

# Singapore's Digital Connectivity Blueprint



Ministry of Communications  
and Information



INFOCOMM  
MEDIA  
DEVELOPMENT  
AUTHORITY

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# Foreword

## By Co-Chairs of the Advisory Panel on Digital Infrastructure

Singapore is recognised for being at the forefront of digital infrastructure development. While digital infrastructure may not be visible to most of us, it plays a key foundational role in the growth of our digital economy and in enabling our people and enterprises to benefit from digitalisation.

Today, digitalisation has created good jobs for our people, opportunities for our enterprises, and enabled our communities to interact with one another and access information with ease. As technology advances, we must ensure that Singapore's digital infrastructure continues to be ready for the future.

As the Co-Chairs of the Advisory Panel on Digital Infrastructure, we have had robust and deep discussions with the panel members and other industry partners on the way forward for Singapore's digital infrastructure. These rich and insightful discussions have culminated in this Digital Connectivity Blueprint, which sets out Singapore's future-oriented approach in digital infrastructure planning, so that our people and enterprises can create and capture opportunities arising from digital and tech trends in a safe and sustainable way.

At its core, the Digital Connectivity Blueprint is really about integrated masterplanning – across different infrastructure layers, across sectors, and across time. This is why we have taken an expansive view in setting out our plans for three categories of digital infrastructure – hard connectivity and compute infrastructure, soft infrastructure such as digital utilities, and the nexus between physical and digital infrastructure such as sensors, middleware and autonomous robots. In addition, the close partnerships across the public and private sectors will continue to be key to the growth of digital connectivity for our collective digital future. Which brings us to the last but equally important form of integration – across time – where we always have an eye to the future in planning the development of Singapore's digital connectivity, even as we ensure that we meet our current needs.

Put together, this is a uniquely Singapore approach to masterplanning for our digital connectivity in a coordinated way, where we signal our commitments to remain at the cutting edge in building future-ready digital infrastructure. Given the speed at which technology evolves, we will also continually review and refresh our plans to enable our people and enterprises to capture new opportunities.



**Dr. Janil Puthucheary**  
Senior Minister of State for  
Communications and Information



**Mr Irving Tan**  
Executive Vice President,  
Global Operations, Western Digital

## 01

# An Introduction to Singapore's Digital Connectivity

## Our Digital Economy Today

**Countries around the world are reaping the benefits of an expanding global digital economy.**

With growing digital adoption, innovation and trade, the global digital economy is estimated to reach 24% of global Gross Domestic Product (GDP) by 2025, up from 15% in 2016<sup>1</sup>.

**As a digital hub, Singapore plays our part in contributing to global growth.**

Digitalisation in sectors such as maritime, aerospace and financial services has allowed Singapore to expand our role as a hub and drive greater growth in Southeast Asia and globally. For instance, the digitalisation of Singapore's maritime sector has enabled more efficient supply chain management through Singapore to different parts of the world. In frontier innovation, we host a vibrant ecosystem of start-ups, global investors, entrepreneurs and researchers that develop new solutions for the global market.

**Being at the forefront of digitalisation and the global ecosystem unlocks economic opportunities for all sectors in Singapore.**

Digitalisation is woven into the very fabric of enterprises; many processes,

service offerings and jobs today are already underpinned by it in one way or another. Concerted investments in digital capabilities will augment existing enterprises and jobs, while providing the potential for new ones in the future. Such investments encompass those in infrastructure as well as talent. Together with other essential elements such as our ecosystem of innovators and skilled workforce, digital infrastructure is fundamental to unlocking greater economic opportunities.

**Digitalisation has already brought about tangible economic and social benefits for Singapore.**

The Information and Communications (I&C) sector, comprising industries such as software development and online services, is one of the fastest growing in Singapore. In 2022, it grew by 8.6%, compared to 3.6% for the overall economy. Its local workforce has also grown by 42% from 2017 to 2022. The digital economy extends far beyond the I&C sector. Many other sectors have tapped on digitalisation to maintain their competitive edge. For example, Singapore has carved a niche in high-value manufacturing and enabled automotive

<sup>1</sup> Source: Oxford Economics and Huawei Technologies, Digital Spillover (2017). Estimates based on broad definition that spans the direct and indirect value from digital technologies.

manufacturing to build a presence here through effective deployment of digital technologies. In banking and finance, the adoption of innovative fintech solutions has strengthened Singapore's position as a leading financial centre in the region. Overall, both the I&C sector and digitalisation in other sectors have contributed to the growth of Singapore's digital economy, which has expanded strongly to account for approximately 17% of Singapore's GDP in 2022. In addition, widespread

digital access has fostered a more engaged society. As of 2022, 99% of Singaporean households have Internet access, 90% have computer access and we have a high mobile penetration rate of 170%. These enable greater social interaction and more access to information through digital means. Overall, digitalisation has allowed Singaporeans to embrace new ways to live, work and play. These include remote work, hybrid learning and telemedicine.

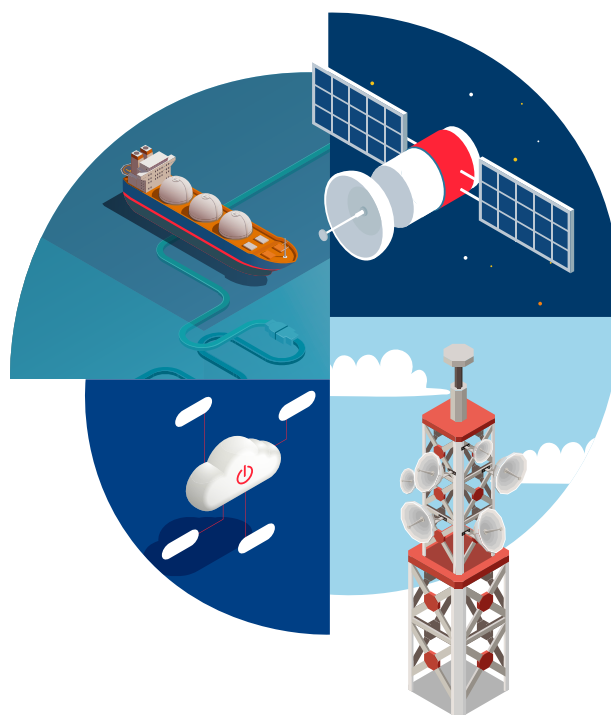
## The Foundational Role of Digital Connectivity

**Digital connectivity is the 'invisible foundation' that powers the growth of the digital economy.**

This connectivity goes beyond Singapore. It transcends boundaries and allows us to be plugged into the global ecosystem. The infrastructure underlying digital connectivity, including to our regional and international partners, allows this to happen. This infrastructure is often less visible – submarine cables laid across ocean floors, satellites in space, optical fibre cables laid underground and mobile base stations on rooftops. Parts of it are even invisible, like the radio frequencies that transmit wireless communications. Working seamlessly behind the scenes, they are the foundation upon which our digital economy and society thrive.

**Singapore is recognised for being at the forefront of digital infrastructure development.** We were ranked first for technology infrastructure in the International Institute for Management Development (IMD)'s World Competitiveness Yearbook 2022, and second for connectivity in Economist Impact's Global Digital Cities Index 2022. We have also been ranked among the top three for Internet bandwidth speed by the International Telecommunication Union since 2013. Singapore also has the highest median fixed broadband download speed in the world<sup>2</sup>.

**Singapore's future-oriented approach and commitment to making strategic investments ahead of demand have allowed us to provide quality digital connectivity.** Today, we already have high levels of digital connectivity. We have had nationwide fibre-to-the-home since 2013, providing gigabit connectivity. We also achieved 95% outdoor coverage on our first two 5G Standalone (SA) networks in end-2022. By investing in digital infrastructure before use cases and 'killer applications' were well-defined, we have been ready to embrace opportunities when demand matured, and to have the required capacity to deal with unexpected challenges.



<sup>2</sup> Source: Ookla Speedtest Global Index (April 2023).

### Singapore's Nationwide Fibre Broadband Network (NBN)

When Singapore made the decision to build the NBN in the mid-2000s, 30 Mbps speeds on then-copper-based infrastructure were more than satisfactory. However, we envisioned that fibre-to-the-last-mile would be pivotal for the future growth of then-budding digital services, such as e-learning, high-definition entertainment and online collaboration. Hence, Singapore took the leap to make NBN a reality. It was a large-scale endeavour requiring substantial investment. The Government invested S\$1B to support the building of core network infrastructure and the active transmission layer. This enabled competitively priced broadband plans for all Singaporean enterprises and consumers. Today, 1 Gbps plans are the standard in homes, costing as low as S\$30 per month. The NBN's value was made starkly apparent during the COVID-19 pandemic, as we had more than sufficient buffer capacity to cater for the surge in bandwidth demand, to transition smoothly and seamlessly to digital work and online interactions.

### 5G Standalone (SA) Mobile Networks

Singapore was among the leading countries that made the decision to build 5G SA mobile networks directly in 2020, versus the incremental Non-Standalone (NSA) networks. This was to realise the full range of capabilities that 5G has to offer, including ultra-low latency, network slicing and pervasive Internet of Things (IoT). Spectrum was allocated, with clear security and resilience design requirements. This was supported by testbeds and grants to facilitate adoption and testing of use cases. These investments have yielded early fruit with increasing 5G adoption in sectors such as manufacturing, logistics, maritime, healthcare and security.

## A Future-Oriented and Holistic Approach for the Next Bound

This Digital Connectivity Blueprint, developed in consultation with an Advisory Panel on Digital Infrastructure and other industry partners, sets the direction for the next bound of Singapore's digital connectivity. It outlines (i) our strategic priorities and (ii) moves in emerging areas to stay ahead of the curve.

**As part of these plans, we will continue to invest ahead of demand.** This considers technological trends shaping future demand for digital infrastructure.

**We look beyond traditional hard infrastructure and plan for the entire 'digital infrastructure stack'.** Singapore views this stack as comprising three layers – hard infrastructure, physical-digital infrastructure, and soft infrastructure.

**Hard Infrastructure.** We will enhance traditional connectivity, including submarine, satellite, broadband, mobile and Wi-Fi networks. In addition, we will include plans for Data Centres (DCs) and cloud computing to meet growing demands for data computation and storage.

**Physical-Digital Infrastructure.** We will move into the nascent space of physical-digital infrastructure to enable greater interaction between different digital infrastructure components and their integration with the physical world.

**Soft Infrastructure.** This layer, the Singapore Digital Utility (DU) Stack, comprises the foundation for key digital transactions to be conducted seamlessly and securely, upon which businesses can innovate, build and deliver useful platforms and applications.

While Singapore has taken a long-term view, we will continuously review and adapt our plans in line with rapid advancements in digital technology.

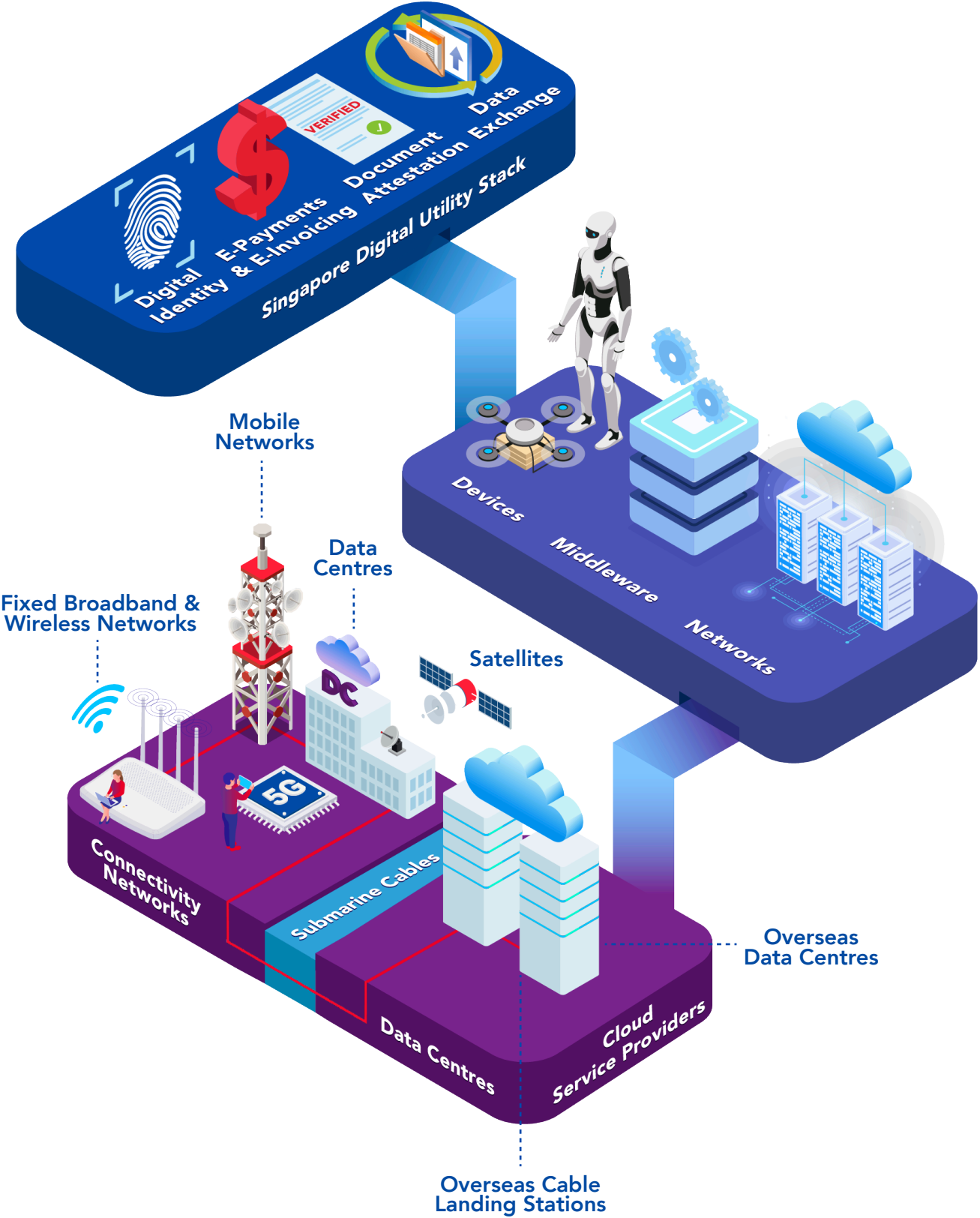


Fig. 1: Overview of Singapore's Digital Infrastructure Stack

**Taken together, this blueprint serves as a strong foundation upon which Singapore realises better opportunities, stronger trust, and empowered communities.**

**Better Opportunities** – where digital infrastructure provides the foundation for innovation and new growth prospects. Enterprises of all sizes and across all sectors, including global and regional companies here in Singapore, will be able to deliver new services, transform their operations and diversify their markets. Collaboration with our global and regional partners will also be strengthened. Our people will benefit from productivity enhancements in existing jobs as well as the creation of higher-value jobs.

**Stronger Trust** – where people and enterprises can be assured of the security and resilience of our digital infrastructure to participate in our digital economy and society. Our people will have the confidence to transact digitally, and enterprises will be able to provide seamless and secure digital services.

**Empowered Communities** – where digital infrastructure enables better service delivery and enhances potential for new forms of social interaction. This strong foundation that we are building will improve lives, empower communities and ultimately provide the connectivity that brings our society together.



## 02

# Future Trends and Opportunities

## Trends Shaping our Digital Future

### Artificial Intelligence (AI)

AI holds the potential to unlock new capabilities in many areas, from fraud detection by financial institutions to predictive analytics for managing healthcare crises. While traditional AI methods have a narrower focus on solving specific problems within specific domains, the rise of Generative AI opens up many new and transformative possibilities<sup>3</sup>. These foundational models have a generalised capability enabling them to be directly applied to a very diverse set of tasks. They are not restricted to natural language processing tasks, such as those performed by Large Language AI Models. They can be extended to alternative formats such as images and videos. This transforms the innovation process through rapid information analysis and generation of options and alternatives.

The impact of Generative AI will be very significant across many sectors and industries. Increased demand for such models will lead to corresponding demand for compute power, including specialised compute infrastructure such as Graphics Processing Units (GPUs). As data processing is often not done on end-user devices, connectivity also needs to support real-time transmissions for multiple inference calculations (i.e., when a query is made to the Generative AI model). High-bandwidth connectivity is therefore crucial to AI as more users

will tap on the available processing power (e.g., on the cloud) to perform both training as well as deployment of AI models. There are also opportunities to tap on compute infrastructure more efficiently. For example, GPUs can be made more data and energy efficient (e.g., via biologically-inspired chip designs and new model architectures).



<sup>3</sup> Generative AI models are based on Transformers, a neural network architecture that has ignited a radical shift in AI. Notable advances, like GPT4, open up a range of possibilities in multiple sectors, from writing assistance and image generation to generation of programming code, finance, and even drug discovery.

## Ubiquitous Autonomy

Autonomous systems are beginning to make a wider impact. In logistics, for example, autonomous robots are deployed at scale to improve productivity and safety in warehouses. While more nascent, fully driverless vehicles are also being trialled in various parts of the world. Some trials are more localised, such as between terminals within a port. Others are of a larger scale, such as driverless ride-hailing and delivery services. The ubiquitous deployment of autonomous systems will allow better optimisation of resources, enhance productivity and open up new possibilities.

To enable large-scale autonomy, pervasive and low-latency connectivity will be needed. Driverless vehicles will require a suite of both in-vehicle and street furniture sensor and processing technologies, coupled with connectivity infrastructure, to link them up and process data and signals in real time.

Low-latency, stable connectivity is critical to enable the requisite reaction times, given the high safety requirements and speed of movement of vehicles, especially in a complex urban environment.



## Immersive Experiences and Multi-Party Interactivity

The online experience has traditionally been two dimensional – digital content on webpages, images and videos are consumed via the flat screens of electronic devices. Extended Reality (XR), which encompasses augmented and virtual realities (AR and VR), will continue to develop and add fidelity, richness and 3D texture to not just the online experience, but also user interaction across digital and physical environments. Beyond gaming and entertainment, XR is also increasingly being used in education and training, healthcare (e.g., surgical planning) and maintenance works.

The rise in immersive experiences, when coupled with multiple-party interactivity (a third participant will need connections to two others, the fourth to three others and so on), will place an increasing load on our digital infrastructure. It has to cater for an increase in demand for bandwidth and symmetric speeds (both upload and download) as the end-user is now a key generator of real-time activity and content. Additionally, lower latency is required to enable real-time, in-sync experiences and support prolonged immersive interactions (e.g., mitigating motion sickness). Overall, this connectivity must be delivered consistently to the last mile in homes or workplaces.

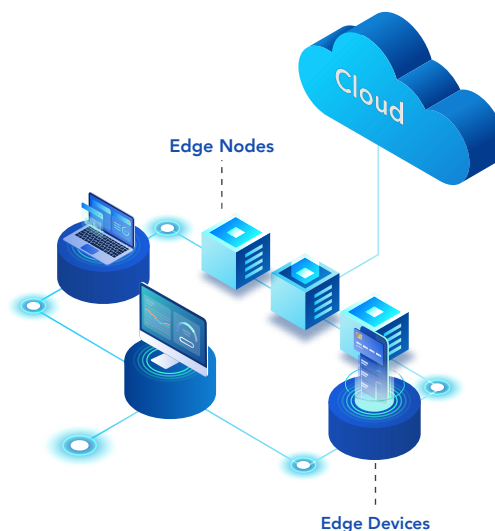


## Distributed Cloud with Edge-Centric Compute

Traditional centralised cloud computing is being augmented with a more distributed network of edge computing resources. In this new paradigm, data is processed and stored closer to end users. This allows for real-time processing of data streams from Internet of Things (IoT) devices, mobile devices and other sources, enabling new applications and services. This also buttresses both more widespread use of AI (e.g., edge computing for AI to analyse real-time data from medical devices for remote monitoring of patients' health) as well as the deployment of more ubiquitous autonomy (e.g., edge computing to improve the safety and speed of decision-making in autonomous vehicles).

The shift to edge computing will require distributed infrastructure, reliable connectivity, more efficient

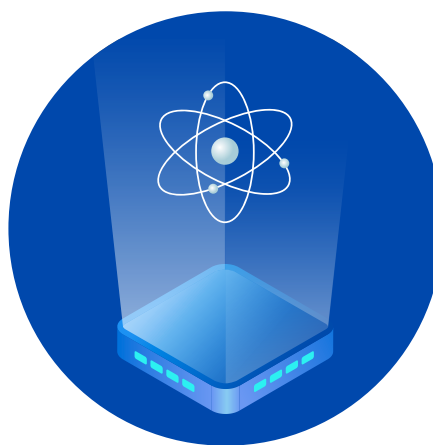
and localised data centres (DCs) as well as networking equipment and software that can support edge computing applications.



## The Quantum Leap

Advancements in quantum technology present new possibilities. Quantum computing is poised to give rise to major breakthroughs across sectors, with its exponentially higher compute performance in areas such as cryptography, medicine, optimisation and data analysis. In medicine, for example, quantum computing has the potential to simulate complex chemicals and accelerate the development of new drugs and treatments for diseases.

While quantum computers can be a significant force for good, they could also be used to weaken and break current encryption methods. We will need to be ready to enable a quantum-safe network, using Post-Quantum Cryptography and Quantum Key Distribution. The latter leverages the basic properties of quantum physics to enhance the security of digital connectivity.



## Playing to Singapore's Unique Circumstances

Being a small, dense urban city state, Singapore will have to deal with these trends in unique ways, which include accounting for limitations in land, carbon and spectrum. Our circumstances present opportunities for us to drive innovation and serve as a useful model for other urban cities.



### Carbon

The increase in demand for compute and connectivity infrastructure will indirectly contribute to carbon emissions. DCs, a critical component of our compute infrastructure, are the biggest indirect emitters of carbon in Singapore's Information and Communications (I&C) sector. While Singapore is energy-disadvantaged and has limited scope for a significant carbon sink, we see this as a driving force for greater energy efficiency and pioneering a longer-term growth pathway for new Green DCs to support our growing digital economy, while ensuring sustainability. At the same time, this presents new business opportunities, including the creation of a new sustainability economy.



### Radio Spectrum

Spectrum is an essential resource for wireless communications. Amidst scarce spectrum resources due to our unique geography, Singapore will continue to ensure strategic allocation of spectrum and regional coordination.

At the same time, Singapore possesses strengths that we will harness as we navigate future trends.

**Singapore's small, urban environment** allows us to achieve widespread domestic connectivity more easily and bring together different ecosystem players to enhance our digital infrastructure and develop digital solutions. Singapore will continue to tap on this unique strength by investing early to enhance our connectivity while building up complementary digital infrastructure components to enable innovative use cases.

**Singapore's position as a trusted hub** allows us to forge collaborations with regional and global partners to enhance international connectivity and explore cross-border opportunities. It also allows us to work together in related areas such as tech governance and talent development that are vital to realising the potential that digital connectivity enables.

**Singapore's established industries**, built up over the years, provide a strong base for our people and enterprises to capitalise on digital connectivity and push the frontiers of digital solutions. Examples of these key sectors include advanced manufacturing, healthcare, financial services and maritime.

## 03

# Singapore's Priorities

## Staying Ahead of Future Trends and Demand

To take advantage of the technology trends over the next decade, Singapore will take decisive steps to build up our digital infrastructure in these areas:



### Ramp up network capacity

The need for faster speeds and higher symmetric bandwidth will rise with data-intensive autonomous systems and immersive digital experiences coming to the fore. Beyond the traditional focus on bandwidth, near-zero latency will be crucial to enabling cutting-edge enterprise innovations that hinge on real-time, seamless and reliable connectivity.



### Maximise compute power

Connectivity must be complemented by top-tier compute infrastructure that strengthens Singapore's attractiveness as a digital hub and reaps maximum value from trends such as Generative AI and edge-centric models. This enables the growth of top-end compute already present here.



### Integrate the infrastructure stack

The benefits of greater connectivity and compute are amplified by stronger linkages and interoperability across (i) hard, physical-digital, and soft digital infrastructure that enable new use cases; and (ii) systems, including across borders, for greater scale and network effects.



### Ensure security and resilience

With pervasive digitalisation that increasingly powers critical functions, Singapore's digital infrastructure must be (i) secure against threats; and (ii) resilient to minimise the risks of network disruptions and to recover speedily from disruptions. This strengthens confidence among domestic users as well as international partners across all domains.

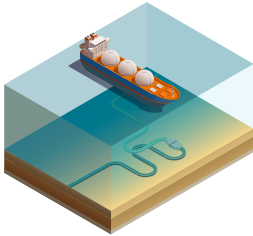


### Design for sustainability

Sustainability will be a key design factor in Singapore's digital infrastructure, so that we grow our digital economy while meeting long-term climate commitments.

## Strategic Priorities

Singapore has identified **five strategic priorities** which will underpin our digital infrastructure for the next bound.



**Provide capacity to enable submarine cable landings to double within the next 10 years.** Openness to the world has been a cornerstone of Singapore's approach to economic development. The digital economy is no exception. Singapore is already a leading submarine cable hub globally, in terms of the number of cables landed and total capacity. We will intensify the use of space and landing resources available, so that operators can expand and further diversify the network of submarine cables. This will potentially catalyse at least S\$10B in overall submarine cable investments, strengthening digital connectivity between Singapore, Southeast Asia and the rest of the world.

**Build seamless end-to-end 10 Gbps domestic connectivity within the next five years.** To enable high-speed, low-latency connectivity across homes, offices and on the go, Singapore will (i) facilitate a tenfold bandwidth increase of our Nationwide Broadband Network (NBN); (ii) allocate spectrum to unlock faster Wi-Fi networks; and (iii) allocate spectrum to 5G Standalone (SA) networks to enhance their performance and support enterprise adoption. We envision a future where smooth 'handover' between different modes of connectivity also enables seamless movement between outdoor and indoor environments, paving the way for game-changing innovations (e.g., in logistics).



**Ensure world-class resilience and security.** Compute infrastructure such as cloud and data centres (DCs) are increasingly critical to the digital services we use every day. We are working with providers to enhance the transparency of and accountability for resilience and security risks in compute infrastructure, aligned with international best practices. This will complement efforts Singapore has taken to ensure our connectivity infrastructure is secure and resilient by design through redundancy and diversity.

**Pioneer a roadmap for growth of new Green DCs and push the sustainability envelope.** DCs in Singapore will increasingly be energy efficient. We are setting our sights on the future and will chart the longer-term growth pathway to new Green DCs that achieve the ambitious objectives of expanding capacity for the digital economy and enhancing strategic value capture while ensuring environmental sustainability. Growth of new green DCs could require investments of S\$10-12B to materialise.



**Drive greater adoption of the Singapore Digital Utility (DU) Stack, to expand the benefits of seamless digital transactions.** The Singapore DU Stack was designed to provide soft infrastructure for people and enterprises to perform functions core to digital transactions – starting with identity, payments and invoicing, then extending to the verification of documents and exchange of data. The DUs will deliver greater value to people and enterprises through enhanced functionality and extension of global linkages, to deepen interoperability and broaden the network effect. As the digital landscape evolves, we will explore new use cases and sectors that will benefit from our current DUs. We will also identify emergent DUs to further enrich the Singapore DU Stack.

## Moves into New Frontiers

Beyond the strategic priorities, Singapore will make moves in more nascent and frontier areas to reap future opportunities. This will require an adaptive and calibrated approach. These moves are:



### **Advancing the vision of a Quantum-safe Singapore within the next 10 years.**

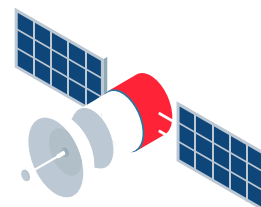
Investing ahead to secure our networks remains key. Our dense urban context and pervasive fibre network grant us an advantage in implementing quantum-safe communications. Singapore will pilot quantum-safe networks and Quantum-as-a-Service solutions for commercial customers. Known as the National Quantum Safe Network Plus (NQS<sup>+</sup>), this will allow us to test, innovate and push the boundaries on both technical and commercial deployments.

**Putting in place foundations for pervasive autonomy.** Autonomy enhances productivity, especially in manpower scarce Singapore. Having the second highest industrial robot density globally<sup>4</sup> places Singapore in a good position to employ autonomous systems. Singapore will (i) improve the reliability and security of devices and networks through standards setting; (ii) foster interoperability through intervention at the middleware layer (e.g., the Robotics Middleware Framework); and (iii) bring ecosystem players together through the orchestration of pilots and use cases. In the near term, integrated autonomous systems hold the potential for deployment of heterogeneous robot fleets in specific locations, with the ambition to extend integration across sectors nationally.



**'Greening Software'.** From more intensive use of everyday digital applications to the rise of energy-intensive enterprise applications of AI, demand trends indicate that the greening of hard infrastructure alone will not be enough to offset the rise in emissions over the next decade. Software will also need to be sustainable. Singapore will build an ecosystem of stakeholders, including industry and research institutions, through testbeds and sandboxes, to move green software development, standards and measurement forward.

**Enabling innovative solutions in key industries with Low Earth Orbit (LEO) satellite services.** LEO services will benefit larger countries more by bringing connectivity to remote or underserved locations. For a small, densely-built country like Singapore, the benefits will be felt in areas like maritime and aviation, where we have developed into global hubs. The added high-bandwidth connectivity provided by LEO satellite technologies opens up opportunities for innovation that will buttress our competitiveness. Furthermore, we are already a key satellite connectivity node and will enhance this through ensuring sufficient spectrum resources for satellite systems and developing pro-enterprise frameworks and policies.



<sup>4</sup> Source: International Federation of Robotics, World Robotics 2022 Report.

Singapore's plans for our strategic priorities and moves into new frontiers are detailed in the subsequent chapters:

Chapters 4 to 6 set out how Singapore will enhance the hard, physical-digital and soft components of our digital infrastructure to reap gains in the digital space.

Chapters 7 to 8 set out how we will address the issues of sustainability as well as resilience and security that cut across the digital infrastructure stack, and turn these into opportunities for Singapore to drive innovation and thrive in the digital economy.



# 04

## Hard Infrastructure

### Ramping up capacity ahead of demand

Today, people and enterprises benefit from Singapore's quality digital connectivity and the wide range of digital services it enables. We will continue to **invest ahead of demand** to strengthen international and domestic connectivity and bolster our role as a global digital hub.

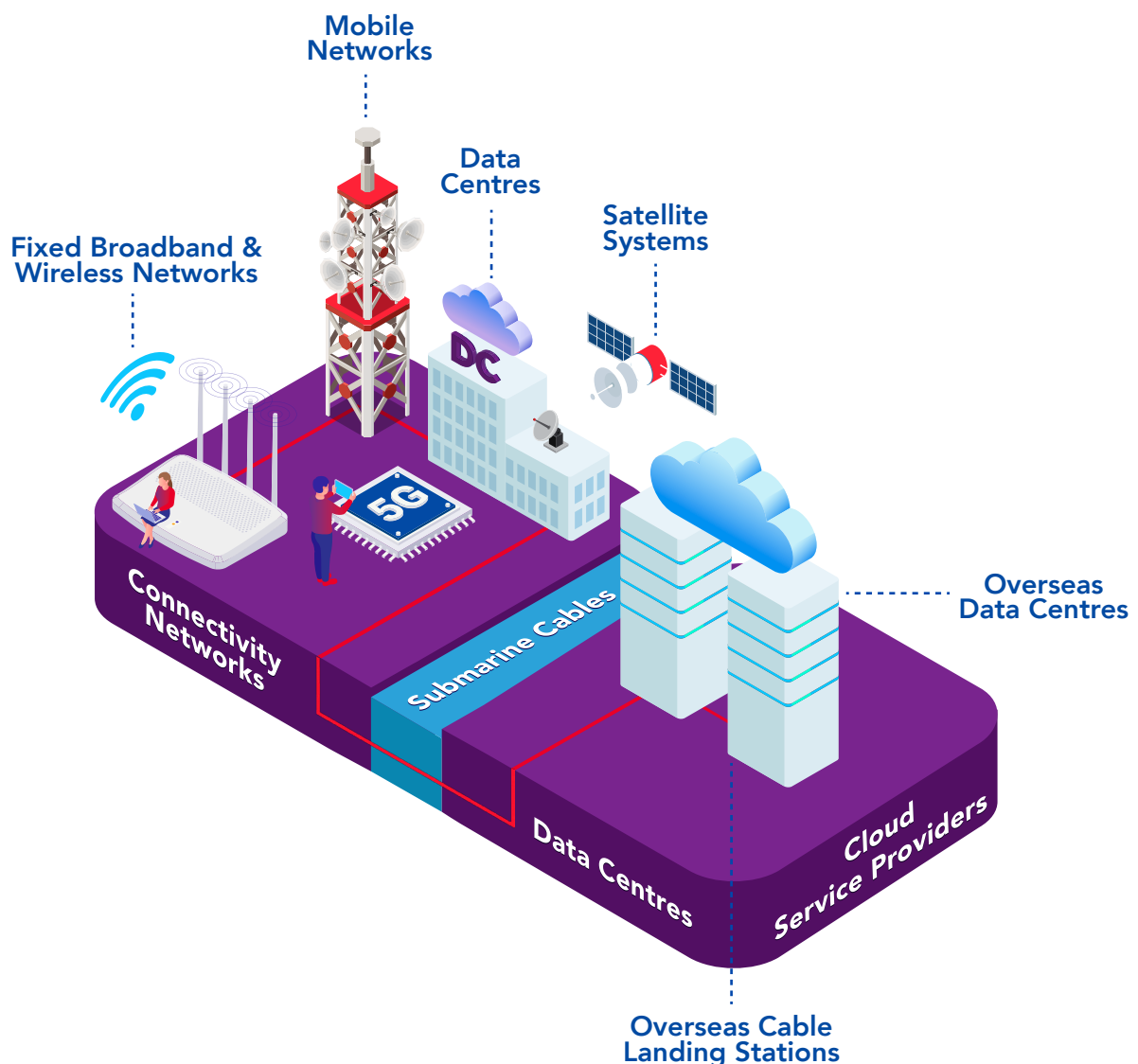


Fig. 2: Overview of Singapore's hard digital infrastructure

## International Connectivity

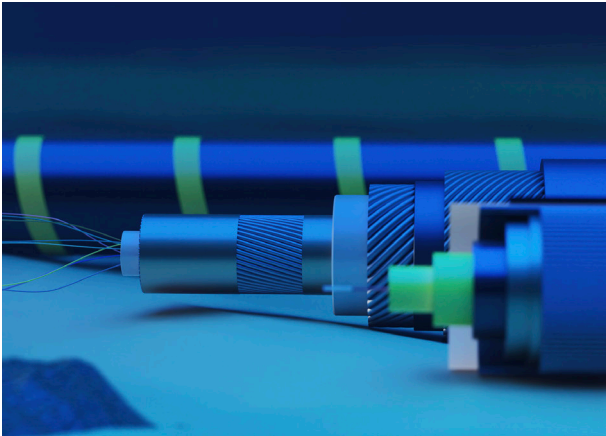


Photo credit: Getty Images

### Providing capacity to enable submarine cable landings to double within the next 10 years

Singapore is a global submarine cable hub in terms of the number of cables landed and total capacity. Today, we are a sought-after site for submarine cable operators, and increasingly data centre (DC) operators and cloud service providers (CSPs). Our direct connectivity to many countries allows easy access to the global Internet traffic and cross-border data flows that power the digital economy – from cloud-based digital platforms to content delivery and a host of other digital services and business transactions.

While managing the natural constraints of scarce land and sea space, Singapore is committed to providing landing space and resources to enable our submarine cable landings to double within the next 10 years. This will continue to enhance the diversity of our international connectivity and support the growing bandwidth needs of the digital economy.

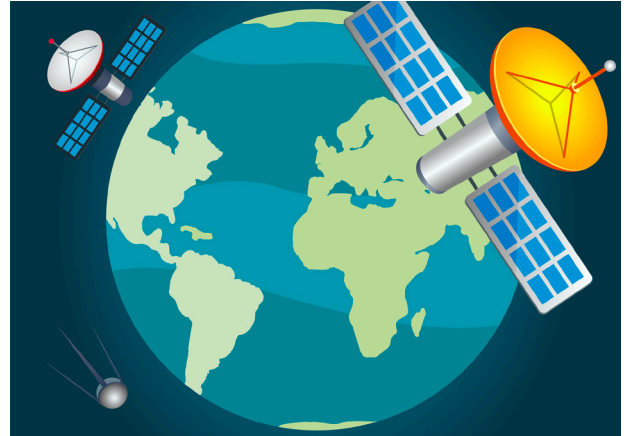


Photo credit: Getty Images

### Enabling growth of Low Earth Orbit (LEO) satellite services

Globally, satellites play an important role in providing telecommunications connectivity from space. While Singapore is a small city state, we are a global maritime and aviation hub. Satellite connectivity is an integral element supporting this status. This is why we have a concentration of local and international companies in our satellite ecosystem engaged in a range of activities across the value chain. These satellite players also provide services such as broadcasting, global positioning, navigation and geo-spatial monitoring for environmental sustainability.

Singapore is set to significantly expand our seaport<sup>5</sup> and airport<sup>6</sup> capacity to stay ahead as the world's premier maritime and aviation hub. LEO satellite technologies have the potential to further augment the growing communication needs of these two sectors.

We will facilitate the deployment of LEO satellite services by ensuring sufficient spectrum resources for satellite systems and setting up frameworks that provide greater guidance and operational clarity. This will be done in tandem with the International Telecommunication Union as it reviews the rules and norms to ensure spectrum harmonisation for the co-existence of LEO and non-LEO satellites.

<sup>5</sup> The new Tuas Port will handle up to 65M Twenty-foot Equivalent Units (TEUs) per annum by the 2040s, double of today's capacity.

<sup>6</sup> The new Terminal 5 in Changi Airport, will increase Changi Airport's overall capacity to 135M passengers per annum, compared to 85M today.

## Domestic Connectivity



### Seamless end-to-end 10 Gbps connectivity within the next five years

Digital connectivity has become essential to our daily lives – people on the move rely on mobile networks, while households and enterprises rely on fibre broadband and Wi-Fi for fast and reliable Internet connections. Our connectivity infrastructure must be built to support consistent user experience in terms of speeds and latencies, so that devices are 'handed over' in real-time, across indoor and outdoor settings and across the different connectivity modalities of fibre, mobile cellular and Wi-Fi. This seamless connectivity will pave the way for future enterprise applications, such as pervasive autonomy. Doing so requires both enhancing and harmonising across the different network components.

Singapore's past investments in the NBN have laid the foundation for our Smart Nation and the transformation of our digital economy. Today, 98% of all homes have broadband access, with 1 Gbps speeds as the norm.

Looking ahead, Singapore will embark on a nationwide upgrade of our existing NBN infrastructure in partnership with the industry and facilitate a ten-fold increase in speed in the next five years. Broadband speeds of up to 10 Gbps, alongside Wi-Fi 6E and our 5G SA networks, will provide end-to-end 10 Gbps connectivity. We will initiate a call for collaboration with the industry and aim to commence the upgrade in mid-2024.



### Unlocking faster Wi-Fi for seamless indoor connectivity

Wi-Fi provides last mile connectivity, especially in-building and within homes and offices. It rides on and wirelessly extends the base of high-speed fibre broadband connectivity. Singapore's Wi-Fi and broadband connectivity need to grow in tandem to fully enable seamless end-to-end 10 Gbps connectivity.

In May 2023, we allocated 500 MHz of extra radio frequency spectrum in the 6 GHz band for Wi-Fi use. This will enable the deployment of Wi-Fi 6E technology that is capable of supporting speeds of up to 9.6 Gbps, or double the maximum bandwidth of previous-generation Wi-Fi technology.

The next generation of Wi-Fi (i.e., Wi-Fi 7) is expected to provide even higher potential peak speeds of up to 30-40 Gbps. We will continue to monitor global and industry developments while studying options for the release of more spectrum capacity.

## Enabling new opportunities for enterprise transformation with 5G Standalone (SA) capabilities

Singapore has taken an ambitious step to deploy 5G SA mobile networks directly. While 5G Non-Standalone (NSA) networks – which are grafted on top of existing 4G networks – are cheaper, we committed to rolling out a more cutting-edge 5G SA network from the outset. This better leverages the scarce spectrum available in Singapore with a direct leap to full-fledged 5G capabilities that provide not just potential peak speeds of up to 20 Gbps, but also advanced capabilities such as network slicing, ultra-reliable and low latency communications and extremely dense device connections.

Singapore is one of the first countries in the world to achieve nationwide 5G SA coverage by end 2022. Close to two years after the launch of 5G services, more than 1.2M subscribers, making up 13% of all mobile subscriptions, have also migrated to 5G.

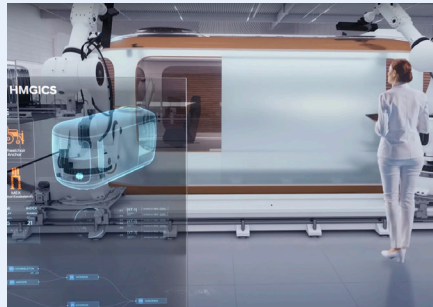
As we invest ahead of demand, the potential is in spurring enterprise transformation. We have committed S\$70M under our 5G Innovation

Programme to accelerate the adoption and commercialisation of 5G solutions. Singapore is also the first country to extend 5G SA coverage to the sea so that 5G solutions can be enabled for the maritime industry and support growth of our maritime hub. We aim to achieve full 5G SA coverage at Singapore's offshore coast by mid-2025.

Our investments in 5G SA provide a good starting baseline to leverage further advances in 5G technology. For example, forthcoming 3rd Generation Partnership Project (3GPP) Releases are expected to facilitate enhancements in areas such as industrial automation, vehicle-to-everything applications, network slicing, AI and XR. Complemented by Reduced Capability (RedCap) devices that are small-sized, power-efficient, secure and cost-effective, 5G is also set to facilitate more effective deployment of IoT (e.g., low power and low-cost trackers that can support ubiquitous logistics tracking and supply chain management over-the-air).



Photo credit: Hyundai



### Hyundai Motor Group Innovation Centre in Singapore

Automated high precision, low margin of error automotive manufacturing using 5G

More than a hundred autonomous mobile robots will be deployed in the production of electric vehicles on the factory floor in the Hyundai Motor Group Innovation Centre in Singapore (HMGICS).

5G's ability to support a large number of connected devices and low latency enables seamless real-time communication between the robots and their automated control system. This real-time communication ensures that the required materials are accurately and safely delivered in this high precision, low margin of error operation.

These 5G-enabled autonomous robots will enhance the productivity and quality control in the production process. The robots will also facilitate a highly customised, agile and dynamic manufacturing process that will allow Hyundai to develop built-to-order electric vehicles for Singapore.





Photo credit: Weston Robot Pte Ltd

## Autonomous surface cleaning vessel

### 5G enabled solution to improve workplace safety

Autonomous surface vessels developed by Weston Robot will be used to perform garbage collection and inspect water bodies in Singapore.

The autonomous vessels use video analytics to detect and remove rubbish and safely respond to emergencies in real-time. These capabilities are enabled by 5G which

supports the high data uplink bandwidth required to transmit vast amounts of video data for analysis, and low latency required for real-time communications.

The adoption of these unmanned vessels will improve workplace safety by relieving workers from having to manually clean our rivers. In time, these physically demanding jobs will be managed by a single operator overseeing multiple unmanned vessels at a command centre.

## Future communications – Investing in new capabilities

Singapore will need to similarly invest ahead to build capabilities in emerging and future communications technologies, such as Open Radio Access Network (Open RAN) and 6G, so that we are ready to capture future opportunities. Open RAN, which allows the disaggregation and virtualisation of RAN functions through an open interface, is developing quickly and increasingly being deployed globally. 6G, the next generation of mobile cellular networks, holds potential for the future and is expected to be deployed from 2030.

Singapore is laying the foundation to be future-ready. We have made an initial investment of S\$70M for Singapore's first national Future Communications Research and Development Programme (FCP). This includes the launch of the Future Communications Translation Lab @ Singapore Institute of Technology (FCTLab@SIT) in end-2023, a testbed that will facilitate industry adoption of nascent technologies in future communications that are tied to commercial applications. In support of the Open RAN ecosystem, we are setting up Southeast Asia's very first Open Testing and Integration Centre (OTIC). Singapore will

also strengthen international collaboration in 6G by forging partnerships with leading research institutions<sup>7</sup>.



<sup>7</sup> The FCP has signed Memoranda of Understanding (MOUs) with 6G Flagship, the world's first 6G research program at Finland's University of Oulu and the 6G Global Forum led by South Korea.

## Asia & Pacific OTIC

Developing Open RAN cybersecurity assurance and solutions

Southeast Asia's first OTIC was launched in Singapore under the FCP in February 2023. The centre will support comprehensive testing and integration activities for Open RAN solutions.

The OTIC provides rigorous cybersecurity assurance which is critical for addressing new cybersecurity challenges that result from Open RAN's open and multi-vendor nature. It also enables the validation of Open RAN applications in specific verticals that are critical for Singapore and the region, such as the maritime industry.

## Compute – World-class compute infrastructure that is resilient, secure and sustainable

Compute infrastructure (i.e., DCs and the cloud services they host) powers the workloads that manage large-scale digital applications. They play an increasingly key role in Singapore's digital infrastructure landscape and our digital economy by enabling efficient data management, processing and storage, while providing security, availability and scalability of digital solutions. As key technological trends develop, more compute infrastructure will be needed to meet the rising demand for computational power.

Singapore will continue to welcome investments in new DCs that anchor more advanced and efficient computational power here, so that enterprises can ride on the positive momentum in the digital economy and advance in digitalisation and innovation. This comes in tandem with our commitment to increase the capacity for Singapore's submarine cable landings, which provide more international and regional connectivity for DCs. We will work with the industry to build green and energy-efficient DCs in line with our long-term climate commitments – this is discussed further in the sustainability chapter.

## 05

# Physical-Digital Infrastructure

## Integrated physical-digital infrastructure (PDI) holds opportunities

PDI refers to the integration of physical infrastructure and digital infrastructure. While nascent, the ability to do this well offers opportunities for future growth. The key building blocks in PDI are:

- *Devices* that sense and collect data from the physical environment. The data is transmitted digitally over the network layer. Some devices, known as actuators, further translate the data into physical motion.
- *Networks* that provide the connectivity for data transmission between physical devices.
- *Middleware* that bridges diverse devices, data in the network layer and end-user applications. It provides a common language for interoperability across the layers.

While each building block plays a distinct role, the integration and deployment of devices and software at scale will enable holistic benefits. Therefore, PDI provides the foundation for Singapore to overcome key challenges such as limited workforce, dense urban buildings and infrastructure. It allows us to leverage: (a) greater **autonomy** to enhance productivity, (b) better system-level **optimisation** in use of scarce resources and (c) enhanced **agility** and flexibility to deploy systems where they are needed, with shorter lead-time and improved effectiveness.

## PDI will enable greater Autonomy, Optimisation and Agility

### Autonomy

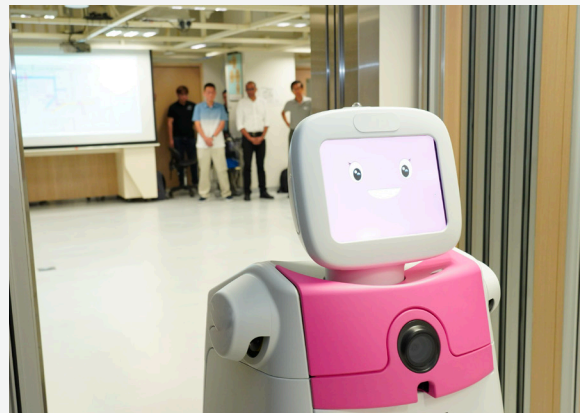
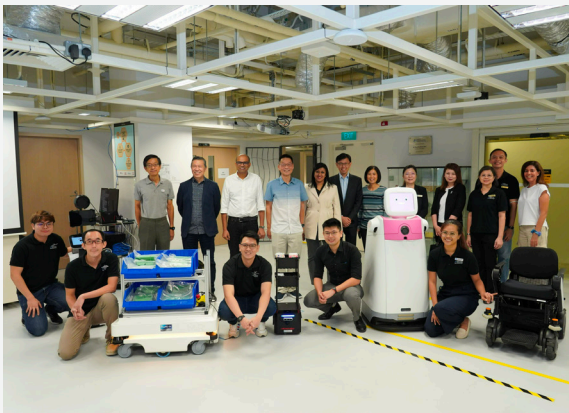
Autonomy is a broad and expansive capability that allows systems to operate independently without the need for direct human control. When deployed at scale, autonomous systems lead to increased efficiency.

#### Use of autonomous mobile robots (AMRs) and middleware for healthcare

Today, the landscape for autonomous systems is diverse and growing, with availability of physical devices collecting real-time data, enabled by connectivity networks (e.g., Wi-Fi or mobile) and integrated through middleware.

To enable safe and efficient integration of robots in buildings, Changi General Hospital's (CGH) Centre for Healthcare Assistive and Robotics Technologies (CHART) – in partnership

with Open Source Robotics Corporation (OSRC), Integrated Health Information Systems (IHIS) and Hope Technik – has developed the world's first Robotics Middleware for Healthcare (RoMi-H), paving the way for multiple robots with different proprietary systems from different technology providers to communicate with each other as well as physical infrastructure. A concrete example is the ability of AMRs to take lifts!



*Photo credit: Changi General Hospital's Centre for Healthcare Assistive and Robotics Technologies*

RoMi-H enables robots to not only navigate autonomously in human-rich environments, but allows the deconfliction of navigation routes with robots of different makes across common pathways. It also aids the integration of robots with the broader building and built environment, ensuring that robots can execute their tasks in a coordinated manner.

With RoMi-H successfully test-bedded at CHART, it is being deployed progressively at CGH, as well as other healthcare institutions and buildings, to enable the interoperability of multiple proprietary robots. These crucial developments are a boost to Singapore's robotics ecosystem, enhancing efficiencies and augmenting operations and care that matters to patients and the community.



## Optimisation

PDI can enable optimisation of complex and interconnected systems by collecting and analysing vast amounts of data in real-time. This leads to better utilisation of resources and freeing up of manpower to focus on higher value-add roles.

### Dynamic sensing in toilets to optimise manpower deployment

The use of 'people count' sensors and feedback panels in optimising manpower planning for toilet cleaning has been effective in sensing the level of dirtiness in toilets, where cleanliness levels are mostly associated with grime and mud arising from usage. These have been found to be more cost-effective than sensors for aerosol compounds, which can also be triggered by cleaning detergents that contain ammonia.

With such dynamic sensing applied across public spaces, cleaners can be activated to

prioritise their efforts in a more timely and purposeful way. There is also significant potential to scale up the optimisation of manpower deployment across facilities.

Under the Environmental Services (ES) Industry Transformation Map (ITM) 2025, there is a focus to intensify innovation, digitalisation and technology adoption. The digital solutions, especially for sensor technologies, are adopted by cleaning companies and premises to enable cleaning on demand.

## Agility

PDI has the potential to enable agility at scale – deployment of sensors and actuators for a wide range of purposes, across many locations, all at once. This deployment is flexible and can be done with short lead time because of the underlying infrastructure.

### Agile deployment of sensors

With advanced technologies in fuel cell battery and solar panels, coupled with effective 5G coverage across Singapore, mobile sensors can be quickly deployed at off-grid sites or moved between multiple locations to gather data without the need for power or data infrastructure. Deployed rapidly within several hours and at short notice, stakeholders can access real-time information remotely, enabling faster response time and proactive decision-making.



Photo credit: National Environment Agency

For example, organisers can easily set up and scale temporary IoT sensing networks across the island to monitor large-scale events (e.g., Singapore's National Day Parade<sup>8</sup>). Other examples include the National Environment Agency (NEA)'s deployment of temporary surveillance cameras to monitor high-rise littering at housing estates (CCTVs can be put up quickly in a span of a few days) and use of CCTVs and speed sensors to monitor for speeding personal mobility devices on public paths.

<sup>8</sup> A large-scale celebration event held annually on 9 August in Singapore to commemorate our independence. In 2022, about 25,000 people gathered at the event to mark Singapore's 57<sup>th</sup> birthday.

## Enabling PDI in Singapore's urban environment

To facilitate the wide deployment and adoption of PDI-enabled solutions, we need an interconnected ecosystem of devices, networks and middleware with minimal silos. This requires an environment that ensures security, fosters interoperability and supports innovation. To this end, the Government's key roles lie in strengthening the middleware, growing the ecosystem and setting standards.

### Foster interoperability and catalyse network efforts through interventions at middleware layer

The key role in enabling PDI is the middleware layer, which facilitates interoperability and enables easier deployment and integration of solutions. While a nascent space, Singapore has started to facilitate interoperability between physical infrastructure assets (e.g., buildings, lifts) and AMRs through the Robotics Middleware Framework (RMF).

Catalysed by the National Robotics Programme (NRP), the RMF is an open-source framework for the orchestration of robot fleets and managing robot traffic. The framework deconflicts operations between different vendors' robots and infrastructure assets (e.g., indoor lifts and doors), ensuring safe deployment and optimal efficiency, as well as reducing integration costs.

In anticipation of the growing need for large-scale autonomy, we will enhance middleware features and develop new capabilities, such as multi-system integration to achieve seamless operation of multiple autonomous systems. The approach will be to architect a 'system of systems' approach to scale and proliferate the benefits of autonomy.



### Bringing ecosystem players together through collaborations in pilots and use cases

We will also play a catalyst role by bringing ecosystem players together to address future demands. This is done through collaborations in pilots (e.g., large-scale complex commercial deployments of RMF involving multiple buildings and multiple AMR use cases, ranging from cleaning robots to delivery robots) with enterprise users (e.g., building owners, hotels, logistics companies), industry partners (e.g., system integrators, AMR companies) and the research community.

## Improving interoperability and security of devices and networks through standards setting

The ecosystem for devices is dynamic and mature. Likewise, the networks that connect the devices have well-established protocols and standards. Looking ahead, we will continue to see close collaboration between different stakeholders to uphold interoperability and security of devices and networks using internationally-harmonised standards.

The recent introduction of a new Singapore Standard (SS 695:2023) on IoT Interoperability for Smart Nation, which consolidates existing Technical References, lowers the barrier of entry and fosters the development of innovative and interoperable solutions.

The upcoming development of a new Singapore Standards on IoT Security for Smart Nation, which aligns and harmonises newly published international security standards into a new set of national IoT security standards, is slated to begin from the second half of 2023. This new standard aims to provide the security guidance to the local industry in supporting the nation-wide IoT projects.

The upcoming review of the Code of Practice for Info-communication Facilities in Buildings (COPIF) aims to enhance use of 'street furniture' to support PDI deployment. Street furniture refers to the existing infrastructure along our streets, such as lamp-posts, which can enable ubiquitous 5G antenna deployment for massive machine-type communications.

## Being Future-Ready

Singapore will continue to adopt a systematic and coordinated approach in planning and driving deployment of PDI solutions, in partnership with the industry, while keeping an eye on developments enabled by emerging technologies. Given the speed at which technology evolves, emerging innovations such as Generative AI and digital twins will accelerate PDI developments.

### Open Digital Platform: Digital backbone of Punggol Digital District



Image is for illustration purposes only.  
Photo credit: JTC Corporation

Singapore's industrial developer, JTC, is developing Punggol Digital District (PDD) as the nation's first smart and sustainable business district. At the heart of the district is its District Operating System known as the Open Digital Platform (ODP). The ODP's Open Standard Multiprotocol Middleware serves as an interoperability layer, connecting different district systems and allowing sharing of data and control functions. It also uses AI and machine learning to optimise utility and manpower resources to achieve sustainability targets and supports smart business operations like robotics.

In addition to the Middleware, the ODP has a second crucial capability – its digital twin. Built as a real-life 3D model of PDD, the ODP's digital twin represents an exciting development for digital firms. With its repository of real-time district data, businesses and students in PDD can utilise the ODP's digital twin to perform simulations and prototyping in a risk-free and lifelike environment.

The ODP can potentially be scaled up to support the digital twinning of Singapore as a whole, where datasets from various sources can be overlaid together for operations planning (via historical play and simulation) and where different smart solutions can be integrated for maximum utility. Combining Building Information Modelling and Geographic Information System, the digital twin in the ODP provides accurate data for data analytics and machine learning, improving the building management user experience while optimising resources.

## 06

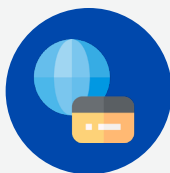
# Soft Infrastructure

## Singapore Digital Utility Stack

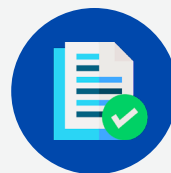
To maximise benefits to the economy and society, hard infrastructure needs to be complemented by a public soft digital infrastructure stack, which we term the Singapore Digital Utility (DU) Stack. It contains four baseline foundational DUs essential to broad-based digitalisation:

**Digital Identity**

How do people and enterprises identify themselves in digital transactions?

**E-Payments and E-Invoicing**

How do we pay and get paid digitally?

**Document Attestation**

How do we check the authenticity of digital documents?

**Data Exchange**

How do we exchange digital information in a trusted and secure manner?

### How are DUs like physical utilities?

The term “utilities” is used with deliberate reference to the catalysing role of traditional physical utilities. Physical utilities (e.g., water, electricity) are necessary for people and enterprises to participate in the physical economy. For example, a common electricity grid enables people to power their homes and offices. In addition, businesses build a diverse range of appliances and sites of concentrated economic activity (e.g., factories), on the foundation of this utility. Similarly, DUs will serve as that foundation for participants to engage in the digital economy. They provide a base layer upon which digital appliances (i.e., applications)

and digital factories (i.e., platforms) can be built to enable ease of interoperability and facilitate positive network effects.



The Singapore DU Stack has been developed to achieve the following outcomes:

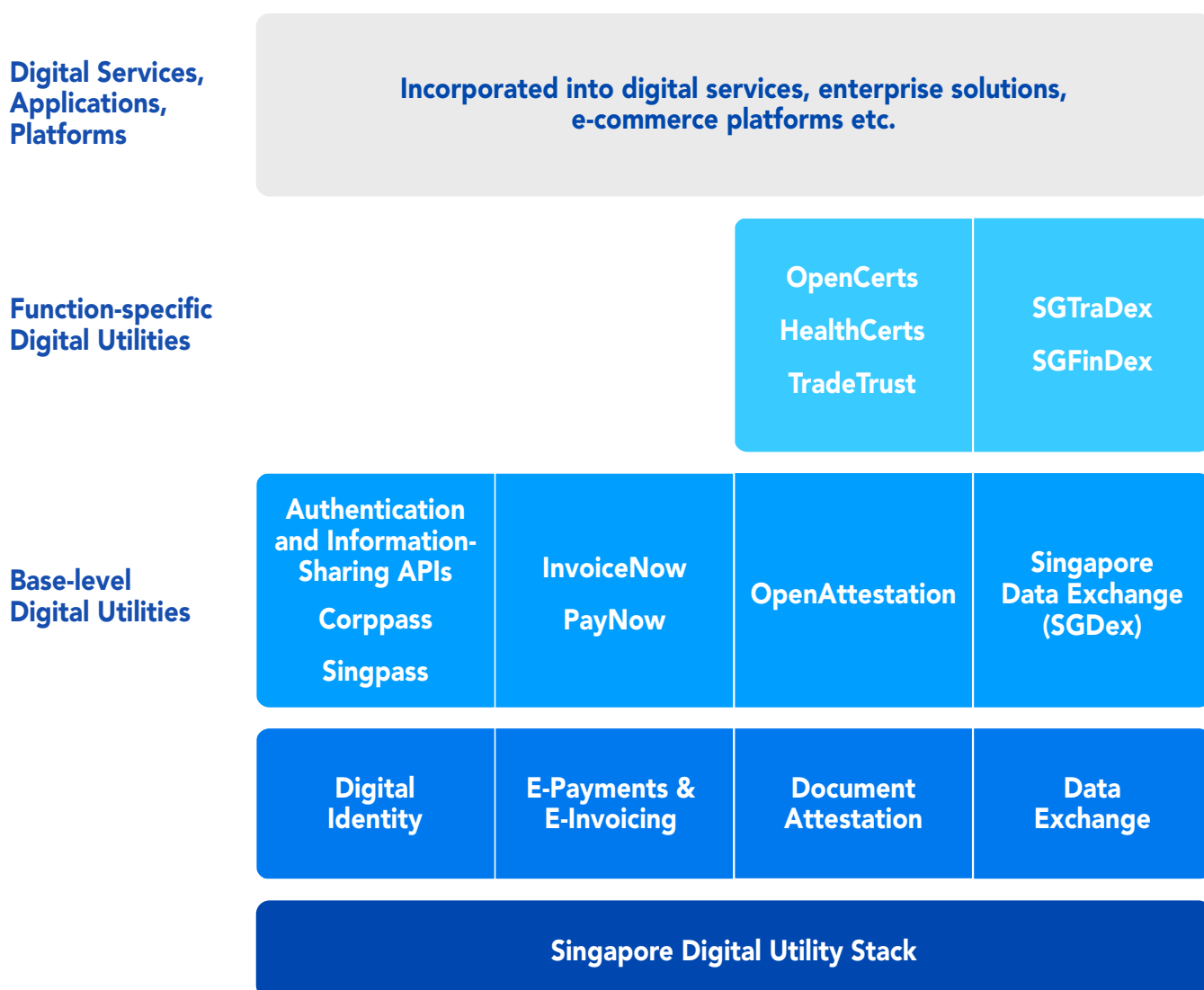
**Provision of foundational functionality** – as a base upon which innovative solutions can be built to enable digital transactions.

**Harmonisation and interoperability** – to minimise fragmentation and walled gardens, and facilitate interoperability across both domestic and international parties.

**Provision of trust and security** – to ensure that people and enterprises have confidence in adopting digital solutions and navigating the digital economy.

**Facilitation of broad-based adoption** – to catalyse the network effect which maximises the potential value of DUs to people and enterprises.

## Overview of the Singapore DU Stack



The Singapore DU Stack is the foundation upon which the broader enterprise ecosystem, beyond the government, can come together to create innovative digital solutions.

## Digital Identity

Unlike in the physical world, digital interactions do not require users to see the other party they are transacting with. This increases the need for users to provide credible proof of identity to access critical digital services. Ubiquitous use of digital identity solutions will serve to reduce friction from delays in identity verification online and further enable the digitalisation of a broader range of critical services.

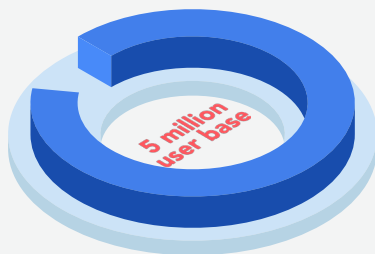
### Singpass and Corppass

Singapore has developed **Singpass** and **Corppass** to provide residents and enterprises a digital identity which can be used for both government and private sector transactions. Singpass is the trusted digital identity for Singapore residents, while Corppass is the trusted digital identity for enterprises.

Building on this digital identity layer, a set of Application Programming Interfaces (APIs) were created to support authentication and information sharing. For example, **Myinfo** is an API which enables citizens and residents to manage the sharing of their government-held personal data to autofill digital forms.

These allow Singapore residents to enjoy significant convenience in accessing public and private sector digital services. For example, by using Singpass to verify her identity, a Singaporean entrepreneur can register her business and incorporate her company in a single online application that takes just 20 minutes, without the need for physical mail, or an in-person meeting.

Singpass has seen widespread adoption in Singapore, across a broad range of both public and private sector e-services.



Singpass serves **97%** of Singaporean Citizens and Permanent Residents aged 15 and above



Singpass is used for more than **2700** e-services across over **800** public and private organisations



Up to **80%** reduction in time taken to apply for services, by using Myinfo



## E-Payments and E-Invoicing

The volume of consumer and enterprise transactions is expected to increase, fuelled by the growth in e-commerce and enterprises expanding their domestic and international reach. Interoperable e-payments and e-invoicing systems are becoming more crucial to support seamless domestic and international transactions.

### PayNow and InvoiceNow

Singapore's e-payment and e-invoicing layer comprises PayNow and InvoiceNow:

**PayNow** is a secure funds transfer service that allows users to receive money in their participating bank account via mobile number, NRIC/FIN, or UEN, or participating e-wallets via virtual payment address (VPA). PayNow has two first-of-their-kind cross-border e-payment linkages – to Thailand's PromptPay<sup>1</sup> and India's Unified Payments Interface (UPI)<sup>2</sup>.

PayNow has seen widespread adoption, among both people and enterprises:

PayNow is offered by 20 banks and 5 non-bank financial institutions, with a more than 90% adoption rate among both people and enterprises.



In Jan 2023, PayNow recorded 32 million domestic transactions, including 9 million corporate transactions.

**InvoiceNow** is a nationwide e-invoicing network which facilitates the direct transmission of e-invoices across enterprise finance systems that operate on the open and standardised Peppol network.

InvoiceNow unlocks cost savings for enterprises by removing the need for manual data entry, thus reducing errors and costs associated with paper-based invoices. When enterprises use InvoiceNow, they are also connected to the Peppol network, which enables greater reach to a wider network of companies worldwide.

InvoiceNow is estimated to deliver savings of S\$8 per invoice for those transacting from efficiency and productivity gains.



55,000 companies are on the InvoiceNow network, with over 800,000 entities worldwide on the Peppol network.

<sup>9</sup> PayNow's first-of-its-kind linkage with PromptPay was launched in 2021, enabling customers of participating banks to send and receive funds across Singapore-Thailand in real time, using just a mobile number.

<sup>10</sup> PayNow's linkage with the UPI system was launched in 2023, enabling similar convenience and was the first such linkage to include a non-bank financial institution as a participant (i.e., Liquid Group).



### Seamless e-invoicing with InvoiceNow

Konica Minolta sends out an average of 1,500 invoices a month from its Accounts Receivable System to a diversified customer base that includes large enterprises, SMEs and Government agencies.

The company joined the InvoiceNow network in 2021 and is now able to digitally deliver almost 1,000 e-invoices a month directly to Government agencies via its Accounts Receivable System. By leveraging InvoiceNow, Konica Minolta was able to eliminate the need for repetitive and time-consuming manual invoicing, improving productivity and efficiency.



Photo credit:  
Konica Minolta Business Solutions Asia

**“With InvoiceNow, Konica Minolta has been able to significantly reduce manual effort and errors in invoice creation and management. Operating on the open-standard Peppol network has made month-end closing plain sailing.”**

*Mr Leslie Peh, General Manager for National Sales Operation, Konica Minolta Business Solutions Asia*

## Document Attestation

Difficulty in verifying the authenticity and provenance of digital documents may be a barrier to broader digitalisation of documentation, especially where industry practices differ. Document attestation solutions, which support the verification of digital documents, can be critical to overcoming these challenges.

### OpenAttestation



Singapore developed **OpenAttestation**, an open-source framework to simplify the issuance and verification of digital documents using blockchain technology. OpenAttestation helps to:

- Ensure that the content of a document has not been modified since its creation
- Check that the document issued remains valid
- Check the identity of the document issuing party

OpenAttestation's data model is aligned with the World Wide Web Consortium's (W3C) Verifiable Credentials Data Model standards, which ensures compatibility of OpenAttestation documents across other Verifiable Credentials wallets. A range of function-specific document attestation utilities have already been built on OpenAttestation, supporting specific use cases. Other function-specific utilities can also be easily developed, building off the core OpenAttestation utility.

## Examples of Function-specific Document Attestation Utilities



**OpenCerts** enables educational institutions to issue and verify tamper-resistant digital academic certificates to students.



**HealthCerts** enables the issuance of digital COVID-19 test results and vaccination certificates that are in line with international standards and Singapore's requirements for use during travel.



**TradeTrust** enables the digitalisation of trade documents, including transferable ones such as Bills of Lading, into Electronic Transferable Records (ETRs) that comply with the requirements of the UNCITRAL Model Law on Electronic Transferable Records.

### World's first fully paperless live ETR cross-border trade with TradeTrust

In Q1 2023, ExxonMobil, Bunkerchain and VLK partnered with IMDA to execute the world's first fully paperless live ETR cross-border trade using TradeTrust. By eliminating the need for manual verification of physical documents by various parties, TradeTrust reduced the processing time required for this transaction from three hours to several minutes. This shortened the vessel waiting time at berth, which translated to lower demurrage cost.

**"Frameworks like TradeTrust increase efficiency and cost savings while maintaining high standards and trust, and we hope that this successful trial will lead to increased interest from the industry to adopt similar standards."**

*Mr Low Say Lim, Asia Pacific Liquids Logistics and Distribution Manager, ExxonMobil Asia Pacific*

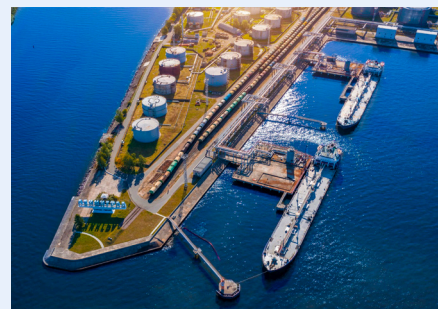


Photo credit: ExxonMobil Asia Pacific

## Data Exchange

The vast amount of data generated by the digital economy could guide better decision-making for the benefit of our economy and society. Data exchanges that facilitate the safe and seamless sharing of data between relevant parties will be key to enabling this. Widespread adoption of interoperable data exchanges could generate efficiencies for both existing B2B processes and B2C use cases (e.g., data for financial planning).

### Singapore Data Exchange (SGDex)

Singapore has developed the **Singapore Data Exchange (SGDex)**, to support relatively nascent developments in data exchanges. SGDex serves as a neutral, trusted and secure data exchange layer that enables data sharing across private and public participants with user consent. This data exchange layer with common data standards facilitates the development of function-specific data exchanges on top of it.

### Examples of Function-specific Data Exchanges

#### sgfindex

**SGFinDex** allows people to provide consent and retrieve their consolidated personal financial information from participating financial institutions and government agencies, to better understand their overall financial health. By bringing together key financial players across the ecosystem, consumers can access a holistic view of their financial data in a single application of their choice, even as customers of different financial institutions.

#### sgtradex

**SGTraDex** pilots the sharing of trade data among supply chain ecosystem partners (e.g., shippers, logistics providers). By facilitating quick sharing of data across the highly fragmented supply chain ecosystem, SGTraDex helps to improve end-to-end visibility across the ecosystem, leading to potential efficiency and productivity gains.

#### Faster access to financing enabled by SGTraDex

Kenoil Marine Services, an established bunker supplier in Singapore, has exchanged over 400 documents digitally with their financing bank via SGTraDex since June 2022. By eliminating manual filing and circulation of documents, SGTraDex enabled Kenoil to reduce time taken for these processes by two thirds. This has provided Kenoil greater operational efficiency and faster access to financing.

**"Having near instantaneous visibility of our transactions is a game changer for us as well as our trading partners and financing banks."**

*Desmond Chong, Managing Director, Kenoil Marine Services*

## Next bound for the Singapore DU Stack

### Driving Greater Adoption

Given the growing importance of the Singapore DU Stack, Singapore will continue to drive adoption through:

- Improving access to InvoiceNow for newly incorporated companies. This includes moving towards using InvoiceNow as the default e-invoice submission standard for all Government vendors.
- Enhancing InvoiceNow and TradeTrust through more value-added services (e.g., invoice financing) and support for new document types.
- Expanding SGFinDex by exploring the addition of more financial institutions and a wider range of financial information.
- Exploring new sectors and use cases for data exchanges, including healthcare and green financing.

### Driving Cross-Border Usage

As a hub for international trade and finance, Singapore recognises the importance of seamless digital interactions that transcend borders, especially where international counterparts may have different established systems. Singapore will continue to work with international partners in support of cross-border recognition and interoperability of our DUs with overseas systems, to unlock network effects beyond our shores, through:

- Exploring cross-border use cases for digital identity.
- Increasing the number of PayNow cross-border e-payment linkages.
- Working with international partners to expand the use of TradeTrust documents.
- Working with international standards bodies and technical experts to develop standards for Verifiable Credentials, to support broader compatibility of OpenAttestation and its associated utilities, with other Verifiable Credentials solutions.
- Improving international connectivity of SGTraDex with other data sharing platforms.

Singapore's initial forays in enabling broad-based digitalisation underscore the importance of developing our soft digital infrastructure. When adopted at scale, the Singapore DU Stack will enable people and enterprises to carry out critical everyday digital interactions – with domestic and international partners – in a seamless, trusted and secure manner. Singapore will continue to drive the adoption and cross-border use of DUs to unlock greater opportunity and efficiency for the Singapore ecosystem.

As the digital domain develops, Singapore will continue to explore what new DUs might be needed and how the Singapore DU Stack can evolve to support the emerging and future needs of our people and enterprises.

# 07

## Sustainability

### Pushing the Envelope of Sustainability

Sustainability is a key issue, which will impact many segments of the economy and society going forward. At the same time, as digital technology continues to advance and the supporting infrastructure continues to expand at a rapid pace, they will in turn contribute to both greenhouse gas (GHG) emissions as well as provide potential enabling tools to tackle sustainability issues.

Globally, while the tech sector is currently one of the smallest contributors to GHG emissions, the growth of the digital economy can lead it to contribute around 1/6 to 1/3 of GHG emissions by 2050<sup>11</sup>. This

is also driven by increasingly energy-intensive technology such as AI and blockchain.

Under the Paris Agreement, Singapore has committed to peak emissions at ~60 million tCO<sub>2</sub>e before 2030 and achieve net zero emissions by 2050<sup>12</sup>. As a small country, Singapore is alternative energy-disadvantaged and has limited scope for a significant carbon sink. Nonetheless, we are committed to push the envelope of sustainability to enable strategic growth of the tech ecosystem. This means approaching digital infrastructure with a focus on energy efficiency and pioneering green solutions.



<sup>11</sup> "The real climate and transformative impact of ICT: A critique of estimates, trends and regulations", ScienceDirect (2021)

<sup>12</sup> These targets are contingent on technological advances and the economic viability of low-carbon technologies such as hydrogen and carbon capture, utilisation and storage (CCUS) and effective international collaborations in areas such as carbon credits and renewable energy imports.

## Greening Hardware – Pioneer a roadmap for growth of new Green DCs

DCs are a critical component of our compute infrastructure and an important enabler of the digital economy. They provide the backbone of data management, processing and storage and house compute. They host digital platforms and services that serve not just Singapore but also the region (e.g., video streaming services, fintech payment systems), as well as inter-connection facilities such as Internet exchanges that digitally hub Singapore to the world.

Singapore is currently one of the top DC hubs in Asia Pacific, having significant market size, excellent fibre connectivity and availability of cloud services<sup>13</sup>. However, DCs are the biggest indirect emitters of greenhouse gases in Singapore's I&C sector, contributing 82% of the sector's emissions. Our strategic priority is to chart the path towards green DCs that are energy-efficient and will be powered by renewable sources. This will enable a sustainable growth of new Green DCs in Singapore. This will be pursued through the following measures:



**Managing entry.** Managing the entry of new DCs<sup>14</sup> to ensure sustainable and energy-efficient growth, while providing strategic value to Singapore. New DCs will bring in state-of-the-art technologies for energy efficiency and sustainability.

**Developing standards.** Turning the constraint of our tropical climate into an opportunity, we have developed and issued the world's first Tropical DC standards<sup>15</sup> to drive energy efficient DCs. DCs operating in tropical climates can use these standards to determine the optimal operating temperature that ensures reliability while reducing energy usage for cooling. We are working towards pervasive adoption of the Tropical DC standard in Singapore. We will also review the incorporation of these standards in the 'Green Mark for DCs' certification requirement. Beyond efficient cooling, a critical element less emphasised is the efficiency of the IT equipment itself. We will explore the adoption, development of standards and certifications for energy-efficiency at the IT Equipment level.



**Driving technology innovation.** We will work with DCs to push boundaries in adopting the latest innovations to improve sustainability. These include leveraging energy-efficient cooling and electrical systems, as well as supporting wider-scale use of direct liquid cooling.

**Pioneering net-zero Green DC growth pathway.** Singapore remains committed to the sustainable growth of the DC sector. We will chart a roadmap towards the growth of net-zero, green DCs that are powered by renewable energy, considering the necessary resource requirements (e.g., land, power grid and generation capacity, energy sources and pathways). This includes working with the industry for innovative proposals to push the boundaries.



## Greening Software – Pioneering developments in a nascent space

Energy savings from improving hardware energy efficiency alone is likely insufficient. The increase in digitalisation and pervasiveness of complex, bandwidth-intensive digital software and applications will lead to increased energy usage and carbon emissions. The proliferation of AI use will likely add pressure for greater compute. Estimates show that training an AI model (termed pre-training or finetuning) can consume more electricity than the annual consumption of 120 households<sup>16</sup>. The ongoing use of the model (termed inference), with billions of requests being processed annually, can consume more than 1.5 times that used to train the model.

While nascent, investing in the development of green software will be an important next bound. This ranges from the core principles of efficient coding to emerging developments and standards for low-data, low-energy AI models and neural network designs<sup>17</sup>. There is also ongoing work to better measure how energy consumption can be directly attributable to software use, especially when done on the cloud.

Driving innovation in green software requires international partnerships across governments, academia and industry. Domestically, the research community in Singapore has started to build capabilities in green software research. Singapore will continue to deepen partnerships with the research community and industry partners.

<sup>13</sup> Ranked by Cushman & Wakefield's Data Center Advisory Group in "Global Data Center Market Comparison 2023" report. Major ranking factors are i) market size, ii) fibre connectivity and iii) cloud availability.

<sup>14</sup> Following extensive consultation with the DC industry, the Economic Development Board, Digital Industry Singapore and IMDA launched the pilot DC-Call for Application in July 2022 to facilitate the building of new DCs and to allow for the calibrated and sustainable growth of DCs in Singapore.

<sup>15</sup> DCs operating in tropical climate countries can use the new Singapore standard to determine the best operating temperature, from 26°C or higher, for optimising energy efficiency whilst safeguarding operational reliability for customers' IT equipment. For every 1°C increase in the DC operating temperature, DCs can potentially achieve 2% to 5% energy savings.

<sup>16</sup> Estimated by Google and UC Berkeley in a research paper "Carbon Emissions and Large Neural Network Training" in 2021. The research paper is led by David Patterson, Professor of Computer Science at UC Berkeley and Distinguished Software Engineer at Google.

<sup>17</sup> For example, Zeus, a new energy optimisation framework for deep learning models developed by University of Michigan, could reduce energy usage by up to 75%. Industry itself is also forming initiatives to create new software standards – e.g., the Green Software Foundation.



## 08

# Resilience and Security

## Ensuring resilience and security of our critical connectivity infrastructure

With more people and enterprises relying on digital infrastructure, it is vital to ensure resilience and security – any disruption or compromise would have widespread impact.

### Ensuring resilience

Singapore's wired and wireless connectivity infrastructure is designed to be resilient with high availability, on par with the best globally. Connectivity infrastructure is built with **design principles of network redundancy and diversity**, to safeguard against widespread service disruption. We adopt resilient architecture such as diversity of connectivity paths and network redundancy with fail-over capabilities. For example, Singapore's 5G networks are built to minimise bottleneck situations.

With the increasing complexity of technologies and networks, it is not possible to completely eliminate service outages. We work with the industry to raise the resilience of networks, improve situational

awareness, and ensure speedy incident response and service recovery in times of service disruption. Such baseline requirements cover timeliness of service restoration to minimise impact. We require service providers to conduct regular audits on their networks and infrastructure, technical processes, and business continuity plans.

At the systems level, resilience is further achieved through a diversity of networks, with multiple service providers offering a variety of mobile and Internet services and digital solutions. This is achieved through facilities-based competition to have a diversity of players.

### Ensuring security

Security must be an integral and upstream consideration in designing and protecting our digital infrastructure. This is vital to ensuring that our digital environment remains safe and trusted. To ensure that key networks are **secure-by-design**, requirements including measures to protect, detect,

respond to and recover from cybersecurity incidents are imposed. In addition, digital infrastructure that have been designated as Critical Information Infrastructure<sup>18</sup> (CII) are required to comply with cybersecurity requirements from the Cyber Security Agency of Singapore (CSA).

<sup>18</sup> A CII is a computer or computer system necessary for the continuous delivery of an essential service, which includes telecommunications.



In particular, Singapore's 5G mobile networks adhere to the security-by-design principles. These include:

#### **Defence-in-depth**

Multi-layered defensive mechanisms increase security against different attack vectors.

#### **Zero-trust**

No implicit trust of requests to access systems. Continuous verifications must be done on all

requests before granting access.

#### **Network Element Assurance**

Only network equipment that have passed stringent security tests can be deployed.

Beyond baseline compliance, we work in partnership with network providers to uplift the cyber security skillsets of their engineering teams and develop programs to strengthen their capabilities in detecting vulnerabilities, and threats.

## **Enhancing resilience and security of our expanded digital infrastructure stack**

### **Enhancing resilience and security based on international best practices**

Beyond Singapore's connectivity infrastructure, our compute infrastructure such as cloud and DCs are increasingly critical. Disruptions to this infrastructure can have significant impact, given the knock-on effect on the digital services and operations that rely on them. Major jurisdictions such as the European Union Member States, UK, and Australia have begun to impose resilience and security requirements on these newer digital infrastructure. Similarly, Singapore is working with cloud and DC providers to enhance the transparency and accountability of their operations by adopting measures that are aligned with international best practices. This is important given that these

providers serve local and global enterprise users with business models built based on resilience and security.

The CSA is reviewing the Cybersecurity Act to strengthen the cybersecurity of the expanded digital infrastructure stack (including cloud services and DCs). The intent is to mitigate cyber risks and ensure that we stay on top of digital threats and risks to Singapore's connectivity. Beyond this, we will review and update our policies to enhance the resilience and security safeguards for our expanded digital infrastructure stack.

## **Advancing vision of a Quantum-Safe Singapore in 10 years**

Looking further into the future, we expect the advent of quantum computers (QCs) to have wide-ranging impact and present new opportunities and risks. QCs will unlock unprecedented advancements in computing power, simulation, and optimisation with the potential to transform industries and create new opportunities for innovation. At the same time, QCs will introduce new security risks as they can break most encryption algorithms that we rely on today.

Singapore needs to be ready to adopt quantum security technologies, such as Post-Quantum Cryptography<sup>19</sup> (PQC) and Quantum Key Distribution<sup>20</sup> (QKD), which will allow our communications and computing networks to be resistant against quantum attacks. We will move to implement quantum safe technologies as they mature, by phasing in PQC and QKD so that organisations continue to be resilient and secure in the quantum age.

<sup>19</sup> PQC is a software-based algorithm that is near impossible for QCs to solve. The global PQC standardisation process, led by the US National Institute of Standards and Technology, is expected to complete by 2024. After standardisation, companies providing digital solutions will be able to use standardised PQC algorithms to protect their solutions against QCs-based attacks.

<sup>20</sup> QKD is more nascent and is a hardware approach to quantum-safe communication, involving the transmission and detection of quantum signals for more secured key exchange. QKD is increasingly being developed to support the connectivity between locations that are typically protected by appliances with encryption capabilities.

### Developing quantum-safe networks in Singapore through NQSN+.

Leveraging the Centre for Quantum Technologies (CQT)'s experience of over 10 years in quantum research, the National Quantum Safe Network (NQSN) was set up in 2021 as a platform for collaborators across private, research, and government organisations to conduct nationwide trials for quantum-safe communications technologies including QKD and PQC. This year, Singapore will launch the **National Quantum Safe Network Plus (NQSN+)**, which will serve as a scalable quantum-safe network that can deliver quantum-safe communications nationwide.

The NQSN+ will start with two telcos, where each will develop a pilot network architecture that can scale nationwide with existing fibre networks. Both telcos' networks will be interoperable, allowing users on one telco's network to communicate securely and seamlessly with users on the other telco's network.

The NQSN+ telcos will also establish operational processes and train new manpower capabilities to maintain and operate this network. Enterprises can work with the NQSN+ telcos to integrate quantum-safe solutions into their business-critical use cases.

In the future, NQSN+ will be integrated with quantum-ready networks from other cities, allowing enterprises to deploy quantum-safe solutions across global markets.

### Supporting progress in the standardisation of quantum security technologies.

As part of Singapore's efforts to push the next bound of interoperable quantum-safe networks, we are co-leading a new work item with Japan on establishing a QKD protocol framework at the International Telecommunication Union. We have also worked with the industry to release a QKD reference specification in Singapore, which provides guidance to telcos and users keen to deploy QKD-based networks. Singapore will continue to support international standardisation efforts to enable the realisation of an interoperable, quantum-secure global communications network.

### Moving towards a Quantum-safe Singapore in 10 years.

While Singapore continues to invest in and pilot new quantum technologies, we will also need to continually ensure that our key digital infrastructure is secure. We will move to secure our CII in key sectors with quantum-safe solutions so that organisations continue to be resilient and secure. With strong research capabilities and a pervasive nationwide fibre network, Singapore is in a good position to use quantum technology to further enhance network security for CII and enterprises handling sensitive data.

# 09

## Conclusion

Singapore's digital infrastructure is foundational to our vibrant, shared digital future. This blueprint sets out our ambition to ensure that our digital infrastructure remains world-class and future-ready. It represents Singapore's commitment to stay ahead by growing our digital connectivity to create better lives and exciting opportunities for our people and enterprises.

To achieve this, we will double down on the following strategic priorities:

- Provide capacity to enable submarine cable landings to double within the next 10 years.
- Build seamless end-to-end 10 Gbps domestic connectivity within the next five years.
- Ensure world-class resilience and security for our digital infrastructure.
- Pioneer a roadmap for growth of new Green Data Centres (DCs) and push the sustainability envelope.
- Drive greater adoption of the Singapore Digital Utility (DU) Stack, to expand the benefits of seamless digital transactions.

To maximise opportunities in more nascent areas, we will also make the following moves into new frontiers:

- Advance the vision of achieving a Quantum-safe Singapore within the next 10 years.
- Put in place foundations for pervasive autonomy.
- 'Green Software'.
- Enable innovative solutions in key industries with Low Earth Orbit (LEO) satellite services.

Together, these moves pave the way for **better opportunities, stronger trust and empowered communities** for Singapore's digital future.

## For Enterprises

**Better opportunities** – An expansive network of international connectivity, coupled with a pervasive network of high-bandwidth wired and wireless seamless connectivity, enables enterprises to hub in Singapore and deliver high-end, bandwidth-intensive digital products and services locally and globally. For example, enterprises, especially in the autonomous field, can leverage the interoperable middleware layer to test-bed massive deployments and integration with other systems and assets. Those in the logistics sector can leverage autonomous mobility and systems, which require smooth 'handover' between different modes of connectivity for large-scale deployment. Enterprises can also leverage the Singapore DU

Stack to seamlessly start their enterprise, manage their funds and trade across borders, thereby optimising their enterprise operations and improving productivity.

**Stronger trust** – Enterprises can leverage Singapore's world-class security and resilience standards as a competitive edge to deliver trusted digital services globally. For example, enterprises can tap on the identity and attestation utilities within the Singapore DU Stack to ensure confidence and trust in digital transactions.

## For People

**Better opportunities** – Existing jobs will be transformed and uplifted. For example, the widespread use of autonomous systems (e.g., unmanned systems in hospitals, warehouses) can relieve workers from physically demanding work and provide opportunities for them to upskill to take on higher value roles (e.g., managing multiple systems at a command centre). New job opportunities will also be created with enterprises expanding their operations here to tap on Singapore's position as a digital hub. Professionals are also able to access work opportunities beyond our geographical boundaries via remote work.

**Stronger trust** – Our people can enjoy access to

secure and trusted digital services enabled by the identity layer of the Singapore DU Stack. For example, people can onboard with financial service providers (e.g., open bank accounts, apply for financial products) with confidence.

**Empowered communities** – Our people can benefit from better service delivery and quality of life with pervasive autonomous systems. For example, patients can enjoy more personalised healthcare service, as AI analyses real-time data from remote-monitoring medical devices. Family and friends can better stay connected locally and overseas, by engaging through more immersive and interactive digital platforms.

Building Singapore's digital infrastructure is a continuous journey where we must always adopt a future-oriented approach to enable our people and enterprises to continue to thrive. Coupled with an innovative ecosystem and skilled talent pool that capitalise on digital infrastructure, we will constantly evolve, invest and build ahead to enable new possibilities together.

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