmental monitoring sensors, parking detection, outdoor parking detection

3.3.2 IoT

Similar to global trends, ASEAN will have strong growth potential in IoT technology. Frost and Sullivan expects growth of IoT at 35% and to be a US$7.25 billion market by 2020 [51]. Different countries have announced ambitious national plans to boost their IoT industry. IoT can be implement in different sectors such as manufacturing, transportation and logistics, connected vehicles, smart buildings, infocomm media, utilities, Consumer IoT (Home Security/Home Automation), retail, health, insurance, and construction. Exhibit 18 show some typical use cases for these sectors.

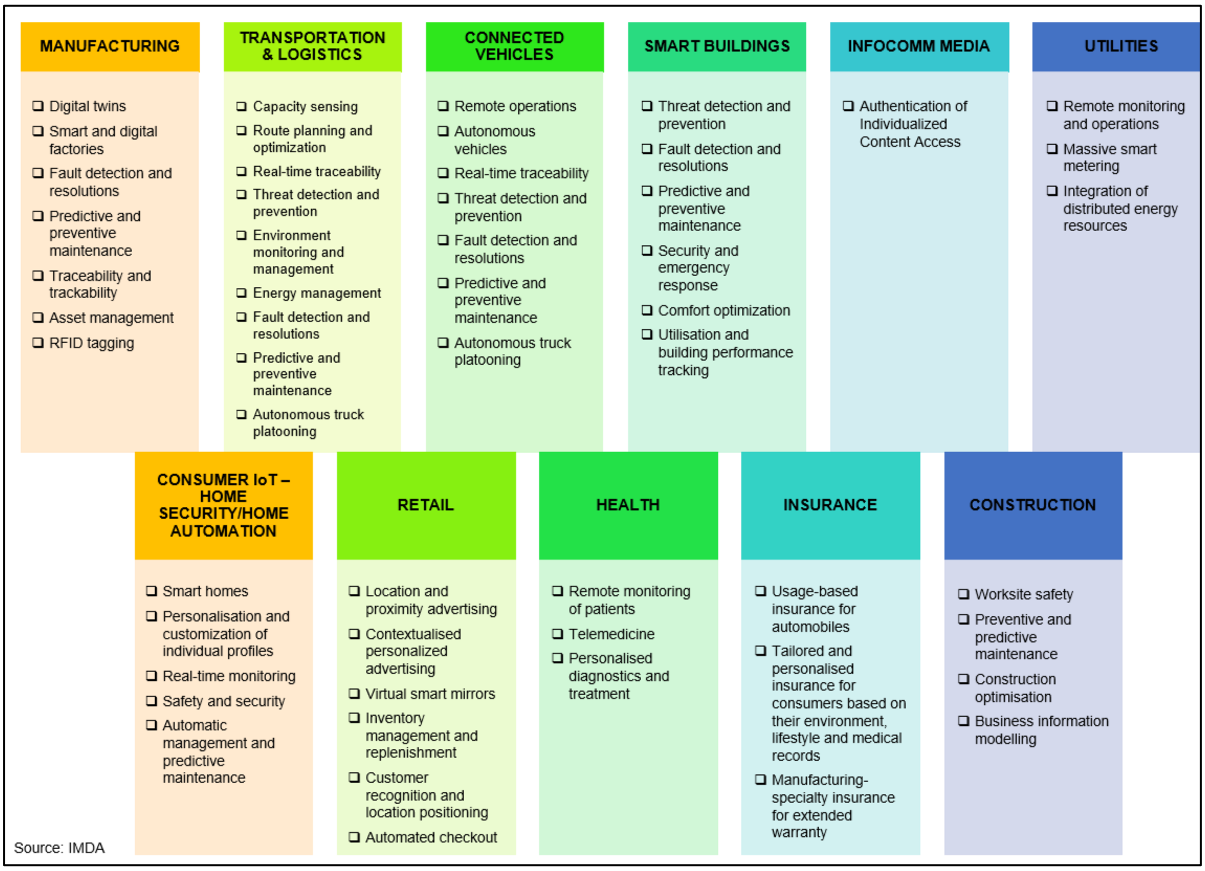


Exhibit 18: Typical Use Cases for IoT by Sectors

In ASEAN, countries are in different stages of IoT adoption. Along with automation, robotics, artificial intelligence and a myriad of others, IoT is expected to be one of the technologies that would enable the businesses including SMEs in the region to be able to experience significant growth. IoT is one of the key accelerators that will play a critical role in creating the "Factory of Future" and given that manufacturing is a key industry in the region contributing to the 21.5% [69] of the GDP in ASEAN in 2016, is expected to be a key driver to IoT adoption and economic growth. Governments in the region are also investing in Smart Infrastructure.

Thailand [70] for example has been a focusing on logistics and manufacturing as they are the key sectors that drive their export-oriented manufacturing economy and IoT will help them remain competitive in the global markets. Thailand has its Thailand 4.0 vision and IoT will play an important role in it. Thailand has also designated the Eastern Economic Corridor as a zone to facilitate global investments to drive developments for an integrated network and eco-system of business opportunities.

Malaysia [70] had come out with its IoT roadmap in 2015. In 2018, Maxis, leading telecom operator in Malaysia had announced plans to trial NB-IoT solutions positioned as an upgrade to their current LTE network. The strategic arm of Malaysian Technology Development Corporation has taken steps to acquire selective IP, which contributes to the overall IoT framework. Although Government push has been on multiple sectors given IoT's pervasive uses cases, Malaysian businesses have shown interest in NB-IoT applications in static assets of utilities, agriculture and Smart Cities applications related to remote monitoring of meters, plantations and street lights.

Indonesia [70] has been approaching IoT from a Smart City perspective on the back of their Jakarta Smart City Master plan. Telkomsel became the first operator to commercialise NB-IoT in 2018. IoT is crucial to the realisation of Indonesia's Industry 4.0 initiative "Making Indonesia 4.0"

Vietnam [70], one of the fastest emerging markets in the world, will be another market to look out for. Similar to other markets, IoT applications will be seen in Smart City use cases in cities like Da Nang, Hanoi and Ho Chi Minh. Local industries such as Food and Beverage are also seeing adoption of IoT in implementing sensors and big data analytics.

Country	Sectors where IoT activity is prevalent				
	Smart Cities	Mfg. & Industrial	BFSI, Retail & Real Estate	Healthcare	Energy
	Mfg. & Industrial	Smart Cities	BFSI, Retail & Real Estate	Automotive & Transport	Healthcare
	Smart Cities	Healthcare	Mfg. & Industrial	BFSI, Retail & Real Estate	Transportation & Logistics
	BFSI, Retail & Real Estate	Mfg. & Industrial	Transport & Logistics	Energy	Healthcare
	Transportation & Logistics	Smart Cities	BFSI, Retail & Real Estate	Mfg. & Industrial	Agriculture

Source: The ASEAN Post; Monitor Deloitte Analyses

Exhibit 19: Top IoT Sectors by Countries

Based on the SWOT analysis and with Singapore having her eye on the APAC region, Singapore should leverage on the advantages in high tech readiness and the presence of innovations hubs to focus on use cases in the sectors with the strongest potential as follows:

3.3.2.1 **Manufacturing**

Singapore leads the region in IoT readiness in the manufacturing sector due to favourable factors. These factors include being ranked high in the ease of doing business, availability of cloud infrastructure, investment in IT and IoT by companies, high labour force productivity and high adoption of robotics in manufacturing processes. Global IoT spend on manufacturing sector is expected to be the largest at US$189 billion in 2018 [50]. Industry 4.0 has been a key driver for IoT spending in the manufacturing sector. There are use cases that Singapore can focus on, such as

a) Use of digital twins (digital replica of physical assets, processes, people, systems and devices) for asset performance and utilisation optimisation;

b) Manufacturing operations such as asset and process optimisation, asset tracking, condition bases monitoring and predictive maintenance;

c) Smart tools to perform manufacturing processes for improvement in production efficiency;

d) Remote monitoring of equipment to reduce downtime; and

e) Sensors installed on engines to reduce downtime via predictive maintenance.

3.3.2.2 Utilities

Countries are increasingly focusing on energy efficiency as a national agenda (Energy 4.0) and is expected to drive increased use of IoT in the utilities sector with use cases primarily in the smart grid applications for gas, electricity and water, such as

a) Inspection at remote unmanned location via sensors;

b) Smart Grids/Meters – more efficient use of energy, real-time billing, network of sensors and controls across the grid to maintain reliability, new insights into grid operations and customer interactions; and

c) Integration of distributed energy resources (e.g. solar, wind, batteries).

3.3.2.3 Healthcare

Driven by the need to reduce the rising cost of healthcare, an aging population around the world and the increasing use of security solutions (addressing key concerns of data privacy and regulation) in IoT. IoT in healthcare is expected to grow at 16% CAGR from 2017 to 2022 from a base of US$110 million in 2017 [58]. IoT in healthcare includes enhanced patient care, reduced costs, reduction in errors, improved patient experience, and improved patient outcomes along with better disease management. Singapore could look into developing such use cases such as:

a) Wearable devices and digitalisation for the delivery of integrated care;

b) Mobile devices with sensors to remotely monitor patients with chronic illnesses;

c) Telemedicine for remote monitoring patients and access to healthcare; and

d) IoT enabled clinical trials to evaluate specific outcomes.

3.3.2.4 Smart City

As the Singapore Government embarks on the Digital Government Blueprint to launch initiatives that incorporate IoT as part of its strategy to digitise and enhance its public services, there are many opportunities and uses cases (especially in Smart City) locally and regionally, such as

a) Connected vehicles;

b) Smart Buildings; and

c) Smart street furniture (e.g. lampposts)

3.4 Contribution to Cloud Native Architecture

As a part of the overall technology roadmap recommendation, Singapore needs to establish a Cloud Native Architecture to improve access to emerging technologies amongst the stakeholders and enable the Services 4.0 ecosystem envisioned. We believe that Future Communications and IoT technologies will be crucial to ensuring the success of the Cloud Native Architecture.

Exhibit 20 below shows how Future Communications and IoT will contribute to various aspects of Cloud Native Architecture. Future Communication technologies such as 5G, NB-IoT, data centres etc. are expected to provide the foundational infrastructure required to support this architecture. IoT on the other hand will contribute to all aspects of Cloud Native Architecture from providing infrastructure (devices) to platforms (e.g. Harmonised IoT platforms, Fog Computing, Microservices (e.g. Device-Management-as-a-service)) and applications (e.g. Smart Factories).

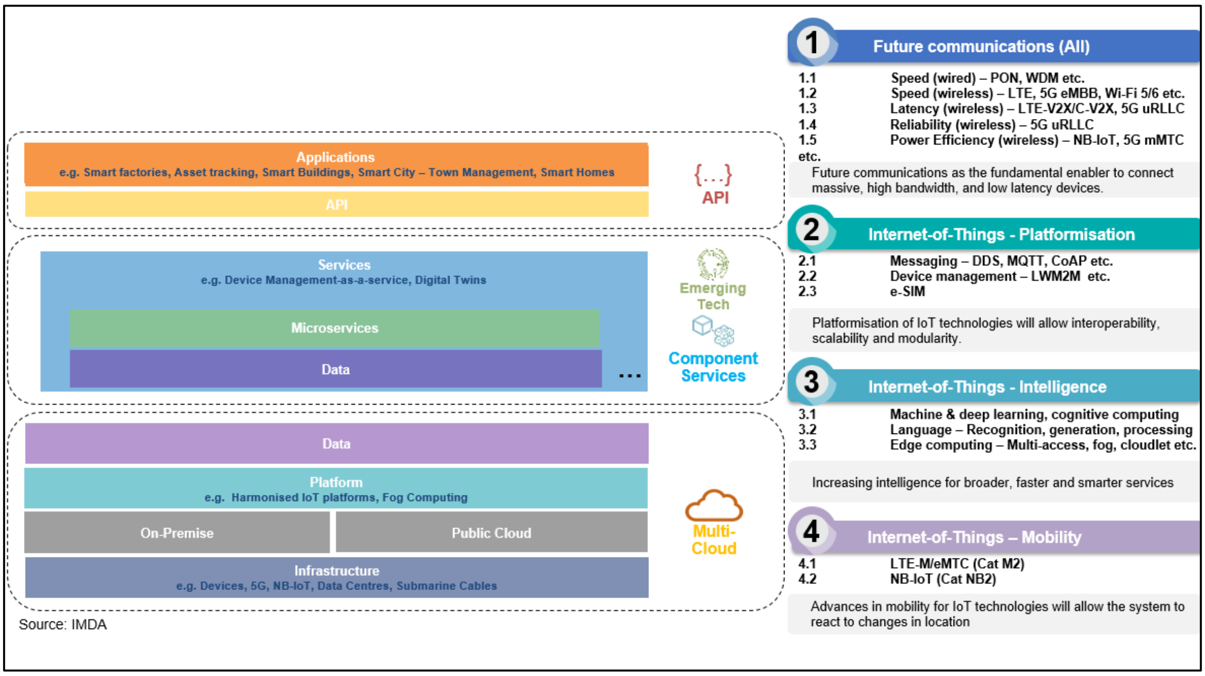


Exhibit 20: Contribution of Future Communications & IoT to Cloud Native Architecture

4 SWOT ANALYSIS

For Singapore to be able to develop the required capabilities in Future Communications and IoT, it is crucial to understand the strengths, weaknesses, opportunities and threats (SWOT). With this understanding, we can ensure that the findings are relevant to their needs and concerns. The framework shown in Exhibit 21 allows for a well-rounded analysis of this matter, with the following key criteria; Market, IP and Talent, Capital, Infrastructure and Ecosystem, Policy and Regulations.

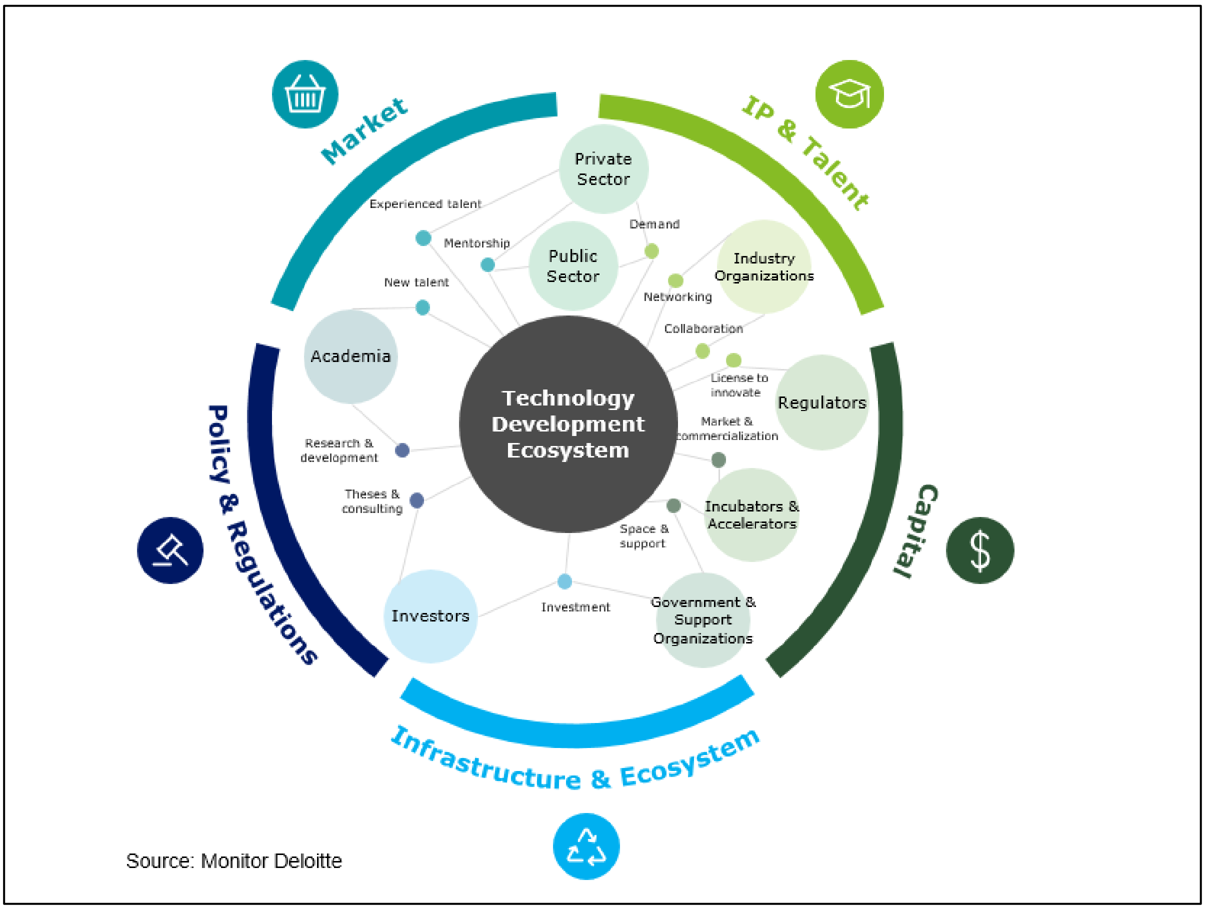


Exhibit 21: Framework for SWOT Analysis (Source: Monitor Deloitte)

A SWOT analysis of the Singaporean Landscape for Future Communication and IoT revealed the following strengths, weaknesses, opportunities and threats clearly indicating the areas in which Singapore should expend resources in order to build the requisite capabilities and become a global player in the same. A quick summary of the result of the SWOT analysis is shown in Exhibit 22 below.

STRENGTHS	WEAKNESSES
1. **Pervasive** and **high-speed** wireless and wired networks	1. **Adoption inertia** and low IoT take off
2. Strong **Government support** and progressive initiatives	2. **Fragmentation** of IoT ecosystem
3. Hot **regional testbed** and **innovation hub** anchor	3. **Small** market size
4. Strong **data centre presence** and **international connectivity**	4. Limited **talent pool**
	5. Loss of opportunities in **diversified use cases**

OPPORTUNITIES	THREATS
1. High **tech readiness**	1. **Aggressive** overseas markets
2. High global **growth** in IoT	2. Limited availability of **new spectrum**
3. **Smart city** use cases	3. Vulnerable to **cyber attacks**

Source: IMDA

Exhibit 22: SWOT Analysis of Future Communications and IoT for Singapore

4.1 Strengths

4.1.1 Strong Government Support and Progressive Initiatives

The Government plays a key role in driving demand and the adoption of IoT and communications with progressive initiatives rollout such as Smart Nation initiative, Digital Economy Framework, Digital Government Blueprint and Industry Transformation Map (ITMs). One of the key initiatives is the announcement of a smart street lighting system with plans to fit sensors and cameras that can collect a wide range of data, track autonomous vehicles in real time and analyse faces.

4.1.2 Hot Regional Testbed

The smart city market is gaining traction, with greater connectivity and “smart-city centres” providing greater resilience to the surroundings. Furthermore, Singapore has also been a testbed for smart cities. From tele-healthcare to manufacturing sectors, multinational firms are participating in Singapore’s smart city transformation with an eye on the plethora of opportunities in Asia, relying on the country’s strong ecosystem of partners, research institutes and start-ups. Notably, companies are using Singapore as a testbed include Philips Healthcare, NXP, Samsung, Huawei, Ericsson, Nokia and self-driving car start-up nuTonomy.

4.1.3 Strong Innovation Hub Anchor

Singapore is perfectly poised to be Asia’s innovation hub, with a strong presence in the region. In 2013, Singapore came top of Solidance’s ‘Most Innovative Asian City’ list [71], ahead of Sydney and Melbourne. Many companies set up innovation labs and Centres of Excellence (COE) in Singapore such as the Siemens Digitalisation Hub, MANN+HUMMEL Global Industrial IoT Lab, Singtel-Ericsson 5G Centre of Excellence and Temasek Polytechnic-Cisco Internet of Everything (IoE) Centre.

4.1.4 Strong Connectivity: Wired and Wireless

The Government has been promoting the usage of broadband Internet access since its Intelligent Nation 2015 (iN2015) initiative. The Next Generation Nationwide Broadband Network (NGNBN), a pervasive nation-wide fibre network, means that all homes and businesses have access to a fibre broadband network. The network effect means that households and businesses are not only able to do existing things faster, increasing productivity, but also enable new capabilities that are previously not possible. This next-generation infocomm infrastructure will drive sectoral transformation in the economy.

3G and 4G high-speed mobile networks that meets world-leading Quality-of-Service (QoS) standards is also prevalent across the country. Nation-wide outdoor, road and MRT tunnels has to meet a minimum 99% service coverage, with in-building service coverage of a minimum 85% to be in effect from 1 January 2019.

4.1.5 Strong Data Centre Presence and International Connectivity

Singapore holds a strong global data centre presence with 50% of the colocation market in Southeast Asia [72], with companies such as Global Switch, Equinix, ST Telemedia GDC, Keppel and Singtel offering colocation data centres. Major cloud players, such as Amazon Web Services (AWS), Google Cloud, Microsoft AZURE, Alibaba Cloud, IBM Cloud and others have also set up bases here, offering digital platforms and services that are key to the digital transformation of companies locally as well as in the region.

Beyond local connectivity, Singapore is also well connected to 38 countries via 19 submarine cables. further strengthening our network infrastructure and connectivity to major Asia Pacific markets. The strengths of our local and international connectivity, along with a stable and conducive operating environment, have made Singapore an attractive choice for international businesses to establish their presence here.

4.2 Weaknesses

4.2.1 Small Market Size

Given Singapore's small market size, constraint of natural resources and small population makes it less attractive for businesses looking for expansion and scalability. When compared to countries such as China, South Korea and the US, the small domestic market implies that the broader regional market will need to be a focus as well for companies.

4.2.2 Limited Talent Pool

Arguably, one of the most challenging aspects of being able to capture opportunities offered by the use of IoT and Future Communications technologies is the lack of robust digital and technical talent. Many of these technologies such as 5G are still emerging and thus, finding professionals experienced in these technologies will be a challenge. Further, professionals in Singapore traditionally pursue business degrees and roles. Thus, there is a limited pool of talent available. The aging population in Singapore, the increased mobility of millennial employees and a lack of understanding of how to reskill existing workers further compound the talent problem.

4.2.3 Adoption Inertia and Low IoT Take-off

Although ranked high in IoT and technology readiness, Singapore faces adoption barriers such as organisational inertia to change, legacy systems, lack of awareness and unattractive business case for change. Legacy processes often stand in the way of new technology adoption and transformation. For instance, despite the development of many initiatives, Singaporeans still prefer to use cash or payments as compared to citizens in China’s leading cities; companies continue the use of legacy networks and devices.

4.2.4 Lack of Diversified Use Cases

Given Singapore's small land size and lack of natural resources, there is limited environmental and geographical diversity. The lack of diversified use cases means Singapore is unable to replicate certain use cases in sectors such as agriculture, forestry, animal farming and natural disaster response that other countries have been able to harness. What works in Singapore, might not be directly exportable to the regional economies.

4.2.5 Fragmented IoT Ecosystem

One of the largest challenges in IoT is the plethora of platforms leading to high fragmentation and lack of interoperability. Deploying IoT solutions on several networks and ecosystems is both expensive and logistically cumbersome for users and thus hinders mass-market adoption. It also prevents technology providers who are more risk-adverse from choosing and investing early in technology, and instead adopt a wait-and-see approach.

There is also a lack of a specific IoT ecosystem to be able to bring all stakeholders together to drive rapid adoption and enable being able to tap into the market opportunity.

4.3 Opportunities

4.3.1 High Technology Readiness

Singapore is poised to be one of the most technologically ready economies [73], according to a study by Economist Intelligence Unit (2018) based on the three key categories – access to the Internet, digital economy infrastructure and openness to innovation. (Exhibit 23)

Singapore was further ranked [74] as among the top three countries (excluding Japan), citing the cloud infrastructure, broadband penetration plus ease of doing business and start-up/ business friendly government environments make it an excellent incubator for IoT solutions in the region". (Exhibit 23)

As a sophisticated market, the companies in Singapore are quite advanced in terms of adoption of technologies. More specifically, the telecommunication companies such as M1 and Singtel have been active in piloting and deploying NB-IoT and platforms over the last two years.

Overall Tech Readiness

Country	Ranking (2018-2022)
Australia	1
Singapore	1
Sweden	1
US	4
Finland	4
France	4
Germany	4
Japan	4
Netherlands	4
Austria	10
Belgium	10
Hong Kong	10
South Korea	10
Taiwan	10

IOT readiness in Asia Pacific (excluding Japan)

Country	Ranking (2018-2022)
South Korea	1
Singapore	2
New Zealand	3

Source: The Economist – Intelligence Unit- Technology Readiness Ranking, IDC IoT Readiness Index 2017; Monitor Deloitte Analyses

Exhibit 23: Technology Readiness Ranking

4.3.2 High Global Growth in IoT

The IoT market is expected to witness exponential growth in number of devices connected across all regions. APAC and ASEAN, in particular are key markets that companies in Singapore will be able to target, given that Singapore is a global hub for innovation in region. Many global firms are already establishing digital competency centres and exploring partnerships in the country to be able to tap into regional opportunities.

4.3.3 Smart City Use Cases

For Singapore, given the Smart Nation Initiative, Smart Cities will be a key sector of focus to develop solutions that can be launched in other global and regional markets. The four key areas for Smart Cities that is likely to witness widespread adoption of IoT and connected services: Mobility, healthcare, public safety and supply chain. These are the likely areas where Singapore has strong potential to develop technologies and solutions to support smart city initiatives to be used in Singapore and subsequently export them to other countries in the region and worldwide.

4.4 Threats

4.4.1 Aggressive Overseas Markets

Countries such as US, China, Korea and Japan have had a head start in developing solutions for their large domestic markets. This may result in a loss of opportunities for companies in Singapore to be able to develop and launch 5G and IoT technologies for the regional and global market. Our traditionally smaller and less active ASEAN and APAC neighbours (such as India, Thailand, Vietnam) are also experiencing accelerated growth spurred by the adoption of IoT and Industry 4.0. Thus, Singapore may find it difficult to maintain the advantages over these nations as previously experienced.

4.4.2 Limited Availability of New Spectrum

Re-farming of spectrum requires extensive coordination with neighbours who have alternative uses for the spectrum. Thus, there may be challenges to able to allocate spectrum required to be able to support 5G and other new wireless technologies.

4.4.3 Vulnerable to Cyber Attacks

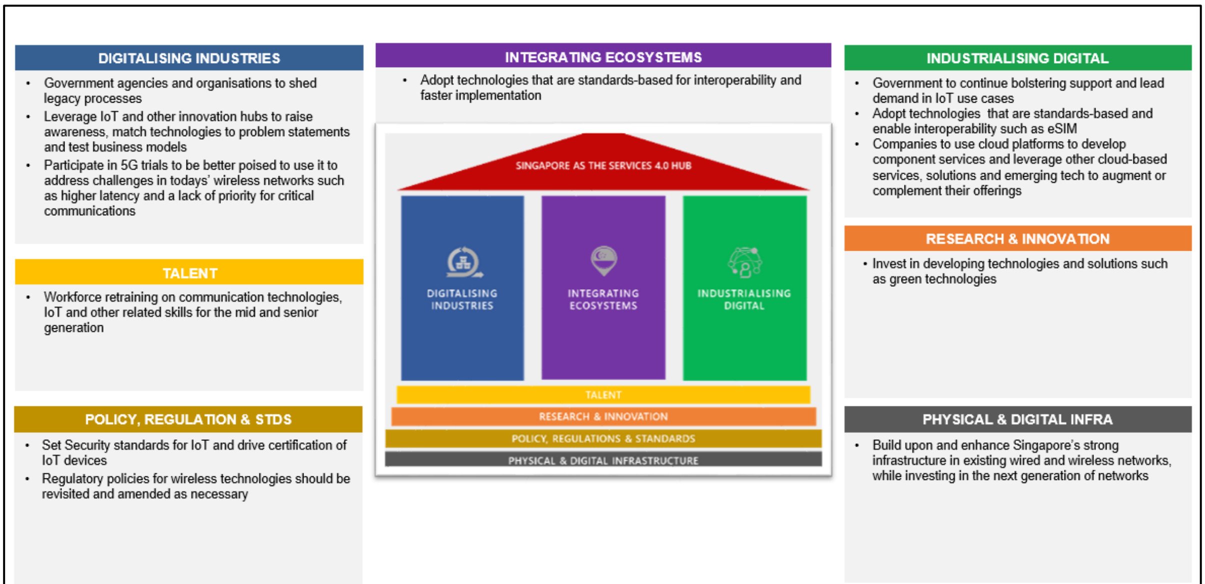
The potential of IoT comes hand in hand with Cyber Security risks. The constant information and data sharing also creates new opportunities for critical information to be compromised and companies are grappling with these challenges. The recent cyberattack on SingHealth Singapore has raised further concerns. The lack of clear security requirements, and even security certifications, for IoT devices and installations are key challenges that could further prevent widespread adoption of IoT. Cyber Security must be by design, central to IoT rollouts and not relegated to the backseat.

4.5 Conclusions from SWOT Analysis

In conclusion, building capabilities in Future Communications and IoT technologies requires a focused set of strategies, with Singapore's unique strengths and weaknesses in mind. These recommendations need to enable development of local technology capabilities and drive adoption of Future Communications and IoT technologies amongst industries, in order to tap into the strong regional growth potential.

Singapore has a strong Infrastructure in place, is a strong innovation hub, is backed by a strong Government and has a very active Communications industry. These have been some of the reasons contributing towards its high rank in technology readiness assessments. However, it will be crucial to continue to build on the existing capabilities to able to develop a favourable ecosystem for both IoT and Future of Communications in order to tap into the regional market. This can be achieved through Government driving necessary policy and regulation, encouraging companies to adopt platforms and standards, acting as a key enabler for industry adoption and establishing talent programmes. These will be discussed in more detail in the next chapter.

5 RECOMMENDATIONS



Source: IMDA

Exhibit 24: Alignment of Recommendations in Future Communications & IoT to DE Framework

Based on the several guidelines developed from the SWOT analysis of Singapore Landscape, four main recommendations have been identified, which will be further elaborated in this chapter:

a) Continued Government Leadership for Digitisation;

b) Encourage adoption of Standards, Platforms and Cloud Native Architecture;

c) Key enabler for Greater Industry Adoption; and

d) Continuous Learning for Digital Transformation.

5.1 Continued Government Leadership for Digitisation

In order to realise the envisioned digital future enabled through Future Communications and IoT, the Government will need to lead the efforts and have a pivotal role to play: as policy maker and regulator, adopter and educator and infrastructure enabler and builders.

5.1.1 Ensure the Relevant Policies and Regulations for IoT and Future Communications are In Place

The Government will need to be a key enabler by setting relevant policy to facilitate industries to adopt IoT.

On a national level, there needs to be collaboration among Government agencies in the IoT discussion in order to formulate corresponding national policy and strategy, conceptualise key projects and identify key challenges to be addressed. One of the key countries taking a similar approach is Ukraine that has been taking steps in making its capital smart, with IoT playing a big role in tackling problems from healthcare to agriculture. In addition, given that Cyber Security is a key component of IoT and data privacy is a national concern, the Government should consider drawing up a national security policy for IoT including setting security standards and drive certification of IoT devices.

Regulatory policies that will have impact on 5G such as antennae and base station placement should also be revisited and amended as necessary. Given the exponential growth in small cell expected as 5G testing and adoption grows, urban planners should review current base station and small cell deployment regulations and design. Currently, antennas for base stations are not allowed to be placed at the edge of HDB building due to public safety concerns. As 5G will be offered at higher frequencies and hence have smaller cell coverage, not allowing installation at building's edge would reduce even further the reach of a cell's coverage. Thus, Government will need to work with telecommunication providers and urban planners to address this policy to facilitate offering of 5G. Urban city planners should also review regulations to enable denser deployment of small cells, including making available power sources at public and private buildings and other regulations that will enable making power and connectivity available to street furniture.

5.1.2 Lead Demand in IoT in Smart Cities and other Public Sectors Projects

To drive IoT, Government needs to continue bolstering support and lead demand in IoT use cases by driving widespread public sectors adoption of IoT.

Singapore can look to integrate IoT further in the Smart Nation initiative to be able to derive further benefit from IoT and set a framework in place for private sectors to follow suit. With a dense urban build up, the Government plays a key role in leading demand in the Smart city use cases such as smart lighting, smart metering, lifts monitoring, smart car park, traffic lights management, township management and smoke detection. While aggregating requirements and specifications, the Government should encourage solution providers to build scalable and cost effective solutions for pilots, trials and testbeds such that full-scale deployments can be easily rolled out and made applicable to other sectors and possibly be exported internationally.

The Government should also focus on ensuring that IoT is integrated into new infrastructure projects. For example, the Government can drive lead demand in the use of IoT and deployment of future communications in building major transportation infrastructure such as Terminal 5 airport and the construction of the mega port in Tuas. Thus, this will lead to encouraging local enterprises to build innovative solutions (e.g. facilities management) which can then be replicable to other airports and seaports.

This aggregated committed demand from multiple agencies within the public sectors gives substantial scale and scope, which will provide Singapore with an opportunity to play a leading role in the regional IoT ecosystem. IoT platforms and solutions developed in Singapore for certain verticals can be exported to the region and beyond.

The Government should also actively highlight successful case studies and promote various programmes that related to IoT such as Smart Nation, Industry 4.0 and other related initiatives that will encourage IoT adoption by private sectors.

5.1.3 Lead the Efforts to ensuring the Requisite Infrastructure is in Place

As part of the efforts to enabling Future Communications, the Government will need to work with the private sectors to build the requisite infrastructure and make it affordable for enterprises to adopt.

The Government will need work with the private sectors to build upon and enhance Singapore's strong infrastructure in existing wired and wireless networks. One key enabler in this category will be ensuring fibre connectivity and backbone by making enhancements and expansions of the nationwide fibre network. The Government should work with the telecommunication providers and other key stakeholders to ensure that technologies such as DWDM [75] (Dense Wavelength Division Multiplexing) are used to increase capacity over existing fibre networks and enable scalability. The increased capacity enables more data types and volume on the same fibre strand, such as CPRI and OSAI for cellular front haul connectivity, SAN for storage networks. Other interventions such as 10G subsidy programs should be formulated to enable affordable 10 Gbps connectivity to enterprises.

As discussed earlier, the vision of Services 4.0 where emerging technologies are to be offered on the proposed Cloud Native Architecture. This vision is expected to drive a surge in demand for increased capacity and computing power. There will be a pressing need for more sophisticated data centres. It is also expected that the Multi-Clouds will require greater interconnections between cloud platforms placing greater demand on inter-DC and inter-Cloud connectivity in terms of both bandwidth and latency. A DC-to-DC backbone fabric will be required to provide a low-latency and high-bandwidth communication between data centres to meet these requirements. The Government should encourage the private sectors to build the requisite data centres in Singapore by providing them with subsidised land and electricity and ensuring that the backbone fibre required in in place. These data centres can be housed in IMDA's proposed Data Centre Park in Singapore.

In order to realise the visions of exporting solutions and services developed in Singapore as part of the Services 4.0 vision in the region and globally, there will be further demand on capacity in submarine cables. The Government should continue to encourage and support the landing of submarine cables that connect Singapore to other countries.

5.1.4 Lead Efforts in Investing in Developing Technologies and Solutions

Singapore should invest in developing green technologies and solutions to mitigate the lack of natural resources and land needs. These would enable optimal use of land, energy and water. The Government should consider setting up programmes that provide funding for R&D in these green technologies for both academia and industries to work together to develop solutions. The benefits can be leveraged beyond the domestic market as Singapore as can consider exporting these technologies to other regional and global markets. We should be mindful that Singapore has unique circumstances and instead of only investing in technologies that can only work in Singapore, we should diversify to ensure that some of the investments would potentially be exportable.

5.2 Standards, Platforms and Cloud-Based Services

The Government will need to work industry players to ensure adoption of standards and standard based platforms to ensure rapid development and adoption of IoT and Future Communications technologies. As part of the Services 4.0 vision, they will also need to build an ecosystem to enable the adoption of Cloud Native Architecture.

5.2.1 Encourage Industry to Adopt Standards-based Technologies including eSIM

It is imperative to adopt technologies that are standards-based. There are several standards and bodies including IEEE, 3GPP, Wi-Fi Alliance, Bluetooth Special Interest Group (SIG), Open Mobile Alliance (OMA). Standards enable interoperability, prevents vendor lock-in and encourage rapid adoption of technologies. For example, the drive by China towards standardising NB-IoT has enabled rapid proliferation of IoT in the country. While the Singapore Government need not take a similar approach and recommend a specific standard, it could still encourage the industry to work together towards adopting globally recognised standards to enable rapid growth of IoT and Future Communications technologies.

One such technology and standard that could enable this interoperability for IoT is eSIM. eSIM technology is expected to permeate more consumer and M2M IoT devices over the next few years, which enables remote provisioning of mobile operators' profiles. It is envisaged that M2M IoT devices are likely to benefit from eSIM, as these devices could be located across very diverse, unsupervised and inaccessible locations rendering the replacement of physical SIM cards impractical and expensive. The adoption of eSIM technology in M2M devices is thus likely to be a key driver for IoT. Thus, the Government should work with the telecom operators and IoT device manufacturers to accelerate to accelerate the widespread adoption of eSIM.

5.2.2 Establish a Common Standards-based framework for Platforms to Enable Rapid Adoption of IoT

Globally, platforms have been one of the key drivers for the adoption of IoT. However, rapid proliferation of proprietary platform has also led to fragmentation. Adoption of IoT can be further accelerated with the development and adoption of standardised platform to connect the different hardware and software solutions. Well-defined technical specifications can be developed with the technology providers for standardised protocols, APIs and interfaces for the collection, management and access to services and data. The Government should work with large IoT platform providers to ensure that they build and adopt harmonised platforms to enable rapid adoption of IoT. The Government can also encourage IoT sector specific platforms for industries that Singapore will prioritise for Services 4.0.

5.2.3 Establish a Services 4.0 Ecosystem for Companies to Embrace a Cloud Native Architecture to Build and Leverage Component Services

Currently, in Singapore, only 30% of organisations have adopted cloud computing [76] and there is still limited understanding of what Cloud Native solutions are. As the Services 4.0 vision is built on a Cloud Native Architecture, the Government should organise programmes that encourage and facilitate enterprises to participate in this ecosystem. Thus, enterprises will need to be supported to migrate their infrastructure to a Cloud Native Architecture. Technology solution providers will need to be encouraged to develop cloud based component services and leverage other cloud-based services, solutions and emerging technologies to augment or complement their development, for instance AI as a service, identity as a service (e.g. GSMA's Mobile Connect), device management as a service and data discovery as a service. Component services can be exposed and discovered within the harmonised platform to enable different IoT application. Telecommunication companies should also be encouraged to lead this transformation by creating new services via platforms, cloud and component services, especially for enterprise customers.

5.3 Key Enabler for Greater Industry Adoption

The Government will need to be a key enabler to facilitate greater industry adoption to build the ecosystem for Services 4.0 system by leading the way as a role model. Key activities include establishing innovation hubs to enhance the development and adoption of IoT and Future Communications technologies and bringing together industry players to participate in 5G pilot tests.

5.3.1 Shed Legacy Processes, Increase Digitalisation and Enable Access to Data

The Government will need to be role model by changing legacy processes, adopting greater digitalisation and allowing access to certain relevant data. Government agencies and organisations will need to shed legacy processes and systems and adopt a more agile way of working. The Government also has plans to adopt a Cloud Native Architecture and to build component services on this Cloud Native Architecture. Government can consider enabling access to anonymised data obtained through the Smart Sensor Network and other Smart City devices for companies in the private sectors to be able to use to build innovative solutions. Such activities are expected to be key catalysts in building the ecosystem envisioned for Services 4.0.

5.3.2 Enable Industry to Leverage Innovation Hubs

The Government should enable industry to leverage innovation hubs focused on IoT and relevant communication technologies by bringing together key stakeholders to collaborate. As part of these innovation hubs, industry, academia and government will need to collaborate to enhance R&D in IoT and Future Communications by identifying and investing in developing technologies and solutions and enabling rapid and innovative commercialisation and implementation of these technologies. To accelerate adoption and translate technology readiness into true transformation ground-up, industries can leverage innovation hubs to raise awareness, match technologies to problem statements and test business models. These are key forums where enterprises can learn more about and get access to relevant IoT technologies and platforms to be able to integrate and launch solutions. Other such hubs for Digital transformation including Services 4.0 and Cloud Native are to be established. SMEs in Singapore can leverage Government initiatives such as the IMDA SMEs Go Digital Programme [77] in the adoption and provision of digital technologies and capabilities.

5.3.3 Enable Next Generation Wireless 5G Networks

Given the transformational nature of 5G and the inherent expected advantages, it is critical for the different stakeholders to being able to able to understand the benefits. As, 5G standards are in the process of being finalised and will require high investment costs, it is unlikely that 5G networks would be rolled-out in a nationwide manner soon. The performance and capabilities of 5G will need to be better understood, investigated and validated through early 5G field trials.

Currently there are 5G trial efforts going on by telecommunication providers but these are discrete efforts with limited collaboration and participation of other players. The Government should work with telecommunication providers to set up 5G field test beds where all relevant stakeholders including companies in other sectors can participate in. Given that industrial and commercial use cases, especially IoT are expected to derive maximum value from 5G, these companies should be encouraged to participate in 5G trials. Participation in the 5G trials will enable these companies to understand the capabilities of 5G to be better poised to use it to address challenges in todays' wireless networks such as higher latency and a lack of priority for critical communications. These capabilities are particularly important for IoT applications.

Currently there is limited network infrastructure sharing in 4G by the telecom operators in Singapore. Given that 5G is expected to be deployed on higher frequencies leading to denser cells deployment, there will be significant investment costs and the requirement of having multiple small cells for each operator. The Government should thus work with the telecommunication providers and encourage infrastructure sharing. This is likely to be more prevalent in 5G to mitigate the business risks and high investment costs. The Government can also work with the industry to ease early adoption such as reviewing the QoS requirements for coverage.

5.4 Continuous Learning for Digital Transformation

In order to enable the development and adoption of Future Communication and IoT in Singapore, having the relevant talent is key. Thus, it will be critical to establish programmes towards enabling re-skilling and continuous learning of existing workforce, developing cross-functional talent as well as ensuring that Singapore's future generations of workers are equipped adequately.

5.4.1 Re-skill Workforce in Relevant Technology Areas

Given Singapore's aging workforce, programmes that focus on workforce retraining for the mid and senior generation are a key imperative. There will be a need for a large number of technical skilled workers with domain knowledge in specific areas of communication technologies such as optical fibre networks, 5G, low power networks and Wi-Fi technologies. Further skilled workers trained in developing platforms, artificial intelligence and edge computing and cyber security for IoT will be crucial to being able to develop and launch relevant IoT solutions.

The Government should work with universities and private sectors to be able to establish programs, courses and projects that the workforce can register. Experts from other countries can also be leveraged by enabling them to come on special immigration visas to set up special programs in Future Communications and IoT.

5.4.2 Developing Talent with Cross Functional and Interdisciplinary Capabilities

While specific niche skills in communication technologies and IoT are crucial to building solutions, cross functional understanding of how these technologies can be capitalised on to generate value is also critical. Broader technical knowledge and skills in software and hardware engineering, network design and optimisation, data analytics and management will be required. Understanding the technical implications on communication technologies of launching Services 4.0 and the Cloud Native Architecture will be important. Thus, cross-domain knowledge and inter-disciplinary R&D capabilities will be required to be able to drive innovation in different vertical applications of Future Communications and IoT. There is also a growing need for business professionals who can understand how the potential of these IoT and Future Communication technologies to generate significant value.

The Government should establish competency centres for Future Communications and IoT along with key private sectors players that will provide access to tools and technologies for workers across different sectors.

5.4.3 Develop Talent Programmes for Related Technologies focused on Schools and College

It is also critical to establish programmes that encourage schools and colleges to build relevant skills in students early on to equip our future generations with relevant digital skills. Singapore should be considering incorporating relevant skills such as programming and basic understanding of software engineering, communication technologies and IoT into the mainstream school curriculum. The Government should work with universities to establish more degree programs and courses related to software engineering, communication technologies and IoT. Programs that offer scholarships, internships and job opportunities should be established to encourage students to pursue these degrees and courses related to software engineering, communication technologies and IoT.

6 SUMMARY

Communications and IoT are and will continue to be engines of growth for Singapore's economy as connections increase exponentially and digitalisation permeates every area of our lives. The journey has already begun, and we cannot afford to be content and should continue to push the boundaries. Our success hinges on our ability to stay relevant in the global ecosystem over the next decade.

Achieving our goals and targets for future services and the digital economy, particularly in communications and IoT, requires the strong participation and support of all stakeholders. The Work Group envisions everyone – individuals, organisations, and government to be part of this ongoing process in shaping Singapore's digital future. The digital future ahead will be an exciting one – we have to be ready to step outside our comfort zones, remain flexible and cross-pollinate to learn from predecessors in overseas markets.

7 APPENDIX A: GLOSSARY

TECHNOLOGY	GLOSSARY
5G Broadcast	As part of Release 14, 3GPP has defined a compelling solution for the future of broadcasting, called LTE EnTV, which builds upon the original eMBMS concepts. For Release 16, LTE EnTV will be evaluated and possibly enhanced to meet the 5G broadcasting requirements, reconfirming the commitment of 3GPP to this industry segment.
5G Enhanced Mobile Broadband (eMBB) (Both Standalone and Non-standalone)	Data-intensive applications that need lots of bandwidth, like video streaming or immersive gaming, to give the same experience on a mobile device that we'd get from fixed fibre-optic. The technologies that will make it happen include Gigabit LTE, massive MIMO, mmWave technologies, spectrum sharing techniques and advanced channel coding.
5G Integrated Access and Backhaul	The 5G integrated access and backhaul project has already been ongoing for some time and it is addressing how to also use 5G NR for the backhaul link. This is an enabler for network densification (due to the physical limitations of wired backhaul) and in turn, will play an important role in the expansion of 5G to higher frequency bands, especially mmWave.
5G Massive Machine Type Communications (mMTC) or Massive IoT	Low cost, low energy devices with small data volumes on a mass scale, such as smart cities. Narrowband IoT will be enhanced with capabilities like voice support, lower latency, location services, device mobility and broadcast for efficient over-the-air (OTA) firmware updates. Qualcomm is proposing the RSMA (Resource Spread Multiple Access) uplink multiple access design for more efficient uplink transmission, as well as a new WAN-managed multi-hop mesh architecture to extend network coverage.
5G NR improvements	The foundational 5G NR technologies have been defined as part of Release 15, but as always, 3GPP continues to improve the core technologies to deliver better user experiences. In this vein, many Release 16 projects were approved to further enhance mobile broadband, and these include device power consumption optimisation in connected mode, NR-NR dual connectivity, network interference management, MIMO and Multi-Transmission Point improvements (mostly for 5G NR and in a smaller measure, LTE), mobility enhancements (5G NR and LTE), and self-organising networks (SON) for NR. These are in addition to the study on Non-Orthogonal Multiple Access (NOMA), which has been ongoing already for some time. Finally, an initial exploration of the usage of 5G NR in high frequency bands (above 52.5GHz) will commence.
5G NR Spectrum Sharing (NR SS)	Extension of spectrum sharing technologies pioneered in LTE to 5G, such as LAA, MulteFire, Citizen Broadband Radio Service (CBRS).

5G NR Unlicensed Access (NR-U)	Same as NR SS.
5G Positioning	5G NR already supports basic positioning techniques in Release 15, and this new study will look at how 5G NR access can be leveraged for new vertical use cases where more accurate positioning can provide additional values. For example, 5G positioning can bring benefits for indoor use cases.
5G Ultra-reliable and low latency communications (uRLLC)	Latency-sensitive services needing extremely high reliability, availability and security, such as autonomous driving and Tactile Internet applications. Technologies are being developed that are specific to particular use cases, like cellular vehicle-to-everything (C-V2X) and real-time command and control for cellular drone communications, as well as those to support the 'no-failure' requirement, such as multiplexing to prioritise mission-critical transmissions over regular traffic or redundant links so that mission-critical devices can connect across multiple networks.
5G-non-terrestrial networks (NTN)	The 5G NR for non-terrestrial deployments project will look at whether and how 5G NR technology can be leveraged for non-terrestrial radio deployments, such as low-orbit satellites.
802.11ac Wave 1/ 2 (Wi-Fi 5)	802.11ac, or Wi-Fi 5, is a transformational wireless LAN technology that represents a significant performance increase over its highly successful predecessor, 802.11n. 802.11n provided the wireless connectivity speeds that businesses needed to embrace Wi-Fi in their day-to-day operations and let workers begin using wireless as their primary network medium of choice. The 802.11ac IEEE standard allows for theoretical speeds up to 6.9 Gbps in the 5-GHz band, or 11.5 times those of 802.11n (Table 1). 802.11ac is coming to market in two releases: Wave 1 and Wave 2.
802.11ad	802.11ad, also called Wi-Fi 1.0, is a proposed specification in the 802.11 family applicable to WLANs (wireless local area networks). 802.11ad represents an extension or update of the current 802.11a standard. Networks using 802.11ad will operate in the 60-GHz (gigahertz) band using OFDM (orthogonal frequency-division multiplexing). The enhancements supported by 802.11ad will facilitate simultaneous streaming of HD (high definition) video to multiple clients in large office environments, as well as faster wireless synchronisation and backup of large files.
802.11ax (Wi-Fi 6)	IEEE 802.11ax, also known as Wi-Fi 6 is a type of WLAN in the IEEE 802.11 set of types of WLANs. IEEE 802.11ax is designed to operate in the already existing 2.4 GHz and 5 GHz spectrums and it will incorporate additional bands between 1 and 7 GHz as they become available. In addition to utilising MIMO and MU-MIMO, the new amendment introduces OFDMA to improve overall spectral efficiency, and higher order 1024-QAM modulation support for increased throughput. Though the nominal data rate is just 37% higher than

	IEEE 802.11ac, the new amendment is expected to achieve a 4× increase to user throughput due to more efficient spectrum utilisation.
802.11ay	802.11ay is a type of WLAN in the IEEE 802.11 set of WLANs. It will have a frequency of 60 GHz, a transmission rate of 20–40 Gbit/s and an extended transmission distance of 300–500 meters. It has also been noted that it is likely to have mechanisms for channel bonding and MU-MIMO technologies. It was originally expected to be released in 2017, but has been delayed until 2019. 802.11ay will not be a new type of WLAN in the IEEE 802.11 set, but will simply be an improvement on 802.11ad.
802.11az (Next Generation Positioning)	Called Next Generation Positioning (NGP), looks at ways to improve the location and positioning of users.
802.11ba (Wake up Radio)	Known as "Wake-Up Radio" (WUR), aimed at extending the battery life of devices and sensors within an Internet-of-Things network.
Advanced Message Queuing Protocol (AMQP)	The Advanced Message Queuing Protocol (AMQP) is an open standard application layer protocol for message-oriented middleware. The defining features of AMQP are message orientation, queuing, routing (including point-to-point and publish-and-subscribe), reliability and security.
Application Security as a Service	Application Security as a Service has several benefits like: reduction of fixed operational costs, help in focusing on core competency, resolving the problems of talent acquisition and retention, reduction of operational management overheads and many more.
Backscatter networking	Backscatter networks operate by remodulating ambient wireless signals such as Wi-Fi. These networks allow transmission using very low-power consumption, perhaps 10 times lower than transmitting directly.
Bluetooth 4.2/5 Dual Mode – Basic Rate/Enhanced Data Rate (BR/EDR)	The Bluetooth BR/EDR radio is designed for low power operation and also leverages a robust Adaptive Frequency Hopping approach, transmitting data over 79 channels. The Bluetooth BR/EDR radio includes multiple PHY options that support data rates from 1 Mb/s to 3 Mb/s, and supports multiple power levels, from 1mW to 100 mW, as well as multiple security options. It supports a point-to-point network topology that is optimied for audio streaming.
Bluetooth 4.2/5 Low Energy (LE)	The Bluetooth BR/EDR radio is designed for low power operation and also leverages a robust Adaptive Frequency Hopping approach, transmitting data over 79 channels. The Bluetooth BR/EDR radio includes multiple PHY options that support data rates from 1 Mb/s to 3 Mb/s, and supports multiple power levels, from 1mW to 100 mW, as well as multiple security options. It supports a point-to-point network topology that is optimised for audio streaming.

Cloud service brokerage	Cloud services brokerage (CSB) is an IT role and business model in which a company or other entity adds value to one or more (public or private) cloud services on behalf of one or more consumers of that service via three primary roles including aggregation, integration and customisation brokerage. A CSB enabler provides technology to implement CSB, and a CSB provider offers combined technology, people and methodologies to implement and manage CSB-related projects.
Cloud-access security brokers	A cloud access security broker (CASB) is a software tool or service that sits between an organisation's on-premises infrastructure and a cloud provider's infrastructure. A CASB acts as a gatekeeper, allowing the organisation to extend the reach of their security policies beyond their own infrastructure.
Constrained Application Protocol (CoAP)	The Constrained Application Protocol (CoAP) is a specialised web transfer protocol for use with constrained nodes and constrained networks in the Internet-of-Things. The protocol is designed for Machine-to-Machine (M2M) applications such as smart energy and building automation.
Conversational User Interfaces	Conversational user interfaces (UIs) are a growing focus for application developers. Sometimes known as chatbots, digital assistants, or cognitive agents, these UIs have come to mobile devices through Siri, Facebook Messenger, Samsung Bixby, and similar offerings. Powered by natural language processing (NLP) and artificial intelligence (AI), they have entered the consumer IoT arena through Amazon Alexa, Google Assistant, and similar voice-activated home-appliance initiatives. They are big in the interactive voice response market.
Data Distribution Service (DDS)	Data Distribution Service (DDS) is a type of Communications Middleware whose concept was standardised and is currently managed by the Object Management Group (OMG). DDS simplifies software systems, and reduces risk and costs through development, integration, deployment, and lifetime maintenance of distributed software systems.
Dedicated Short Range Communications (DSRC)	Dedicated short-range communication (DSRC) is a wireless communication technology designed to allow automobiles in the intelligent transportation system (ITS) to communicate with other automobiles or infrastructure technology. DSRC technology operates on the 5.9 GHz band of the radio frequency spectrum and is effective over short to medium distances.
Deep learning	Deep learning is a subset of AI and machine learning that uses multi-layered artificial neural networks to deliver state-of-the-art accuracy in tasks such as object detection, speech recognition, language translation and others. Deep learning differs from traditional machine learning techniques in that they can automatically learn representations from data such as images, video or text, without introducing hand-coded rules or human domain knowledge. Their highly flexible architectures can learn directly from raw data and can increase their predictive accuracy when provided with more data.

Deep Reinforcement Learning	Deep reinforcement learning (DRL) is an exciting area of AI research, with potential applicability to a variety of problem areas. Some see DRL as a path to artificial general intelligence, or AGI, because of how it mirrors human learning by exploring and receiving feedback from environments.
Device Management (OMA-DM, OMA-CP)	Device Management refers to the management of Device configuration and other managed objects of Devices from the point of view of the Management Authorities. Device Management includes, but is not restricted to setting initial configuration information in Devices, subsequent updates of persistent information in Devices, retrieval of management information from Devices, execute primitives on Devices, and processing events and alarms generated by Devices. Device Management allows network operators, service providers or corporate information management departments to carry out the procedures of configuring devices on behalf of the end user (customer). OMA DM Version 2.0 reuses the Management Objects, which are designed for OMA DM Version 1.3 or earlier DM Protocols. OMA DM Version 2.0 introduces the new Client-Server DM protocol and a new user interaction method for Device Management using the Web Browser Component.
Digital security	Digital security is an all-encompassing term, which includes the tools you can use to secure your identity, assets and technology in the online and mobile world.
Digital Twin and Digital Thread	A digital twin is a virtual representation of a product. It can be used in product design, simulation, monitoring, optimisation and servicing and is an important concept in the industrial Internet-of Things. Digital threads refer to the digitisation and traceability of product “from cradle to grave.” The digital thread connects all the various capabilities in the digital twin back to the part designs, requirements and software that goes into the product represented by the digital twin.
Disaster Recovery as a Service	Disaster recovery as a service (DRaaS) is a cloud computing and backup service model that uses cloud resources to protect applications and data from disruption caused by disaster. It gives an organisation a total system backup that allows for business continuity in the event of system failure.
DWDM	Dense Wavelength Division Multiplexing (DWDM) is a fibre-optic communications technology that uses different wavelength to multiplex (i.e. combine and transmit) multiple signals (or data streams) simultaneously on the same fibre. DWDM can be applied to increase the bandwidth of existing fibre networks

Edge computing technologies (multi-access computing, fog computing, cloudlet, micro-data centre)	Edge computing allows data produced by internet-of-things (IoT) devices to be processed closer to where it is created instead of sending it across long routes to data centres or clouds.
End point protection – Identity and Access Management	Identity and access management (IAM) in enterprise IT is about defining and managing the roles and access privileges of individual network users and the circumstances in which users are granted (or denied) those privileges. Those users might be customers (customer identity management) or employees (employee identity management. The core objective of IAM systems is one digital identity per individual. Once that digital identity has been established, it must be maintained, modified and monitored throughout each user's "access lifecycle.
e-SIM	GSMA Embedded SIM is a vital enabler for Machine-to-Machine (M2M) connections including the simple and seamless mobile connection of all types of connected machines.
Event stream processing	Some IoT applications will generate extremely high data rates that must be analysed in real time. Traditional IT architectures that store and subsequently process data do not have the necessary performance to deliver real-time analysis of such data streams. To address such requirements, distributed stream computing platforms (DSCPs) have emerged. They typically use parallel architectures to process very high-rate data streams to perform tasks such as real-time analytics and pattern identification.
FIDO Authentication Protocol	FIDO (Fast ID Online) is a set of technology-agnostic security specifications for strong authentication. FIDO is developed by the FIDO Alliance, a non-profit organisation, which seeks to standardise authentication at the client and protocol layers. FIDO specifications support multifactor authentication (MFA) and public key cryptography. Unlike password databases, FIDO stores personally identifying information (PII), such as biometric authentication data, locally on the user's device to protect it. FIDO's local storage of biometrics and other personal identification is intended to ease user concerns about personal data stored on an external server in the cloud. By abstracting the protocol implementation with application programming interfaces (APIs), FIDO also reduces the work required for developers to create secure logins for mobile clients running different operating systems (OSes) on different types of hardware.

G-PON	GPON network is capable of transmitting Ethernet, TDM (Time Division Multiplexing) as well as ATM traffic. A GPON network consists of OLT (Optical Line Terminals), ONU (Optical Network Unit), and a splitter. The splitter will divide the signal when needed. The OLT takes in all of the optical signals in the form of beams of light from ONUs and will convert it to an electrical signal. OLTs normally support up to 72 ports. An ONU connects to end users and will send their signals back to the OLT. A GPON network can reach up to 20 km and provide service up to 64 end users. GPON utilises both upstream and downstream data by means of Optical Wavelength Division Multiplexing (WDM).
Hardware Security	Hardware security is the use of chip-based functions to address a number of security needs, including (but not limited to) physical protection, device identification/authentication, remote attestation, and system and data integrity.
IaaS container encryption	Infrastructure as a service (IaaS) container encryption is a way for organisations to protect their data held with cloud providers. It is a similar approach to encrypting a hard drive on a laptop, but it is applied to the data from an entire process or application held in the cloud.
Identity management as a Service	Identity-as-a-Service ("IDaaS") is a cloud-based service that provides a set of identity and access management functions to target systems on customers' premises and/or in the cloud.
Intelligent Mesh	The transition from centralised and cloud-based IoT architectures toward edge-oriented IoT architectures, with intelligence migrating toward endpoints, gateways and similar devices, is underway. However, today's edge architectures are still somewhat hierarchic, with information flowing through well-defined layers of endpoints to the near edge, sometimes the far edge and, eventually, cloud and enterprise systems. However, in the long term, this neat set of layers will dissolve to create a more unstructured architecture consisting of a wide range of "things" and services connected in a dynamic flexible mesh. In this scenario, a smart "thing" such as a drone might communicate with an enterprise IoT platform, a government drone tracking service, local sensors and city-level local cloud services, and then conduct peer-to-peer exchanges with nearby drones for navigational purposes.
IOT PKI and Digital certificates	Digital certificates play a crucial role in establishing identity, and maintaining data and device integrity. PKI uses digital certificates to enable device-to-device or device-to-server identity authentication. Certificates also protect the data exchanged between devices.
IPv6, 6LoWPAN	6LoWPAN is the name of an Internet Engineering Task Force (IETF) standard that defines a compact version of IPv6 for performance-constrained networks. 6LoWPAN brings the benefits of IP networking to mesh and sensor networks, which, in the past, often used proprietary technologies. 6LoWPAN can be implemented in a small-footprint protocol stack appropriate for devices with limited processing power and memory.

Li-Fi	Li-Fi is a Visible Light Communications (VLC) system. Like Wi-Fi, it's a bidirectional wireless communication technology. However, where Wi-Fi uses radio waves to transmit data, Li-Fi uses visible light from LED lightbulbs. Data is transmitted over Li-Fi by modulating the intensity of a light- essentially dimming the light or turning it on and off at a very high speed (see above). The changes are so fast that they are imperceptible to the human eye, so it is not intrusive. This light is then received by a photosensitive detector and demodulated in electronic form. It is then converted back into a data stream, making it usable for video, audio and other internet tasks on a computer or smartphone.
LoRaWAN	The LoRaWAN open specification is a low power, wide area networking (LPWAN) protocol based on LoRa Technology. Designed to wirelessly connect battery-operated things to the Internet in regional, national or global networks, the LoRaWAN protocol leverages the unlicensed radio spectrum in the Industrial, Scientific and Medical (ISM) band. The specification defines the device-to-infrastructure of LoRa physical layer parameters and the LoRaWAN protocol, and provides seamless interoperability between devices.
LTE Advanced	LTE Advanced is the next major step in the evolution of our LTE networks. A new network technology that is expected to both help band-aid the massive increases in mobile data demand, and deliver much higher data speeds for all.
LTE Advanced Pro	LTE-Advanced Pro (LTE-A Pro) will be used for specifications defined under 3GPP's Release 13 (R13) and Release 14 (R14). LTE-A Pro will build on previous iterations to further improve the LTE platform as well as address new use cases.
LTE Enhanced License Assisted Access (eLAA)	Licensed Assisted Access (LAA) is introduced in 3GPP release 13 as part of LTE Advanced Pro. It uses carrier aggregation in the downlink to combine LTE in unlicensed spectrum (5 GHz) with LTE in the licensed band. This aggregation of spectrum provides for a fatter pipe with faster data rates and more responsive user experience. Enhanced licensed assisted access (eLAA), introduced in Release 14, enables both uplink and downlink operation of LTE in unlicensed bands.
LTE Mission Critical (MC) services (MCPTT, MCData, MCVideo)	LTE mission critical services highlighted in Release 14 - include Mission critical push-to-talk, (MPCPTT), Mission Critical Data (MCData), and Mission Critical Video(MCVideo)
LTE-M/eMTC (Cat M1)	LTE Cat M1 is part of the same 3GPP Release 13 standard that also defined Narrowband IoT (NB IoT or LTE Cat NB1) - both are LPWA technologies in the licensed spectrum. With uplink and downlink speeds of 375 kb/s in half-duplex mode, Cat M1 specifically supports IoT applications with low to medium data rate needs.

LTE-M/eMTC (Cat M2)	Enhancement of Cat M1 in 3GPP Rel14, with higher data rate of up to 2.5 Mbps.
LTE-V2X/C-V2X	Cellular-V2X (C-V2X) as initially defined as LTE V2X in 3GPP Release 14 is designed to operate in several modes: • Device-to-device This is Vehicle-to-Vehicle (V2V), Vehicle-to-(Roadway) Infrastructure (V2I) and Vehicle-to-Pedestrian (V2P) direct communication without necessarily relying on network involvement for scheduling. This mode is analogous to the ad hoc communications paradigm used in 802.11p. • Device-to-cell tower is another V2I communications link, which enables network resources and scheduling and utilises existing operator infrastructure. Device-to-cell tower communications constitute at least part of the V2I proposition and is important to end-to-end solutions. • Device-to-network is the V2N solution using traditional cellular links to enable cloud services to be part of the end-to-end solution.
LTE-Wi-Fi Aggregation WLAN Integration using with IPSec Tunnel (LWIP)	LWIP is a 3GPP Release 13 feature that enables Wi-Fi to be more optimally integrated into an LTE Access network. The specification of LWIP currently limits its use to data, and so it is envisaged that it will be typically be used to provide more efficient load balancing between LTE and Wi-Fi through IP level switching or aggregation just above the PDCP layer, enabling LTE users to benefit from the capacity boost of Wi-Fi. WIP is similar to LWA in that both make use of unlicensed 802.11 technologies. The difference is that LWA aggregates LTE and Wi-Fi at the packet data convergence protocol (PDPC) layer, while LWIP aggregates or switches between LTE and Wi-Fi links at the IP layer, just above PDCP. The key advantage of LWIP is that it is able to leverage any legacy Wi-Fi network for increasing the capacity offered to the user. This can be contrasted to LWA that may require significant enhancements to the 802.11 based security and flow control capabilities. LWIP also has the benefit of enhancing uplink performance through IP layer switching, or aggregation between the LTE and Wi-Fi uplinks.
LTE-WLAN Aggregation (LWA)	LWA is a technology defined by the 3GPP. In LWA, a mobile handset supporting both LTE and Wi-Fi may be used by the network to utilise both links simultaneously. It provides an alternative method of using LTE in unlicensed spectrum, which unlike LAA/LTE-U, can be deployed without hardware changes to the network infrastructure equipment and mobile devices, while providing similar performance to that of LAA.

Machine Learning (including Ensemble learning methods)	Machine learning is the branch of computing that incorporates algorithms to analyse data, which is inputted, and via statistical analysis can make a prediction on an output, while incorporating new data as it becomes available, to update the predicted output. Ensemble methods are meta-algorithms that combine several machine learning techniques into one predictive model in order to decrease variance (bagging), bias (boosting), or improve predictions (stacking).
Message Queue Telemetry Transport (MQTT)	MQTT is a Machine-to-Machine (M2M)/"Internet-of-Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/ or network bandwidth is at a premium.
Mixed Reality (both Augmented and Virtual)	Mixed reality (MR) is the merging of real and virtual worlds to produce new environments and visualisations where physical and digital objects co-exist and interact in real time. Mixed reality takes place not only in the physical world or the virtual world, but is a mix of reality and virtual reality, encompassing both augmented reality and augmented virtuality.
Multe-Fire	MulteFire is an LTE-based technology that operates standalone in unlicensed and shared spectrum, including the global 5 GHz band. Based on 3GPP Release 13 and 14, MulteFire technology supports Listen-Before-Talk for fair co-existence with Wi-Fi and other technologies operating in the same spectrum. It supports private LTE and neutral host deployment models. Target vertical markets include industrial IoT, enterprise, cable, and various other vertical markets.
Natural Language Generation	Natural language generation (NLG) is the use of artificial intelligence (AI) programming to produce written or spoken narrative from a dataset. NLG is related to computational linguistics, natural language processing (NLP) and natural language understanding (NLU), the areas of AI concerned with human-to-machine and machine-to-human interaction.
Natural language Understanding	Natural language understanding (NLU) is a branch of artificial intelligence (AI) that uses computer software to understand input made in the form of sentences in text or speech format.
NB-IoT (Cat NB1)	Narrowband IoT (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard developed by 3GPP in Release 13, in June 2016. NB-IoT focuses specifically on indoor coverage, low cost, long battery life, and high connection density. NB-IoT uses a subset of the LTE standard, but limits the bandwidth to a single narrow-band of 200kHz with data rate up to 60 kbps.
NB-IoT (Cat NB2)	Enhancement of Cat NB1 in 3GPP Rel14, with higher data rate of up to 160 kbps.

Near field communication	Near field communication, abbreviated NFC, is a form of contactless communication between devices like smartphones or tablets. Contactless communication allows a user to wave the smartphone over a NFC compatible device to send information without needing to touch the devices together or go through multiple steps setting up a connection.
NG-PON2	ITU G.989, 2015. Not only is NG-PON2 (10G down / 10G up, 10G down / 2.5G up) a higher bandwidth version of GPON, it also enables new capabilities like wavelength mobility and channel bonding.
NG-PON2+ (TWDM-PON, OFDM-PON)	Time wavelength division multiplexing PON (TWDM-PON) provides four or more wavelengths per fibre, each of which is capable of delivering symmetrical or asymmetrical bit rates of 2.5 Gbps or 10 Gbps.
OneM2M	oneM2M provides a set of standards to provide a horizontal IoT platform architecture, enabling applications to connect securely, through standardised APIs, to data sources regardless of the underlying connectivity technology used. It incorporates the most commonly used industry protocols for IoT, such as MQTT, CoAP and HTTP. It offers device management functionality using device management standards from the OMA and the Broadband Forum.
Open Mobile Alliance Lightweight Machine-to-Machine (OMA LWM2M)	OMA Lightweight M2M is a protocol from the Open Mobile Alliance for M2M or IoT device management. Lightweight M2M enabler defines the application layer communication protocol between a LWM2M Server and a LWM2M Client, which is located in a LWM2M Device. The OMA Lightweight M2M enabler includes device management and service enablement for LWM2M Devices. The target LWM2M Devices for this enabler are mainly resource constrained devices. Therefore, this enabler makes use of a light and compact protocol as well as an efficient resource data model. It provides a choice for the M2M Service Provider to deploy a M2M system to provide service to the M2M User. It is frequently used with CoAP.
Optical OFDM (OFDM for optical)	Orthogonal frequency division multiplexing (OFDM) is a modulation technique, which is now used in most new and emerging broadband wired and wireless communication systems because it is an effective solution to inter-symbol interference caused by a dispersive channel. Very recently, a number of researchers have shown that OFDM is also a promising technology for optical communications.
Predictive Analytics	Predictive analytics is the branch of the advanced analytics, which is used to make predictions about unknown future events. Predictive analytics uses many techniques from data mining, statistics, modelling, machine learning, and artificial intelligence to analyse current data to make predictions about future.
Random Phase Multiple Access (RPMA)	RPMA is a low-power wide-area (LPWA) channel access method that utilises the unlicensed, globally available 2.4 GHz ISM (Industrial, Scientific and Medical) band. This means that one radio module can serve applications

	around the world, providing the scale and cost benefits that enable customers to profitably bring IoT solutions to market.
RISC-V	RISC-V (pronounced "risk-five") is an open source instruction set architecture (ISA) based on established reduced instruction set computing (RISC) principles. In contrast to most ISAs, RISC-V is freely available for all types of use, permitting anyone to design, manufacture and sell RISC-V chips and software. While not the first open ISA, it is significant because it is designed to be useful in modern computerised devices such as warehouse-scale cloud computers, high-end mobile phones and the smallest embedded systems. Such uses demand that the designers consider both performance and power efficiency. The instruction set also has a substantial body of supporting software, which fixes the usual weakness of new instruction sets.
Secure by Design	Secure by design, in software engineering, means that the software has been designed from the foundation to be secure. Malicious practices are taken for granted and care is taken to minimise impact in anticipation of security vulnerabilities, when a security vulnerability is discovered or on invalid user input.
Secure processing unit	Secure processing units (SPUs) are additional processor cores integrated onto microprocessors and ASSPs to provide a dedicated processing environment for security-related processes. SPUs typically include private memory resources for program storage, execution and key storage. SPUs may also include dedicated I/O and networking resources. An SPU implements a controlled and restricted communications protocol with the main processor to which it is attached, so as to prevent compromise of the SPU functionality.
Secure Web Gateway	A secure Web gateway is a type of security solution that prevents unsecured traffic from entering an internal network of an organisation. It is used by enterprises to protect their employees/users from accessing and being infected by malicious Web traffic, websites and virus/malware. It also ensures the implementation and compliance of the organisation's regulatory policy.
Security analytics	Security analytics is the process of using data collection, aggregation, and analysis tools for security monitoring and threat detection. Depending on the types of tools installed, security analytics solutions can incorporate large and diverse data sets into their detection algorithms.
Sigfox	Sigfox employs a proprietary technology that enables communication using the Industrial, Scientific and Medical ISM radio band which uses 868MHz in Europe and 902MHz in the US. It utilises a wide-reaching signal that passes freely through solid objects, called "ultra narrowband" and requires little energy, being termed "Low-power Wide-area network (LPWAN)". The network is based on one-hop star topology and requires a mobile operator to carry the generated traffic. The signal can also be used to easily cover large areas and to reach underground objects.

Software-defined security	Software-defined security (SDS) is a type of security model in which the information security in a computing environment is implemented, controlled and managed by security software. It is a software-managed, policy-driven and governed security where most of the security controls such as intrusion detection, network segmentation and access controls are automated and monitored through software.
Speech recognition	Speech recognition is the ability of a machine or program to identify words and phrases in spoken language and convert them to a machine-readable format.
Thread	Thread is a new open standard that assigns an Internet Protocol (IP) address to every device on a network, and that IP address extends through the node. Thread provides device-to-device communication without the need for an application gateway.
Tokenisation	Tokenisation is the process of replacing sensitive data with unique identification symbols that retain all the essential information about the data without compromising its security. Tokenisation, which seeks to minimise the amount of data a business needs to keep on hand, has become a popular way for small and mid-sized businesses to bolster the security of credit card and e-commerce transactions while minimising the cost and complexity of compliance with industry standards and government regulations.
Trusted Execution Environment	The trusted execution environment, or TEE, is an isolated area on the main processor of a device that is separate from the main operating system. It ensures that data is stored, processed and protected in a trusted environment. TEE provides protection for any connected “thing” by enabling end-to-end security, protected execution of authenticated code, confidentiality, authenticity, privacy, system integrity and data access rights.
WDM PON (Dedicated wavelength per user)	An emerging FTTH technology that is vendor-specific in its implementation at the optical layer. A major advantage is the long reach that WDM PON offers, and so it is mostly used today in backhaul scenarios to serve base stations, OLTs, or other aggregation devices.
XG(S)-PON	ITU G.9807.1, 2016. XGS-PON (10G down / 10G up) is a higher bandwidth, symmetric version of GPON. Again, the same capabilities of GPON and can co-exist on the same fibre with GPON. XGS-PON deployments are just beginning.
XG-PON (10G-PON)	ITU G.987, 2009. XG-PON (10G down / 2.5G up) is essentially a higher bandwidth version of GPON. It has the same capabilities as GPON and can co-exist on the same fibre with GPON. XG-PON has been minimally deployed to date.

Zigbee	ZigBee is a mesh network specification for low-power wireless local area networks (WLANs) that cover a large area. ZigBee is based on the Institute of Electrical and Electronics Engineers Standards Association's 802.15 specification. It operates on the IEEE 802.15.4 physical radio specification and in unlicensed radio frequency bands, including 2.4 GHz, 900 MHz and 868 MHz. The specifications are maintained and updated by the ZigBee Alliance.
Z-Wave	The Z-Wave protocol is an interoperable, wireless, RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments.

8 APPENDIX B: REFERENCES

[1] Holdowsky, Jonathan, Monika Mahto, Michael E. Raynor, and Mark Cotteleer. "Inside the Internet of Things (IoT)." Deloitte Insights. August 2015. https://www2.deloitte.com/insights/us/en/focus/internet-of-things/iot-primer-iot-technologies-applications.html.

[2] Main Services Digital Economy Technology Roadmap document

[3] Gohd, Chealsea. "Prepare Yourself for the "tsunami of Data" Expected to Hit by 2025." Futurism. December 2017. https://futurism.com/prepare-yourself-tsunami-data-expected-hit-2025.

[4] "IoT: Number of Connected Devices Worldwide 2012-2025." Statista. https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/.

[5] "Cisco Visual Networking Index: Forecast and Methodology, 2016–2021." Cisco. September 2017. https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.html.

[6] "Singapore Internet Exchange – Bringing The Internet World Closer." Singapore Internet Exchange. https://www.sgix.sg/.

[7] "Worldwide Spending on Augmented and Virtual Reality to Achieve a Five-Year CAGR of 71.6% by 2022." International Data Corporation. May 2018. https://www.idc.com/getdoc.jsp?containerId=prUS43860118.

[8] Wijman, Tom. "Newzoo's 2018 Report: Insights Into the $137.9 Billion Global Games Market." Newzoo. June 2018. https://newzoo.com/insights/articles/newzoos-2018-report-insights-into-the-137-9-billion-global-games-market/.

[9] Hall, Stefan. "Creative Disruption: The Impact of Emerging Technologies on the Creative Economy." World Economic Forum. February 2018. http://www3.weforum.org/docs/39655_CREATIVE-DISRUPTION.pdf.

[10] Fin, Niccola. "$439 Billion to Be Spent Worldwide on Consumer Entertainment by 2021." Global Consumer Entertainment Spend to Hit $439 Billion by 2021 - Press Article. April 2018. https://www.futuresource-consulting.com/Press-Global-Consumer-Entertainment-Content-Spend-0418.html

[11] "Cisco Visual Networking Index: Forecast and Methodology, 2016–2021." Cisco. September 2017. https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.html & MarketLine – Virtual & Augmented Reality – April 2018

[12] Cerwall, Patrik. "Ericsson Mobility Report." Ericsson. June 2018. https://www.ericsson.com/assets/local/mobility-report/documents/2018/ericsson-mobility-report-june-2018.pdf.

[13] Reese, Hope. "Steve Case: The 'third Wave' of the Internet Will Transform Our Institutions." TechRepublic. April 2016. https://www.techrepublic.com/article/steve-case-the-third-wave-of-the-internet-will-transform-our-institutions.

[14] "VR and AR Pushing Connectivity Limits." October 2018. https://www.qualcomm.com/media/documents/files/vr-and-ar-pushing-connectivity-limits.pdf

[15] "West Midlands to Become UK's First Large-scale 5G Testbed." GOV.UK. September 2018. https://www.gov.uk/government/news/west-midlands-to-become-uks-first-large-scale-5g-testbed.

[16] Harbert, Tam. "How 5G Will Make AI-Powered Devices Smarter." IQ by Intel. March 2018. https://iq.intel.com/how-5g-will-make-ai-powered-devices-smarter/.

[17] HPC Wire - HPC and AI – Two Communities Same Future- https://www.hpcwire.com/2018/01/25/hpc-ai-two-communities-future/

[18] Cohen, Reuven. "Global Bitcoin Computing Power Now 256 Times Faster Than Top 500 Supercomputers, Combined!" Forbes. November 2013. https://www.forbes.com/sites/reuvencohen/2013/11/28/global-bitcoin-computing-power-now-256-times-faster-than-top-500-supercomputers-combined/.

[19] Clement, Bret. "State of the Cloud Report." February 2018. https://www.rightscale.com/press-releases/rightscale-2018-state-of-the-cloud-report.

[20] Dalibor, Petrovic. "The Cloud Is Here: Embrace the Transition." Deloitte Review. https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/consulting/ca_cloud_pov_EN_doc.PDF.

[21] Molla, Rani. "Google, Amazon and Microsoft Cloud Businesses Helped More than Double Spending on Data Centers Last Year." Recode. March 2018. https://www.recode.net/2018/3/15/17124300/google-amazon-microsoft-cloud-200-percent-jump-data-center-acquisitions.

[22] Gasparik, Amanda. "Safety-first AI for Autonomous Data Center Cooling and Industrial Control." Google. August 2018. https://www.blog.google/inside-google/infrastructure/safety-first-ai-autonomous-data-center-cooling-and-industrial-control/.

[23] "Cisco Global Cloud Index: Forecast & Methodology- 2016–2021 White Paper." February 2018. https://investor.cisco.com/investor-relations/news-and-events/news/news details/2018/Global-Cloud-Index-Projects-Cloud-Traffic-to-Represent-95-Percent-of-Total-Data-Center-Traffic-by-2021/default.aspx

[24] "Submarine Cable Map 2018." Submarine Cable Map 2018. https://submarine-cable-map-2018.telegeography.com/.

[25] Neilson, Wayne. "Submarine Telecoms Industry Report." Submarine Telecoms Forum. October 2017. https://subtelforum.com/products/submarine-telecoms-industry-report/.

[26] Submarine Networks https://www.submarinenetworks.com/en

[27] "9 Reasons Why Singapore Is the Ideal Data Centre Hub in Asia Pacific." Singtel. November 2017. https://www.singtel.com/business/singtel-global-services/content/9-reasons-why-singapore-is-the-ideal-data-centre-hub-in-asia-pacific.

[28] Mah, Paul. "NEC to Build Bay To Bay Express Submarine Cable System." DCD. July 2018. https://www.datacenterdynamics.com/news/nec-to-build-bay-to-bay-express-submarine-cable-system/.

[29] "Submarine Cable to Connect Southeast Asia." Smart Cities World. March 2018. https://www.smartcitiesworld.net/news/news/submarine-cable-to-connect-southeast-asia-2712.

[30] Mah, Paul. "The Future of Enterprise Data Centers in the Asia Pacific." DCD. September 2018. https://www.datacenterdynamics.com/analysis/future-enterprise-data-centers-asia-pacific/.

[31] Lima, Joao. "Singapore. The New Epicentre of the Data Centre World?" Data Economy. April 2018. https://data-economy.com/singapore-the-new-epicentre-of-the-data-centre-world/.

[32] "Market Research Reports, Marketing Research Company, Business Research by Markets and Markets." Market and Markets https://www.marketsandmarkets.com/.

[33] "The Digital Economy in Singapore." Economic Survey of Singapore Third Quarter 2017. November 2017. https://www.mti.gov.sg/ResearchRoom/SiteAssets/Pages/Economic-Survey-of-Singapore-Third-Quarter-2017/FullReport_3Q17.pdf.

[34] Poroski, Michael. "Forecast: Communications Service Provider Operational Technology, Worldwide, 2016-2022, 1Q18 Update." March 2018. https://www.gartner.com/doc/3869908/forecast-communications-service-provider-operational.

[35] "Indicators | ASEANStatsDataPortal." Indicators | ASEANStatsDataPortal. https://data.aseanstats.org/.

[36] Asian Development Bank. "GDP Growth in Asia and the Pacific, Asian Development Outlook (ADO)." ADB Data Library | GDP Growth in Asia and the Pacific, Asian Development Outlook (ADO). November 2017.https://data.adb.org/dataset/gdp-growth-asia-and-pacific-asian-development-outlook-ado.

[37] "Global State of Mobile Networks-August 2016." OpenSignal – August 2016 https://opensignal.com/reports/2016/08/global-state-of-the-mobile-network.

[38] "Five Trends in Shared Mobile Infrastructure." ITU News. February 2018. https://news.itu.int/five-trends-shared-mobile-infrastructure/.

[39] The Australian Financial Review. "Shared 5G Infrastructure Will Be Needed to Deliver ROI." Which-50. September 2018. https://which-50.com/shared-5g-infrastructure-will-be-needed-to-deliver-roi-2/

[40] Montagne, Roland. "FTTH/B Panorama." Idate Digiworld. September 2017. http://www.ftthcouncil.eu/documents/IDATE_European_FTTH_B_panorama _at_Sept_2017_VF.pdf.

[41] Robin Marsh, "G.fast networks of the future will be with us sooner than you think", July 2018, https://www.ispreview.co.uk/index.php/2018/07/g-fast-networks-of-the-future-will-be-with-us-sooner-than-you-think-guest-editorial.html

[42] Littmann, Dan. "Communications Infrastructure Upgrade: The Need for Deep Fibre." July 2017. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/technology-media-telecommunications/us-tmt-5GReady-the-need-for-deep-fiber-pov.pdf.

[43] "Disrupting Telco Business Through SDN / NFV | Tecnología, Media Y Telecomunicaciones | Publicaciones." Deloitte Spain. December 2014 https://www2.deloitte.com/es/es/pages/technology-media-and-telecommunications/articles/disrupting-telco-business-through-SDN-NFV.html.

[44] "News Releases." Singtel. https://www.singtel.com/about-Us/news-releases.

[45] "FTTH/B Global Ranking." FTTH Council Europe. February 2018. http://www.ftthcouncil.eu/documents/FTTH GR 20180212_FINAL.2.pdf.

[46] "Singtel and VMware to Accelerate Digital Transformation of Enterprises across Asia Pacific - Singtel." April 2018. https://www.singtel.com/about-Us/news-releases/singtel-and-vmware-to-acelerate-digital-transformation-of-enterprises-acros-a.

[47] "Ericsson Expands Unified Delivery Network Ecosystem with New Partner Additions." Ericsson.com. June 2017.https://www.ericsson.com/en/press-releases/2016/4/ericsson-expands-unified-delivery-network-ecosystem-with-new-partner-additions.

[48] Bernold, Heinz, Michael Steiger, Maikel Wilms, and Wolfgang Bock. "A Playbook for Accelerating 5G in Europe." BCG. September 2018. https://www.bcg.com/en-sea/publications/2018/playbook-accelerating-5g-europe.aspx.

[49] Daecher, Andy. "The Internet of Things: A Technical Primer." Deloitte Insights. February 2018. https://www2.deloitte.com/insights/us/en/focus/internet-of-things/technical-primer.html.

[50] Torchia, Marcus, and Michael Shirer. "IDC Forecasts Worldwide Technology Spending on the Internet of Things to Reach $1.2 Trillion in 2022." International Data Corporation. June 2018. https://www.idc.com/getdoc.jsp?containerId=prUS43994118.

[51] ICT practice. "Exploring Opportunities in the South East Asian IoT Market for ICT players in Taiwan." Frost & Sullivan. August 2015. https://www.timglobe.com.tw/upload/image/__III/exploring_iot_opportunities_in_asean.pdf

[52] Schatsky, David, Navya Kumar, and Sourabh Bumb. "Intelligent IoT." Deloitte Insights. December 2017.https://www2.deloitte.com/insights/us/en/focus/signals-for-strategists/intelligent-iot-internet-of-things-artificial-intelligence.html.

[53] "Logistics 4.0: How IoT Is Transforming The Supply Chain." Forbes. October 2018. https://www.forbes.com/sites/insights-inteliot/2018/06/14/logistics-4-0-how-iot-is-transforming-the-supply-chain/#69c00ae880fc.

[54] Heil, Marie-Elisabeth. "Beyond B2B, A Digital Reality Check." Using Digital Twins in Supply Chain. https://www.b2b.com/using-digital-twins-in-supply-chain.

[55] Howells, Richard. "How Digital Twins Can Ensure Your Best-Laid Supply Chain Plans Never Go Awry." Forbes. September 2018.https://www.forbes.com/sites/sap/2018/09/26/how-digital-twins-can-ensure-your-best-laid-supply-chain-plans-never-go-awry/#1707af965eed.

[56] Laurent, Patrick. Deloitte – Using Block Chain & IoT in Supply Chain Traceability." Deloitte Review. https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/technology/lu-blockchain-internet-things-supply-chain-traceability.pdf.

[57] "A Revolutionary Digital Tool for the Healthcare Industry: The Internet-of-Things." Deloitte Turkey. July 2017. https://www2.deloitte.com/tr/en/pages/life-sciences-and-healthcare/articles/digital-health-iot.html.

[58] Research, P&S Market. "Global IoT Healthcare Market Size Is Expected to Reach $267.6 Billion By 2023: P&S Market Research." Globe Newswire News Room. May 2018. https://globenewswire.com/news-release/2018/05/31/1514390/0/en/Global-IoT-Healthcare-Market-Size-is-Expected-to-Reach-267-6-Billion-By-2023-P-S-Market-Research.html

[59] Friedman, Sam. "Telematics: Overcoming the Speed Bumps." Deloitte United States. August 2018.https://www2.deloitte.com/us/en/pages/financial-services/articles/deloitte-center-for-financial-services-overcoming-speed-bumps-on-the-road-to-telematics.html.

[60] Machina & Nokia IoT Study. June 2016“https://www.theedgesingapore.com/article/singapore-iot-market-be-worth-more-700-million-2020-says-nokia”

[61] "Singapore Government Outlines Its Approach to IoT." ComputerWeekly.com. March 2018. https://www.computerweekly.com/news/252437239/Singapore-government-outlines-its-approach-to-IoT.

[62] "New 5G Cross-border Corridor for Connected and Automated Mobility Announced at the Digital Assembly 2018." Digital Single Market. June 2018. https://ec.europa.eu/digital-single-market/en/news/new-5g-cross-border-corridor-connected-and-automated-mobility-announced-digital-assembly-2018

[63] "Five Vectors of Progress in the Internet of Things." Deloitte Insights. June 2018. https://www2.deloitte.com/insights/us/en/focus/signals-for-strategists/enterprise-iot-applications-five-vectors-of-progress.html.

[64] Carrozzo, Gino. "Available on River Publishers: Advancing IoT Platforms Interoperability E-Book." SymbIoTe. July 2018. https://www.symbiote-h2020.eu/blog/2018/07/30/symbiote-2nd-open-call-winners-onboarded-2/.

[65] Schatsky, David, and Avinav Trigunait. "Internet of Things." Deloitte Insights. January 2018. https://www2.deloitte.com/insights/us/en/focus/signals-for-strategists/internet-of-things-iot-adoption-edge-analytics-wireless-communication-networks.html.

[66] "Data Security and Privacy" Deloitte Turkey.. https://www2.deloitte.com/tr/en/pages/risk/solutions/data-security-and-privacy.html.

[67] Jabil. "Navigating Smart Home Data Security Concerns." IoT For All. August 2018. https://www.iotforall.com/smart-home-data-security/.

[68] Cakebread, Caroline. "Consumers Are Holding off on Buying Smart-home Gadgets Thanks to Security and Privacy Fears." Business Insider Singapore. November 2017. https://www.businessinsider.sg/consumers-holding-off-on-smart-home-gadgets-thanks-to-privacy-fears-2017-11/?r=US&IR=T.

[69] "Internet of Things in ASEAN Manufacturing." International Data Corporation. June 2016. https://www.idc.com/getdoc.jsp?containerId=AP41336816.

[70] "The Potential of the Internet of Things for ASEAN." The ASEAN Post. January 2018. https://theaseanpost.com/article/potential-internet-things-asean-1.

[71] Duan, Lin. "Singapore: Asia's Innovation Hub | Articles | Chief Innovation Officer." Articles | Chief Innovation Officer | Innovation Enterprise. September 2016. ttps://channels.theinnovationenterprise.com/articles/singapore-asia-s-innovation-hub.

[72] Lago, Cristina. "Why Are Data Centres Relocating To Asia?" CIO Asia. September 2018. https://www.cio-asia.com/article/3296099/data-center/why-are-businesses-relocating-data-centres-to-southeast-asia.html.

[73] EIU. "Preparing for Disruption: Technological Readiness Ranking." Preparing for Disruption: Technological Readiness Ranking. 2018 https://www.eiu.com/public/topical_report.aspx?campaignid=TechReadiness.

[74] "South Korea Tops IDC Asia/Pacific's 2017 IoT Readiness Index." International Data Corporation. July 2017. https://www.idc.com/getdoc.jsp?containerId=prAP42904617

[75] "Introduction to DWDM Technology." DWDM Technology. 2018. https://www.cisco.com/c/dam/global/de_at/assets/docs/dwdm.pdf.

[76] "Cloud Computing." IMDA, December 2017. https://www.imda.gov.sg/-/media/imda/files/industry-development/infrastructure/technology/cloudcomputing.pdf?la=en

[77] "Home." SME Portal. 2018. https://www.smeportal.sg/.

9 APPENDIX C: WORKGROUP MEMBERS

Dr. Sun Sumei (Chairman of Workgroup 1)	Head of Communications and Networks Cluster, Institute for Infocomm Research, Agency for Science, Technology and Research (A*STAR)
Mr. Mark Chong (Co-Chairman of Workgroup 1)	Group Chief Technology Officer, Singapore Telecommunications Ltd. (Singtel)
Mr. Rajesh Chainani	Managing Director, Cisco Systems Singapore
Mr. David Morrison	Director, Chief Technology Officer, Huawei Technologies (Singapore) Pte. Ltd.
Mr. Chua Hee Tiam	Senior Director, DSO National Laboratories
Mr. Raymond Soh	Vice President, Ericsson Telecommunications Pte. Ltd.
Mr. Quek Yang Boon	Director, Government Technology Agency of Singapore
Mr. Guillaume Mascot	Head of Government Relations APJ, Nokia Solutions and Networks Holdings Singapore Pte. Ltd.
A/Prof. Ben Leong	Associate Professor, National University of Singapore, School of Computing
Mr. Oliver Tian	President, Singapore Industrial Automation Association
Mr. Yao Shih Jih	Executive Vice President / General Manager, InfoComm, ST Engineering Electronics
Mr. Benjamin Tan	Managing Director, SuperInternet ACCESS Pte Ltd
A/P Tony Quek	Acting Head, ISTD Pillar, Singapore University of Technology and Design (SUTD)

Mr. Harin S Grewal	Cluster Director, Networks, Technology and Resilience, Infocomm Media Development Authority
Mr. Koh Wee Sain	Director, National Infocomm Infrastructure, Infocomm Media Development Authority
Mr. Leck Leng Chye	Senior Assistant Director, Infocomm Resource and Technology, Infocomm Media Development Authority
Mr. Lee Han Chuan	Senior Manager, National Infocomm infrastructure, Infocomm Media Development Authority
Mr. Cason Neo	Manager, National Infocomm Infrastructure, Infocomm Media Development Authority