GSMA

IoT for Development:
Use cases delivering impact

GSMA

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The views expressed do not necessarily reflect the UK Government's official policies.

Contents

Abbreviations

3GPP	3rd Generation Partnership Project
AI	Artificial Intelligence
AMI	Advanced metering infrastructure
GSM	Global System for Mobile Communication
ICT	Information and communications technology
IoT	Internet of Things
IP	Intellectual property
ITU	International Telecommunications Union
LEO	Low Earth orbit
LMIC	Low- and middle-income country
LPG	Liquid petroleum gas
LPWA	Low power wide area
LTE	Long Term Evolution
LTE-M	Long Term Evolution Machine Type Communications Category M1
M2M	Machine to machine
MNO	Mobile network operator
MVNO	Mobile virtual network operator
NB-IoT	Narrowband IoT
NRM	Natural resource management
NRW	Non-revenue water
OEM	Original equipment manufacturers
PAYG	Pay-as-you-go
SHS	Solar home system
WAN	Wide area network
WBE	Wastewater-based epidemiology

Glossary of key terms

IoT

Describes the coordination of multiple machines, devices and appliances connected to the internet through multiple networks.

LoRaWAN

A LPWA technology designed to wirelessly connect devices to the internet using unlicensed spectrum. Semiconductor company Semtech holds the intellectual property (IP) for LoRaWAN-supporting chipsets and earns a royalty on each device sale. However, the development and promotion of LoRaWAN technology and its ecosystem is led by the LoRa Alliance, which includes more than 500 member companies.

Licensed LPWA

The mobile industry has focused on developing two complementary LPWA technologies: LTE-M and NB-IoT. Both use licensed spectrum. LTE-M is better suited to devices that require voice support and mobility, while NB-IoT is more appropriate for stationary objects such as smart meters.

LPWA

LPWA technologies have been optimised to serve the IoT market, specifically applications requiring low data rates and infrequent transmissions. Examples of LPWA networks include LoRaWAN, LTE-M, NB-IoT and Sigfox.

M2M

Communication between two or more entities that do not necessarily need any direct human intervention. M2M services intend to automate decision and communication processes.

Sigfox

The most extreme of the LPWA technologies in that it supports very low data transmissions and messaging capabilities to push battery life to its limits. Sigfox uses unlicensed spectrum. Sigfox technology is owned by UnaBiz and licensed to Sigfox Network Operators in individual countries.

Reference architecture

The reference architecture model provides, at a high level, the technology components of a solution. It also provides a common vocabulary with which to discuss implementations.

Virtual mobile network operators

Connectivity service providers that do not own the network infrastructure over which it provides its services, but rather lease these from mobile network operators.

Peak data rates

Maximum achievable data rate per user measured in bits per second.

Latency

Latency refers to the time taken for a packet of data to travel between two points, typically measured in milliseconds.

Foreword

The 2020s are unquestionably the decade in which Internet of Things (IoT) technologies are set to scale. GSMA Intelligence estimates that the total number of IoT connections will more than double between 2021 and 2030, reaching 37.4 billion. Cellular IoT connections across Sub-Saharan Africa and South and Southeast Asia will also more than double over this period, reaching 156 million. South Asia will account for almost 40% of these connections, with rapid digital transformation in India being one of the key drivers of this trend. Meanwhile, in Sri Lanka, commercial IoT projects are coming to fruition - from large-scale deployments in utility to enterprise and industrial applications and applications in the traditional plantation sector.

A major trend that will define the decade is that enterprise IoT, which includes many utility sector deployments, will overtake consumer IoT by the middle of the decade and become the major market driver.

IoT holds huge potential for either improving services or developing completely new ones. Dialog anticipates that IoT-enabled use cases have the potential to tackle global challenges such as climate change and address region-wide challenges in key sectors, including agriculture, energy, waste management, health and transportation. Overall, IoT in low-and-middle-income countries (LMICs) remains at a nascent stage of development; no use case can be categorised as reaching maturity yet. However, several use cases have entered their expansion phase in LMICs, including mechanisation access services in agriculture, asset tracking, smart metering and PAYG cooking.

For instance, in Sri Lanka, Dialog Axiata deployed a smart grid solution developed in partnership with Lanka Electricity Company (LECO) and the Dialog - University of Moratuwa Mobile Communications Research Laboratory (Dialog-UOM Research Lab). Initially enabled by a grant from the GSMA Innovation Fund, the solution enabled LECO to develop smart modem modules for their electricity meters and network monitoring devices to monitor their low voltage power distribution system. Initially deployed in 2016, this initiative enabled LECO to analyse electricity usage and isolate any faults in its grid through a network of smart meters and network monitoring devices. This project has already scaled up and helped LECO to launch fully integrated, prepaid electricity metering - a longtime goal for Sri Lankan utilities, to provide a PAYG option for its customers.

Mobile operators such as Dialog Axiata can benefit from focusing on specific verticals in scaling their IoT offerings as LPWA networks come online in many markets. Weighing the technical and commercial challenges against existing competencies and assets can inform the chances of success. Strategic partnerships will also be central for many operators with only nascent capabilities looking to expand into new areas in this evolving ecosystem. These can include engagements with local tech hubs, building IoT-centric incubator or accelerator programmes, or partnerships with universities and research institutions. At Dialog, we have built a close partnership with the University of Moratuwa (UOM) to fund the Dialog-UOM Research Lab to undertake applied research projects and product development, and focus on products and use cases that are relevant and feasible to gain traction in Sri Lanka. With its success, Dialog expanded its efforts to other engineering universities under "The Future Zone" Innovation Centre Programme to link Sri Lankan Universities with the local industry to solve industry problems.

The availability of sufficient low-cost NB-IoT chipsets and 4G modules will spur significant deployments - particularly in enterprise IoT. We are excited about the adoption of data analytics, artificial intelligence, and augmented reality technologies, which can add value to IoT solutions across a range of areas, such as Smart City, healthcare, and industrial sectors. Dialog Axiata looks forward to continuing to work with the GSMA and other partners to play a leading role in the development of a commercially sustainable IoT ecosystem in the APAC region, and to enable and scale impactful use cases addressing some of the region's most pressing challenges.

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Executive summary

GSMAi estimate that the total number of IoT connections will more than double between 2021 and 2030, reaching 37.4 billion. The 2020s are unquestionably the decade in which IoT technologies are set to scale.

This report examines the connectivity landscape and IoT use cases delivering impact across low- and middle-income countries (LMICs) in three regions: Sub-Saharan Africa, and South and Southeast Asia. LMICs are home to just over 6.5 billion people, with close to half the world's population living in the countries covered by this study. The reason for this focus is to highlight the opportunities for linking IoT to development outcomes.

IoT holds huge potential for either improving services or developing completely new ones. To highlight the opportunity, we discuss 10 purposively selected use cases delivering development impact, drawing attention to the differing requirements of use cases and the organisations breaking ground in the ecosystem.

This report is written for a non-technical audience, and contains chapters outlining the context needed to understand the architecture of deployments, and the ecosystem supporting them.

The IoT market in the focus regions will gather momentum across the next decade

Cellular IoT connections across Sub-Saharan Africa and South and Southeast Asia will more than double between 2021 and 2030, reaching 156 million. South Asia will account for almost 40% of these connections, driven by the growing pace of digital transformation among enterprises in India. Similar trends can be seen in Indonesia, where extensive NB-IoT rollouts by operators are enabling IoT use cases in agriculture and other verticals. IoT development in much of Sub-Saharan Africa is at a more nascent stage and faces greater obstacles compared with the other focus regions. These include more limited investment and innovation in solutions and devices that address local use cases, and lower purchasing power among consumers and enterprises. However, the outlook still remains positive. The number of licensed cellular IoT connections in the region will reach 53 million at the end of 2030, up from 20 million in 2021.

The IoT market in LMICs is evolving to provide a rich array of connectivity technologies

Low-power wide area (LPWA) networks will grow even faster, with compound annual growth rates of between 32% to 63%. Cellular machine-to-machine (M2M) networks — 2G to 5G —are examples of wide-area connectivity technologies designed to support a broad range of devices. These technologies account for the majority of licensed cellular IoT connections across LMICs, driven by their long history and wide coverage footprint. LPWA technologies differ from cellular M2M solutions in that they have been optimised to serve the IoT market, specifically applications requiring low data rates and infrequent transmissions. The low power aspect of LPWA technologies means they can offer a battery life of up to 10 years for connected devices. When combined with low-cost hardware, LPWA solutions can support IoT applications that would otherwise not be commercially viable.

The role of IoT for development can be seen across multiple use cases

IoT has the potential to tackle global challenges such as climate change, and address region-wide challenges in key sectors including agriculture, energy, health and transportation. Overall, IoT in LMICs remains at a nascent stage of development; no use case can be categorised as reaching maturity yet. However, several use cases have entered their expansion phase in LMICs, including mechanisation access services in agriculture, asset tracking, smart metering and PAYG cooking.

The use case analysis in this report shows that a wide range of sensing and actuating devices, gateways and cameras are present in the device layer across the different use cases. Furthermore, IoT use cases have varying network requirements, which significantly impact on their ability to scale.

Accelerating adoption requires collaboration across the ecosystem

The next decade offers enormous opportunity to test and scale innovative IoT solutions. A convergence of developments in the supporting network technologies, a growing and thriving innovation ecosystem, and accelerating levels of digital development in populations and institutions means that deployments are increasing in reach in many markets. Harnessing this opportunity will look very different market-by-market, but there are some common supportive actions that different key stakeholder groups can take.

Policy makers and regulators have a central role, and IoT use cases cannot gain traction without the support of regional and national policymakers to develop the IoT market and capture the social, environmental and economic benefits available. In LMICs, regulators have the opportunity to design regulation at the early stages of the market. Providing regulatory certainty to the rest of the ecosystem is particularly important as the lifecycles of many deployments are in over a decade.

Mobile operators can benefit from focusing on specific verticals in scaling their IoT offering as LPWA networks come online in many markets. Weighing the technical and commercial challenges against existing competencies and assets can inform the chances of success. Strategic partnerships will also be central for many operators with only nascent capabilities looking to expand into new areas. Finally, operators should place a particular focus on adopting an appropriate pricing model across services.

Hardware providers are of course central actors in the ecosystem, but hardware alone is not enough. Developing joint go-to-market strategies with mobile operators and other partners can be key in expanding in new markets. For most use cases, designing with longevity at heart and adopting strong security hygiene are key to ensuring successful deployments.

Enterprises and service providers should be clear about the outcomes they are seeking in deployments, and how IoT deployments fit in their business model. Testing, piloting, and learning – in many cases – will be an important part of this journey. Service providers also have a uniquely important place in interfacing with customers. Both in terms of educating users and building trust in deployments.

Financing partners will need to take a long term view. While some use cases are reaching maturity and have been commercialised, others a nascent and will require patient capital to develop. New technologies are creating new and innovative options for financing. For instance, connected productive assets offer the possibility of a broader range of revenue share models.

Development actors will also have a key role in many markets. Donor funding can play a catalytic role in spurring IoT innovation, especially markets where the IoT ecosystem is still at an early stage. Additionally, development actors, can unite governments and private-sector organisations in ways few other actors can through brokering connections, enabling progressive and proactive regulation, and investing in long-term programmes.

1 Introduction

Low- and middle-income counties (LMICs) are home to just over 6.5 billion people, with 57% of the LMIC population living in the three regions covered by this study. Internet of Things (IoT) solutions offer significant potential for supporting socioeconomic growth, and enable citizens, cities, and states new capabilities to respond to emerging threats. Despite the potential of IoT in LMICs, there is little literature and information on the state of IoT networks and deployments in this context. This report aims to bridge that gap.

This report outlines the opportunities IoT solutions present for achieving development outcomes in LMICs. It provides a framework for understanding IoT deployments and the connectivity landscape. A series of 10 purposively selected use cases then bring these to life by discussing the practicalities of deployments in more detail. This report will provide a guide for navigating IoT deployments from an enabling technology perspective and report on the state of deployments of IoT in LMICs.

In this paper, we review the state of public network deployments for wide-area networks (WAN) operating on licenced and unlicensed bands on the spectrum. It is important to note that the vast majority of IoT deployments are projected to be on local area networks, particularly Wi-Fi. However, many of the use cases for development require wide-area coverage. Table 1 outlines the network specifications considered.

The report is organised as follows:

— **Chapter 1 provides a recent history of IoT and presents the reference architecture,** which provides a conceptual guide to breaking down IoT solutions into the associated technology stacks and vendors.

— **Chapter 2 discusses the IoT connectivity landscape,** and describes the different types of IoT connectivity technologies, their characteristics and availability in LMICs.

— **Chapter 3 explores 10 IoT use cases delivering impact,** and highlights how IoT is being used to improve development outcomes across agriculture, climate, health, humanitarian assistance, transportation and utilities.

— **Chapter 4 looks at trends** shaping the outlook for the IoT sector in LMICs across the next decade.

— **Chapter 5 concludes with a discussion of how different actors can support ecosystem development,** with recommendations on supportive actions for relevant stakeholder groups.

1. In this report we follow the regional classifications used in monitoring the Sustainable Development Goals (SDGs). See: https://unstats.un.org/sdgs/indicators/regional-groups/ [accessed November 2022]

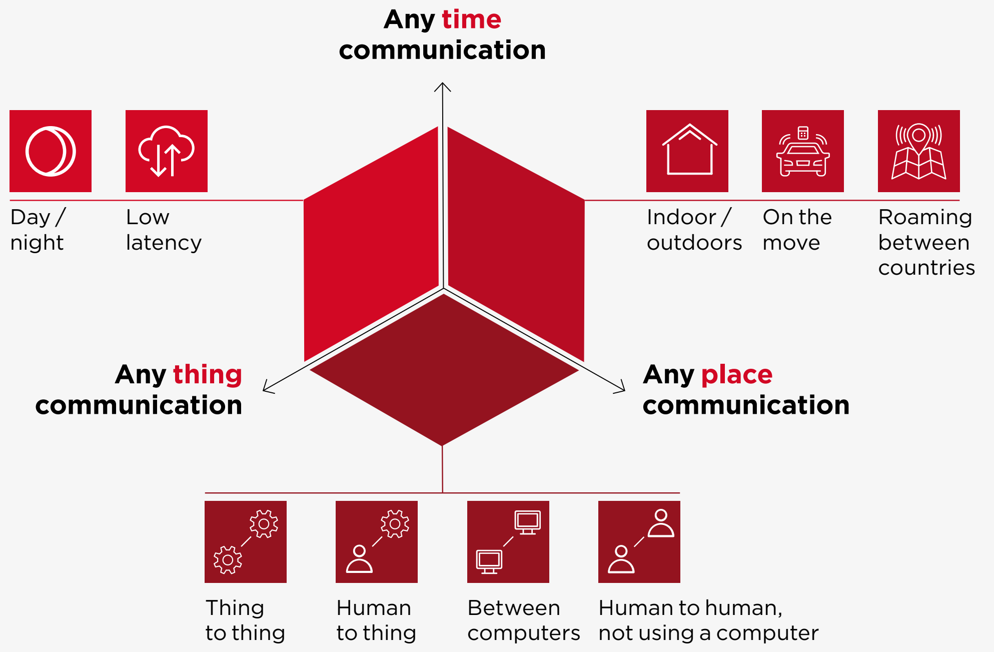
Table 1

Network specifications in scope of this paper

	Network type	Specifications	
In scope of research – wide-area networks	Wide area networks (WAN)	Licensed bands (cellular)	GSM - 2G
			LTE – 3G/4G and 5G
	Low power wide area networks (LPWAN)		NB-IoT and LTE-M
		Unlicensed bands	LoRa
			Sigfox (Zero-G)
	Satellite IoT and hybrid specifications		
Out of scope – short-range technologies	Local area networks (LAN)	Wi-Fi, Ethernet	
	Mesh LAN	Zigbee	
	Personal area networks (PAN)	Bluetooth / Bluetooth low energy (BLE), RFID, NFC	

Figure 1

Communications dimensions



Source: Adapted from ITU-T

1.1 A recent history of IoT

Understandings of IoT

The beginnings of the modern concept of IoT as we are discussing it today should be placed in the machine-to-machine (M2M) era, beginning in the 2000s. Detailed M2M requirements were put in writing by the European Telecommunications Standards Institute (ETSI) in 2010. Specifically:

> *"Machine-to-Machine (M2M) communications is the communication between two or more entities that do not necessarily need any direct human intervention. M2M services intend to automate decision and communication processes."*[2]

Later definitions for IoT include:

> *"IoT includes all devices and objects whose state can be altered via the internet, with or without the active involvement of individuals."* OECD (2020)

> *"A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."* [3] *ITU (2022)*

Rather than being a technology by itself, IoT deployment integrates various technologies related to sensing, automation, software and cloud computing. As shown in Figure 1, IoT adds the dimension any thing communication to the information and communication technologies (ICTs) which already provide any time and any place communication. IoT is an evolution from M2M in the accommodation of scale, where many devices can be networked, and to many applications.

In the 2000s, early M2M use cases were beginning to scale. Prominent examples include smart meters for remote data collection or shut off, and point of sales terminals. As M2M applications proliferated alongside the adoption of mobile phones, the potential for M2M was growing in scope. The mobile industry adopted the more general term IoT, which encompassed the technical capability of connecting physical things that M2M could already cater for, but also reflected the transformative power of these emerging technologies.

2. ETSI (2010). "Machine-to-Machine communications (M2M); M2M service requirements"
3. See: ITU-T Y.4000/Y.2060 Recommendation *[accessed October 2022]*

The need to optimise the connectivity for IoT led to the development of dedicated connectivity standards in the mobile industry. Cellular low power wide area networks (LPWAN) were born to cater for IoT applications that would operate in the licensed spectrum bands using one of the two protocols: Long Term Evolution Machine Type Communication (LTE-M) and Narrowband-IoT (NB-IoT). These are both 3rd Generation Partnership Project (3GPP)-standardised, meaning they have the support of mobile network operators (MNOs).

These standards also stipulate a minimum level of performance and interoperability across vendors and operators, ensuring functionality regardless of who the equipment vendor of the mobile network is. In addition to licensed LPWA, various other technologies were developed for IoT that would operate outside the licensed spectrum, most notably LoRaWAN and Sigfox.

The overarching needs for IoT lie in low device cost, reliability of connection and long battery life. Yet different applications have different priorities and therefore critically in many cases, an IoT deployment can be satisfied with more than one connectivity technology, either used standalone or in combination.

1.2 The IoT reference architecture

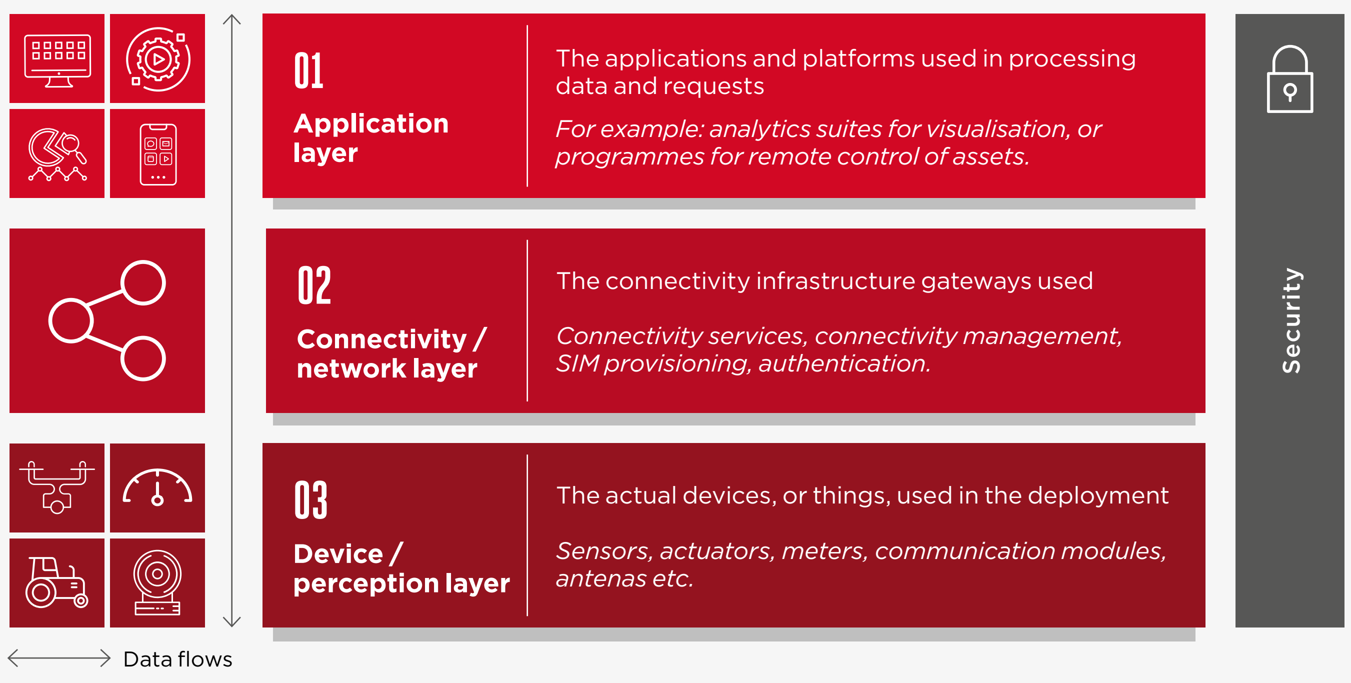
The reference architecture model provides, at a high level, the technology components of an IoT solution. In this report, we use a simplified three-layer architecture in describing and discussing solutions, though more complex five- and seven-layer architectures are often used.

An IoT solution, described end-to-end, will always require these layers, and be comprised of a sensing device that receives a connectivity service and the application that performs the task needed. The device layer is essentially hardware and equipment, the connectivity layer is about connectivity services and any tools needed to deliver and manage the connectivity, and the applications enablement layer is software-based tools and capabilities that make sense of the transmitted data and operate tasks.

It is important to note that all layers have a security component in the sense that security functions are necessary for all device-related, connectivity-related and applications enablement-

Figure 2

IoT solution reference architecture



Note: This depiction of the IoT reference architecture is an adaptation of the original IoT reference architecture as published by the ITU and represents a simplified view of an IoT solution. In reality, IoT solutions are comprised of many devices, sensors, actuators and other connectivity-enabled 'things' that may receive one or more types of communication service.

related functions. Examples of security functions include data confidentiality, firewalls and authentication of registered users.

1.3 From the reference architecture to the ecosystem

The reference architecture model can also be used to map the ecosystem of IoT market players. IoT is neither a technology nor a market on its own. It encompasses many different applications, addressing use cases in various market verticals which can be deployed in different contexts. Some examples of the services and providers needed at each layer are shown in Figure 4.

In addition to technology vendors, for the enablement of IoT solutions the following actors are essential for IoT implementations:

— **System integrators bring various technology components together** and make them workable for individual deployments. Examples include Accenture, Infosys, Capgemini and Tech Mahindra, among others.

— **The actors responsible for shaping the standards, policy and regulatory aspects** of IoT-related spaces, such as 3GPP, International Organization for Standardization (ISO), African Telecommunication Union (ATU), and national regulators (e.g., Telecom Regulatory Authority of India and Nigerian Communications Commission).

It is important to note that the various vendors services, despite typically having one layer as their core focus, do not always adhere to strict boundaries of IoT technology layers. For any IoT vendor, the decision about which layers to focus on is driven by business rationale.

Figure 3
Vendors' offerings across layers

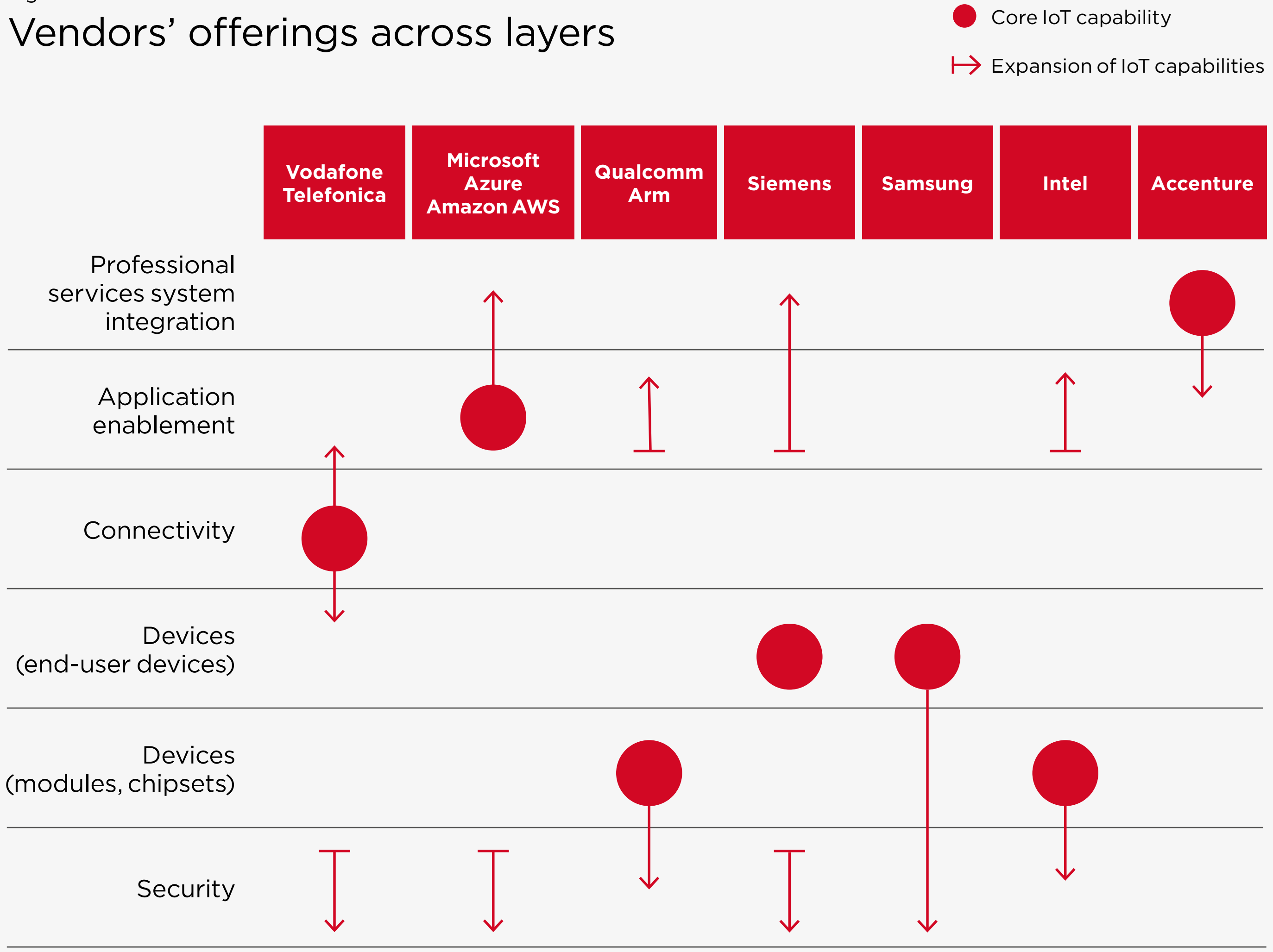


Figure 4
Reference architecture services and vendors

Layer	Services	Example vendors
01 Application layer	• Software platforms that leverage IoT devices generated data and produce insights that are of value to the end user • Typical services include data management, visualization of IoT deployments, monitoring and event-based actions enablement	• PTC Thingworx • Siemens Mindsphere • NVIDIA Omniverse • SAS Analytics IoT platform
02 Connectivity/ network layer	• Connectivity services, e.g. cellular IoT (NB-IoT, 2G, etc.) non-celular IoT (Sigfox, LoRa, Wifi), satellite IoT, short-range and long-range comms • Connectivity management services (e.g. provisioning of connected devices, roaming, etc.)	• Connectivity service providers: Mobile operators (e.g. Vodafone, Orange), Kore Wireless, Sigfox, Siemens Mindsphere • Connectivity management software: Kore Wireless, Wireless Logic
03 Device/ perception layer	• IoT device vendors typically refer to the chipsets manufactures for enabling telecommunication (e.g. NB-IoT modules, etc.) and processing on device (e.g. CPUs, SoC). • Device management (e.g. remote updates) can be performed by device vendors or specialist device management solution providers.	• Chip design: Arm, Qualcomm • Chips (processors): Nordic Semiconductor, NXP Semiconductors • Communications modules: Quectel, Telit, Sierra Wireless

Security

Services:

Software-based services that address security requirements found in all layers of an IoT solution.

For example, in the application layer, security takes care of end-user authorisation, application data confidentiality and user privacy compliance.

Example vendors:

Palo Alto Networks, Kudelski IoT, Fortinet

1.4 IoT connections to 2030

GSMAi[4] estimate that the total number of IoT connections will more than double between 2021 and 2030, reaching 37.4 billion. It should be noted that the vast majority—86%—of IoT device connections are non-cellular, predominantly through Wi-Fi, and this proportion is not projected to change by 2030. A major trend that will define the decade is that enterprise IoT, which includes many utility sector deployments, will overtake consumer IoT by the middle of the decade and continue to pull away. A second major trend is that the vast majority of this growth will be concentrated in Asia, and in particular China (see Spotlight 1).

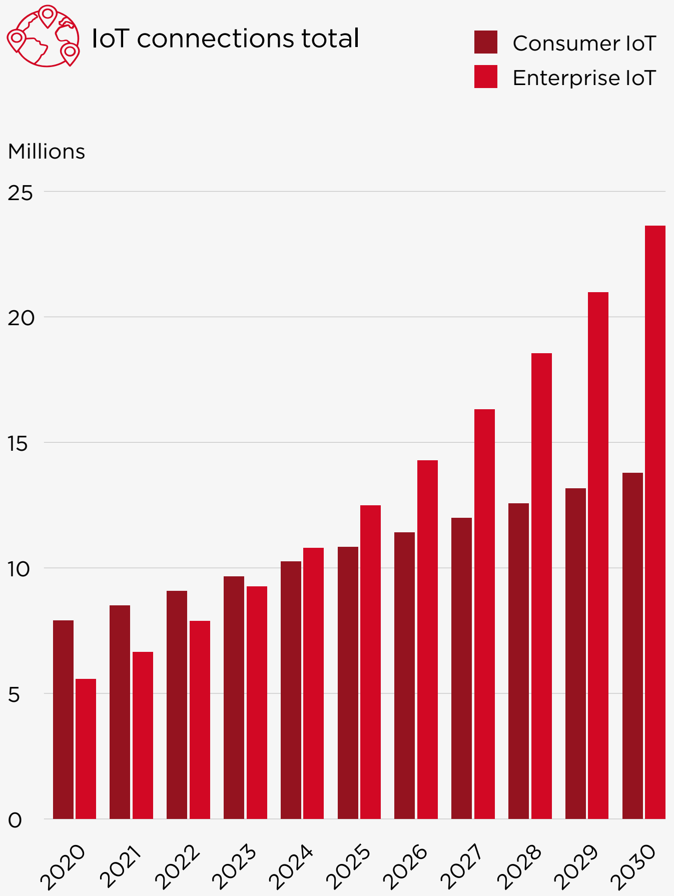
Connections in focus regions

Supported by an expanding IoT ecosystem, licensed cellular IoT connections in the focus regions will more than double between 2021 and 2030, reaching 156 million.[5] Pivotal to this will be the growing role of licensed LPWA technologies, such as LTE-M and NB-IoT. This report will also consider the opportunity to use unlicensed LPWA technologies, including LoRaWAN and Sigfox. Short-range technologies (e.g., Wi-Fi, Z-Wave and Zigbee) are not within the scope of this research, but will provide connections for many millions of devices.

4. https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=67960916&file=201221-IoT-Market-Update.pdf
5. Licensed cellular IoT is the sum of cellular M2M (2G, 3G, 4G and 5G) and licenced LPWA (NB-IoT and LTE-M).

Figure 5
IoT connections 2020 to 2030

IoT connections total



Regional IoT connections

	2020	Net adds (billions)	2030
Asia Pacific	6.0	12.2	18.2
Northern America	3.0	5.0	8.0
Europe	2.6	3.6	6.2
Latin America	0.7	1.0	1.7
MENA	0.5	1.0	1.5
CIS	0.4	0.7	1.1
Sub-Saharan Africa	0.1	0.4	0.5

Source: GSMA Intelligence

Spotlight 1
IoT in China

China is not within the scope of this research, though due to the size and importance of the Chinese market, changes within China have a global effect. China is by far the largest and most developed IoT market globally.[6] 72% of regional licenced cellular IoT connections reside in China, while enterprises in China show one of the highest rates of IoT adoption, with 69% of businesses having already deployed IoT, according to the GSMA Intelligence Enterprise in Focus survey. By 2030, it is expected that just over one in every three connected IoT devices will be in China.

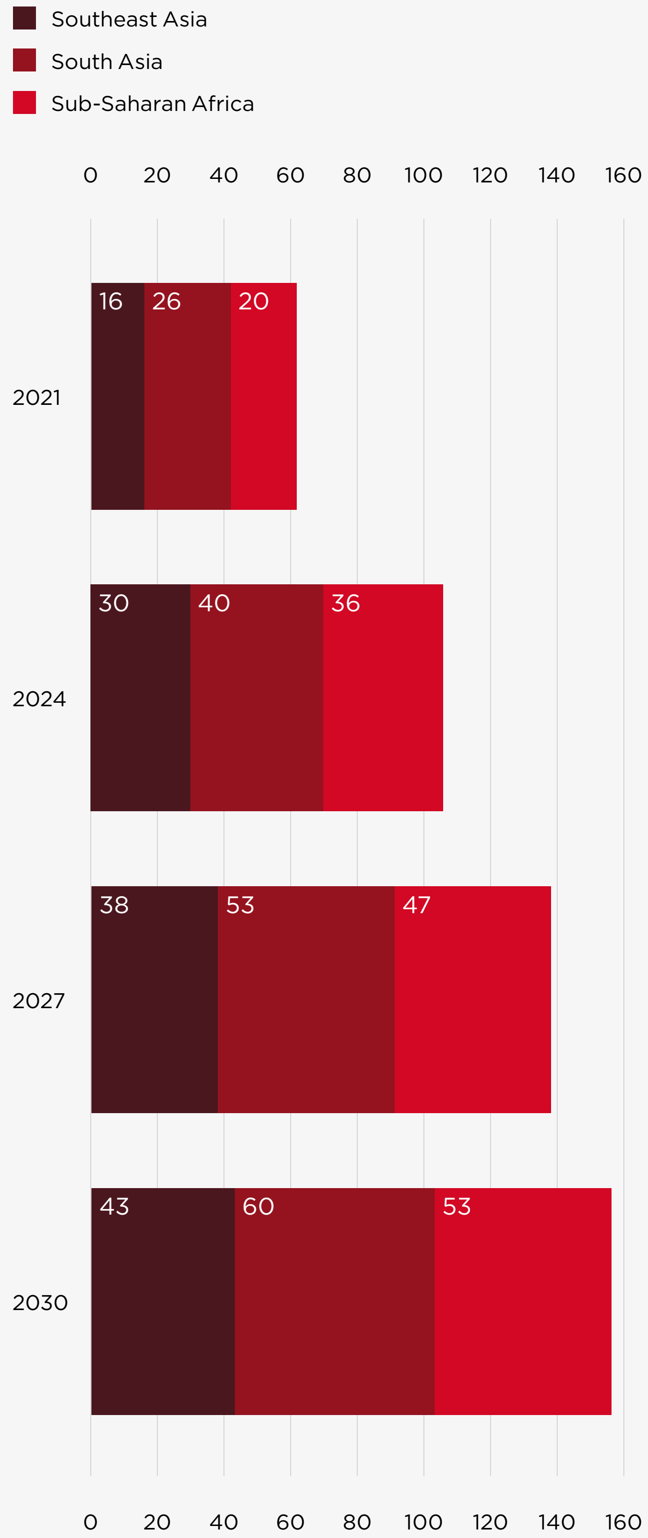
The scale and maturity of IoT in China has consequences for deployments globally, including the focus regions within this study. Most notably, a common theme of the interviews conducted as part of the research for this report was stakeholders noting their reliance on China for IoT hardware. The size of the IoT market in China has created significant economies of scale, driving down IoT hardware costs. However, there are challenges in relying on China for hardware. COVID-19-induced supply chain disruption has focused the attention of some on the importance of onshoring manufacturing capacity.

Revenues within the IoT ecosystem

The IoT layers derived from the reference model can help us break down the overall IoT revenue opportunity. The figures are estimates for the global value split by layer, and while these will vary from solution to solution and country to country, they provide a broad framework for understanding the cost structures of deployments.

6. Zhong, Y. & Kechiche, S., (2019). "Enterprise IoT in China: serving a unique set of market requirements" GSMA Intelligence.

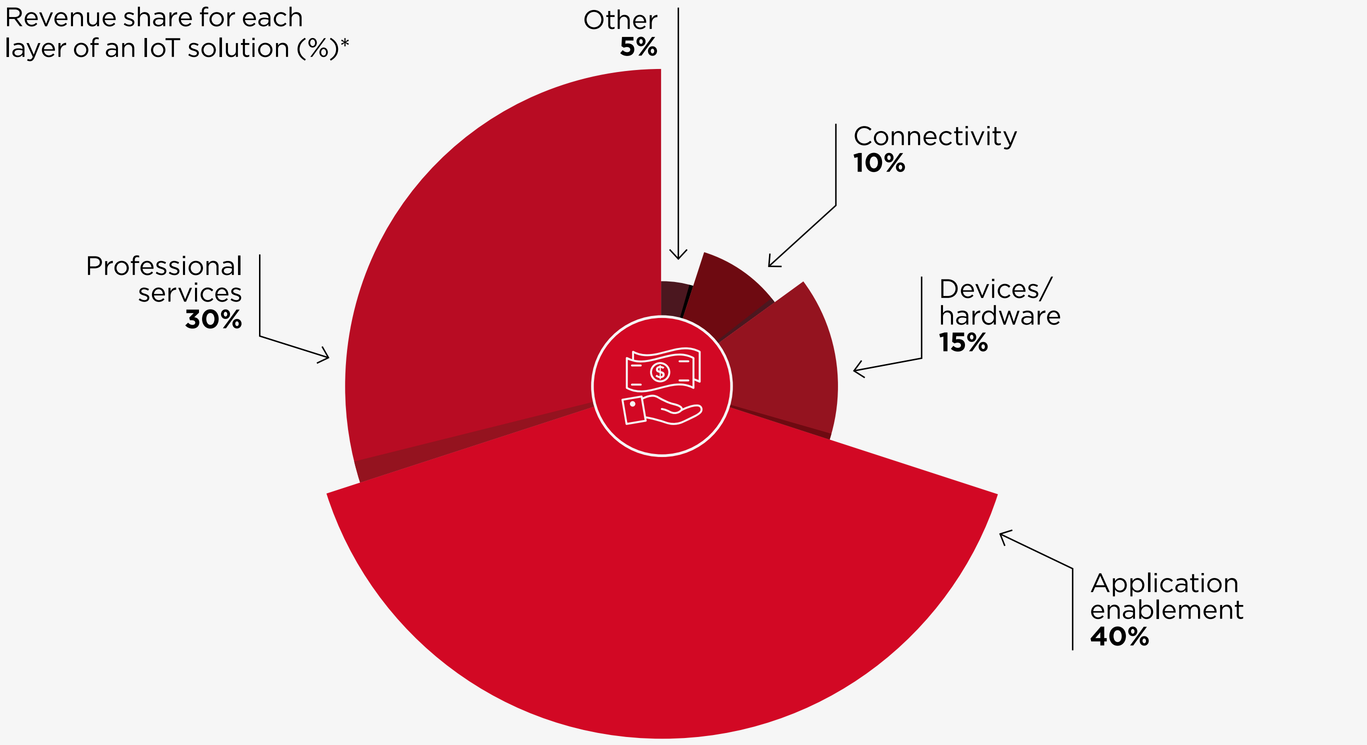
Figure 6
Licensed cellular IoT connections across LMICs in focus regions



Source: GSMA Intelligence

Figure 7

Estimated revenue share for each layer of an IoT solution



*estimate based on broad market trends and observations

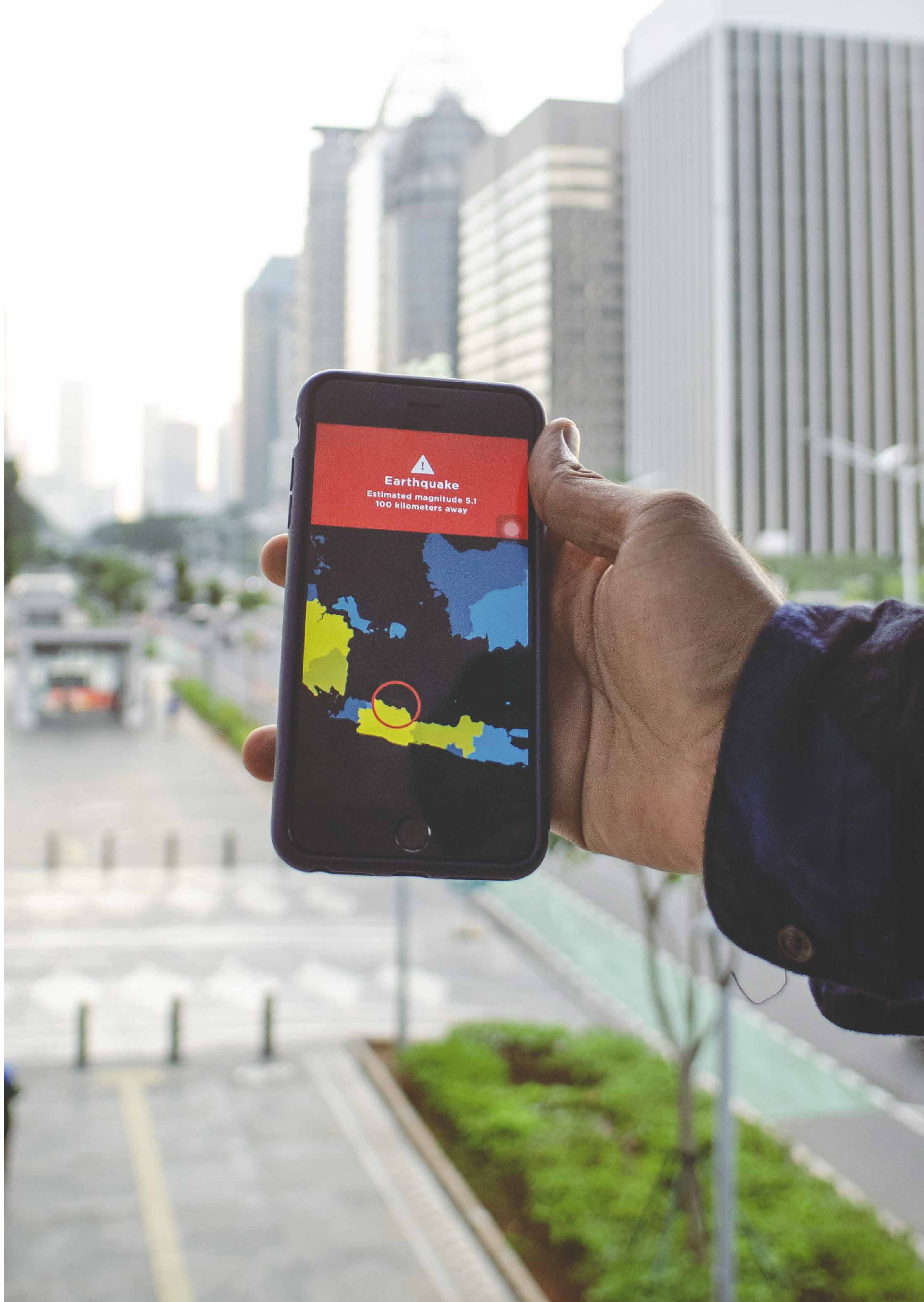
Source: GSMA Intelligence

The largest share in revenue, typically 40-60%, can be expected from the application, platform and services part of the solution. It is typically based on software that, with few customisations, can be replicated in various IoT market verticals and end-customers, and can therefore benefit from economies of scale and the 'stickiness' of software. An example of this can be the Microsoft Azure IoT platform, 'Azure IoT', which is applicable across manufacturing, energy, healthcare, logistics, and other verticals.

Connectivity typically accounts for less than 10% of revenue as Average Revenue per Unit has come to lie in the range of $1-2.50 per device per year for cellular IoT connectivity services in most markets globally.

The cost of hardware can vary, depending on the type of application and requirements, but is generally less than 15%. Costs can be low for simpler devices, like trackers with a couple of sensors, while more sophisticated devices that have to satisfy stricter standards and data processing capabilities, as is the case in complex industrial settings, will have higher costs.

Finally, professional services like system integration, strategy and consulting can be assigned around a quarter of the revenue, especially in more complex deployments where sector expertise is needed and larger scale IoT deployments take place. In the context of less mature IoT markets, as in the case of smaller countries in general and in LMICs, system integration can be performed by the IoT technology vendors themselves, companies like mobile operators or the application enablement platform vendors.



2 The IoT connectivity landscape

In this chapter, we focus on the connectivity layer of the IoT reference architecture model. The IoT market has evolved to provide an increasingly rich array of connectivity technologies to support the demands of IoT applications. Figure 8 outlines the range and maximum data rates for the main specifications, Figure 9 sets out the technologies attributes, and Table 2 lists their main advantages and disadvantages.

Figure 9 explores some of the key differences between licensed and unlicensed LPWA technologies. Two of the major ways in which they differ are their approaches to spectrum and roaming. Unlicensed LPWA technologies rely on unlicensed spectrum, whereas licensed LPWA technologies use dedicated spectrum bands under the terms of the licences issued by regulators. This keeps interference from other radio technologies to a minimum. While both LoRaWAN and Sigfox can support roaming at a technical level, commercial agreements between operators are less common than agreements between cellular operators. The ability to roam on unlicensed LPWA networks is also restricted by the use of different frequencies in each region.[7]

7. Licensed cellular IoT is the sum of cellular M2M (2G, 3G, 4G and 5G) and licenced LPWA (NB-IoT and LTE-M).
8. Bandwidth refers to the maximum amount of data that can be transmitted in a given amount of time.

Table 2

Main connectivity groups

Group	Description	Main advantages	Main disadvantages
Short-range technologies	This group of technologies provide in-building connectivity. Applications that require high bandwidth normally use Wi-Fi, while low bandwidth applications rely on Bluetooth.[8] These technologies are not within the scope of this research.	• Supported by wide array of devices (e.g., mobile phones) • Low-cost connectivity hardware	• Limited area coverage • Limited mobility
Cellular M2M	This consists of 2G, 3G, 4G and 5G networks, which are examples of wide-area connectivity technologies designed to support a broad range of services.	• Good coverage • High data rates • Established vendor ecosystem • Established international roaming agreements	• High power consumption limits battery life • Higher device unit cost
LPWA – **Licensed**	LPWA technologies have been optimised to support machine-type communications. The mobile industry has focused on two complementary licensed technologies: LTE-M and NB-IoT	• Low power consumption (longer battery life) • Low-cost connectivity hardware	• Not yet globally deployed • Low data rates • More nascent vendor ecosystem
LPWA – **Unlicensed**	This class of LPWA technologies uses unlicensed spectrum. It includes LoRaWAN and Sigfox, and many other smaller companies (e.g., Kerlink and Microchip)		
Satellite	Satellite is a niche solution, mostly used to connect IoT devices in remote places.	• Coverage in very remote areas • Suitable for tracking across large distances	• Lower data rates (for most satellite deployments) • Higher latency

Figure 8

IoT connectivity technology vary significantly in terms of data ranges and range

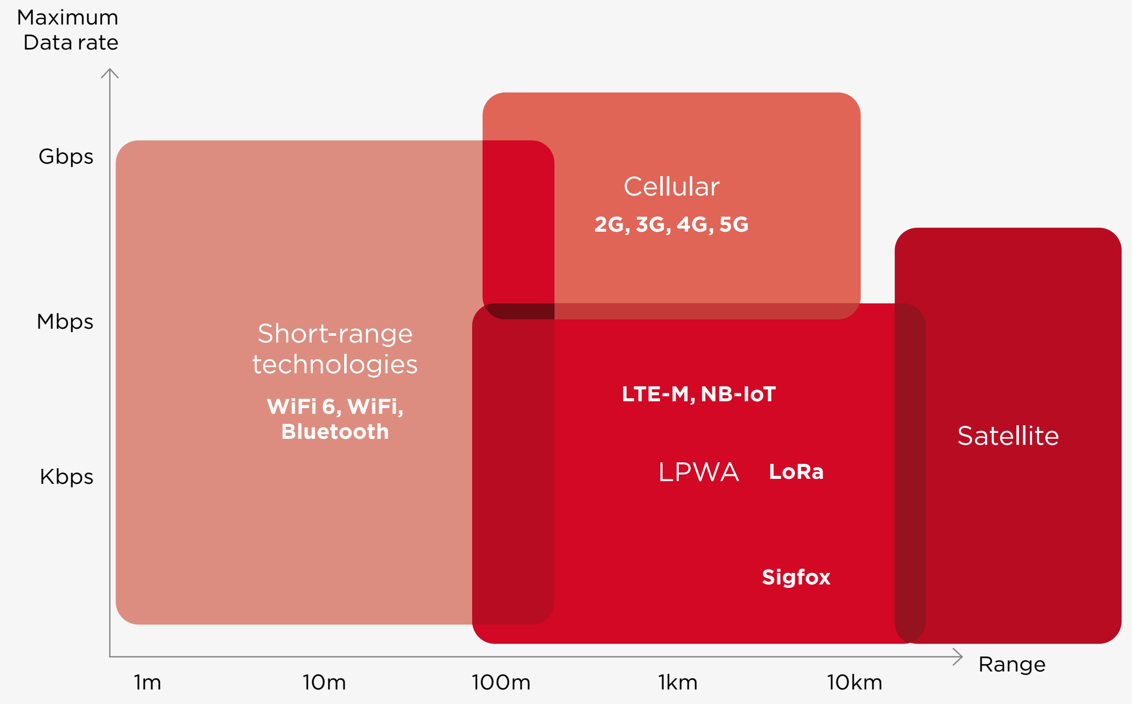


Figure 9

IoT connectivity technology attributes

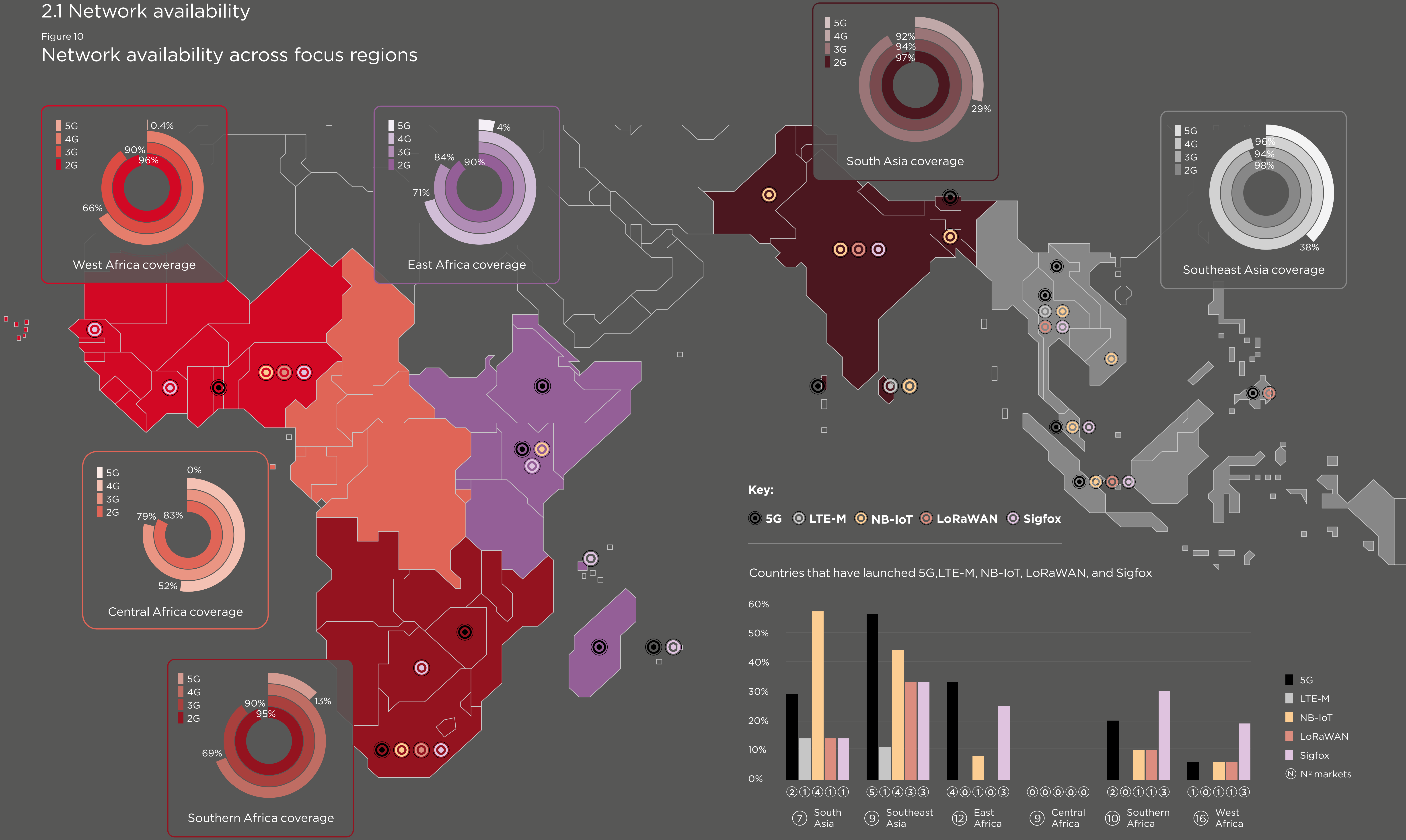
	2G	LTE-M	NB-IoT	LoRaWAN	Sigfox
Bandwidth	●●●○○	●●●●○	●●●○○	●●○○○	●●○○○
Peak data rates	●●○○○	●●●○○	●●○○○	●●○○○	●○○○○
Latency	●●●○○	●●●●○	●●○○○	●●○○○	●○○○○
Battery life	●●●○○	●●●●●	●●●●●	●●●●●	●●●●●
Security	●●●●○	●●●●●	●●●●●	●●●○○	●●●○○
Module costs	●●●●○	●●●○○	●●●●○	●●●●○	●●●●●
Roaming	Yes	Yes	Yes	Restricted	Very restricted
Spectrum	Licensed	Licensed	Licensed	Unlicensed	Unlicensed

Source: GSMA Intelligence

2.1 Network availability

Figure 10

Network availability across focus regions



2.2 Connectivity technology market trends in focus regions

Licensed cellular IoT networks

At the end of 2021, there were 62 million licensed cellular IoT connections across LMICs in South and Southeast Asia and Sub-Saharan Africa. Cellular M2M accounted for 97% of these connections, reflecting its status as the de-facto IoT connectivity solution for mobile operators in these regions. Cellular M2M has a much wider coverage footprint and broader device ecosystem than LPWA technologies (licensed and unlicensed). Cellular M2M has helped to address region-wide challenges by improving resource efficiency in key sectors, such as energy, water, agriculture, transportation, manufacturing and healthcare.

Licenced LPWA technologies (LTE-M and NB-IoT) will experience much stronger growth in the next decade as they support new use cases, as well as IoT devices previously served by legacy networks (2G/3G). LPWA technologies differ from cellular M2M solutions in that they have been optimised to serve segments of the IoT market, specifically applications requiring low data rates and infrequent transmissions such as smart metering. The low-power aspect of LPWA means they can offer a battery life of up to 10 years for devices. Battery life is a key determinant of deployment life-cycle costs, and LPWA can support IoT applications that would otherwise not be commercially viable with previous networks.

LTE-M and NB-IoT are complementary technologies. LTE-M is better suited to devices that require voice support and mobility, while NB-IoT is more appropriate for stationary objects such as smart meters. LTE-M can be deployed in a 4G network, while NB-IoT can be deployed in 2G, 3G or 4G networks. Both LTE-M and NB-IoT are 5G-ready, meaning they are part of the 5G specification and compatibility will be retained as 5G networks are deployed. This gives enterprises certainty that their installed equipment will be supported long-term.

Spotlight 2
Smart meters in Delhi on NB-IoT

In 2021, Reliance Jio and Tata Power Delhi Distribution (Tata Power-DDL) launched a smart metering solution for households using the operator's NB-IoT network.[9] This allowed the companies to connect meters deep inside buildings or in basements without having to worry about replacing the device battery in the next decade. The meters help monitor energy usage in real-time, giving customers greater control over their costs while helping Tata Power-DDL to balance supply and demand. Smart metering solutions can be integrated with digital payments to introduce new tariff plans (e.g., pay-as-you-go (PAYG) services) to reach underserved customers. The efforts of Reliance Jio and other mobile operators to support utility digitisation in India is reflective of the wider digital transformation that enterprises in the country are undergoing, which is driving IoT adoption.[10]

As of mid-2022, NB-IoT has been deployed in 10 LMIC countries[11] in the focus regions of this study, while LTE-M is available in two countries[12] (Figure 10). There is limited public data on NB-IoT and LTE-M population coverage, however Reliance Jio reports 95% NB-IoT population coverage and Vodacom South Africa reports 80% population coverage, which is slightly lower than their respective 4G population coverages.[13,14]

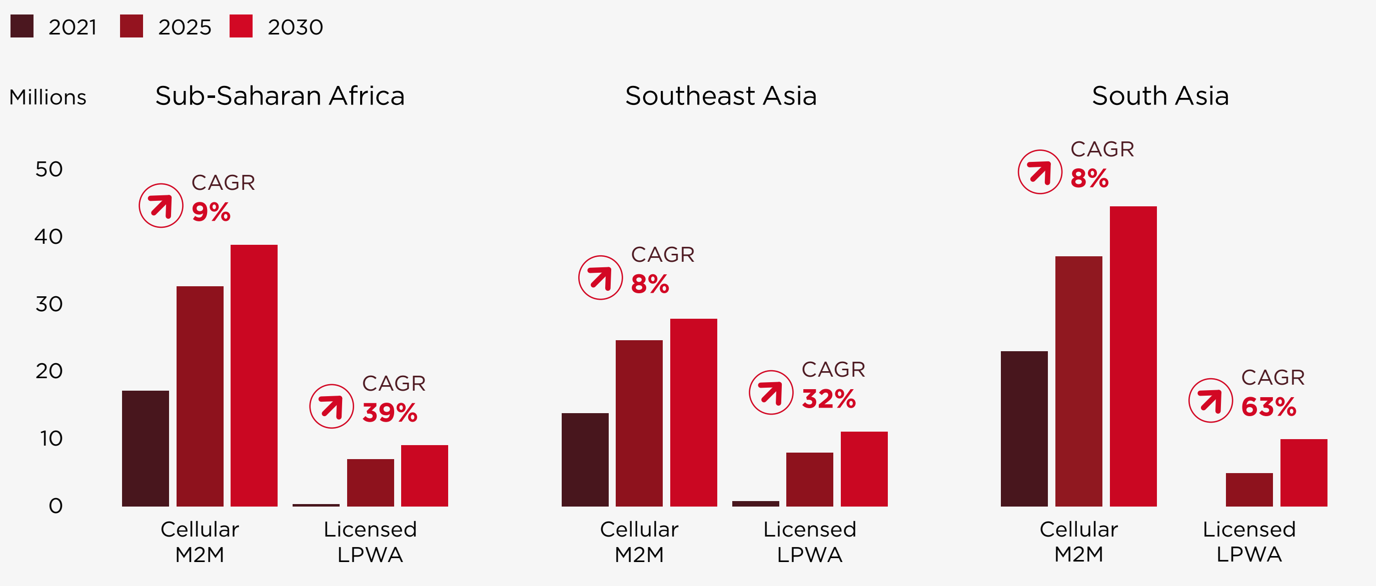
Despite this slow start, our forecasts project licenced cellular connections will more than double in the regions to 2030, with cellular M2M connections having an 8 - 9% CAGR 2021-2030. The growth for LPWA technologies is more dramatic at 23% to 63% across the period, though the total overall connections remain much lower than M2M connections.

9. The Economic Times (2021) "Jio deploys NB-IoT service for Tata Power-DDL's smart meters"
10. Okeleke, K., (2022). "India: on the road to a digital nation" GSMA Intelligence
11. Bangladesh, India, Kenya, Indonesia, Malaysia, Nigeria, Pakistan, South Africa, Sri Lanka, Thailand, and Vietnam
12. Sri Lanka and Thailand
13. Jio (2022) "Smart Electricity Metering"
14. Sim Control (2022) "What is NB-IoT? What is the current status of NB-IoT rollout in South Africa?"

Figure 11
LPWA technologies open up a range of new use cases

	NB-IoT	LTE-M	M2M (2G)
Features: Mobility	Limited	Full	Full
Features: Indoor coverage	Maximun	Very good	Good
Features: Apps	Not possible	Possible	Supported
Features: Data rates	Low	Medium	Medium
Features: Battery life	Maximun	Very long	Medium
Features: Cost modules	Low	Medium	Medium
Example use cases	• Monitoring • Smart city applications • Predictive maintenance • Smart metering	• Asset tracking • Health • Wearables • Alarms/ security • Smart home	• Vehicle telematics • Smart video

Figure 12
Licensed cellular IoT connections to 2030



Note: Compound Annual Growth Rate (CAGR) is for the period 2021-2030

Source: GSMA Intelligence

Unlicensed LPWA: LoRaWAN and Sigfox

LoRaWAN and Sigfox are the two most well-known unlicensed LPWA technologies. LoRaWAN is a LPWA network protocol designed to wirelessly connect devices to the internet. Semiconductor company Semtech holds the IP for LoRaWAN-supporting chipsets and earns a royalty on each device sale. However, the development and promotion of LoRaWAN technology and its ecosystem is led by the LoRa Alliance, which includes more than 500 member companies.

At the end of 2021, LoRaWAN had connected over 225 million devices worldwide,[15] which was slightly below the number of licensed LPWA connections at the time (250 million connections). Public LoRaWAN networks are available in four[16] LMICs in South and Southeast Asia and two[17] in Sub-Saharan Africa. Public LoRaWAN deployments have so far mostly targeted the larger, more developed countries in these regions.

As of January 2022, Sigfox had 20 million registered 'objects' connected to its network (around 5% of worldwide licensed LPWA connections).[18] Sigfox operates networks under its own brand and licences the technology to Sigfox Network Operators in individual countries. Sigfox networks push battery life to its limits as their networks support limited data transmissions and messaging capabilities. As a result, Sigfox tends to be mostly used for applications requiring maximum efficiency such as asset tracking and smart metering. It is available in 75 countries worldwide, including 13 LMICs in South and Southeast Asia and Sub-Saharan Africa.

Satellite: new low Earth orbit (LEO) constellations suggest a growing role in IoT

IoT satellite applications have concentrated on enterprise verticals that require tracking across large distances (e.g. military vehicles, commercial trucking and shipping) or monitoring in remote areas out of reach of land-based networks (e.g. offshore oil rigs and mining pits). Pricing has remained prohibitively expensive though, inhibiting the widespread use of satellite technology in the IoT space. This could change with new LEO constellations. These lower altitude, higher-density networks bring higher performance capabilities in terms of speeds and latencies, and an improved cost structure relative to legacy satellite technology.

15. LoRa Alliance (2022). "LoRaWAN Deployments Achieve Market Leadership; Deliver Strong ROI for IoT Across Wide Spectrum of Industries Across France and Spain"
16. India, Indonesia, Philippines, and Thailand
17. Nigeria and South Africa
18. Majithia, K., (2022). "IoT player Sigfox seeks saviour" Mobile World Live
19. Sigfox (2022). UnaBiz appointed as new owner of Sigfox SA and Sigfox France SAS by the Commercial Court of Toulouse
20. Swarm Technologies "OffGridBox Case Study"

Spotlight 3
Sigfox strategy refresh following an ownership change

In July 2022, Singapore-headquartered IoT service provider UnaBiz acquired Sigfox around seven months after Sigfox began insolvency proceedings.[19] The exact nature of how Sigfox will operate going forward is not yet fully clear; however, the press release issued at the time said Sigfox would "strive towards the convergence of LPWA" and "reinvent itself and collaborate with other IoT communication technologies to seize new market opportunities." To date, Sigfox has been exclusively used by Sigfox operators. This is unlike LoRaWAN, which is used by a range of different companies, including some mobile operators (e.g. Orange and Telkom Indonesia).

Spotlight 4
Satellite IoT enabling OffGridBox to reach remote areas in East Africa

With the deployment of new LEO constellations, satellites are now starting to be more commonly utilised in verticals such as agriculture and energy. For example, LEO satellite provider Swarm Technologies is working with OffGridBox, which provides an all-in-one system using solar energy to purify water and distribute clean energy in remote villages across East Africa. This is done by retrofitting shipping containers with solar panels and a solar energy conversion system. The power generated is stored in power banks which are then sold to individuals. OffGridBox has deployed 47 units across East Africa.[20] The complexity of these units means they require remote monitoring, which is done via Swarm's LEO constellation. OffGridBox's CTO cited cost as the main reason for choosing satellite over other options.

3

IoT use cases with development impact

In this chapter we explore 10 purposively selected use cases, examining the network and device requirements of these, and where they work to improve services and development outcomes. These use cases were selected as they present a broad range of applications and requirements. They are best thought of not as the use cases with the most impact, but those that demonstrate the broadest application of IoT.

Figure 13

Use cases profiled

Higher costs, lower latency, higher reliability (Critical IoT) ↔ Lower cost, lower energy, smaller data volumes (Massive IoT)

Critical IoT	Humanitarian	Disaster response drones	Drones have a range of development applications when it comes to humanitarian assistance. They can be used to predict where a disaster might happen and they can also be deployed at emergency response sites to assess damage in the aftermath of sudden onset events.
Critical IoT	Humanitarian	Early warning systems	EWS monitor, forecast and predict hazards, assess risks, and communicate and disseminate relevant information for people to take action in advance of a shock. These solutions can be implemented for different types of hazards, both natural and man-made.
Critical IoT	Health	Connected medical equipment	Equipping medical devices with connectivity enables healthcare professionals to effectively locate, monitor and manage the devices they use to provide services to patients.
Critical IoT	Health	Health monitoring at home	Health monitoring at home enables the wider reach of healthcare delivery as services can be delivered and managed remotely. Many solutions combine IoT devices, such as wearables and clinical-grade devices, with telehealth services.
Critical IoT	Climate	Forest management	Sensors can be used to support forest management in a variety of ways, including analysing tree growth, measuring air and water temperatures, tracking vulnerable species, detecting chainsaws, and optimising ranger patrol routes.
Massive IoT	Essential utility services	Wastewater network monitoring	IoT-enabled devices help in wastewater monitoring as well as wastewater management, including identifying water treatment processes, managing treatment plants and detecting harmful chemicals in the water.
Massive IoT	Essential utility services	Smart metering	To support modernisation and prepare for future increases in demand, energy and water companies are upgrading to Advanced Metering Infrastructure (AMI) using an integrated system of smart meters, communications networks and data-management systems.
Massive IoT	Essential utility services	PAYG clean cooking	Two types of clean cooking solutions have gained traction in LMICs in recent years: smart meters for liquefied petroleum gas (LPG) cylinders and electromagnetic induction stoves. IoT technology plays an important role in both products in monitoring consumption or through locking technology in PAYG models.
Massive IoT	Agri	Mechanisation access services	IoT devices can be used to track shared agricultural machinery, enabling a single piece of machinery to serve hundreds of farmers who would not typically have access to such equipment.
Massive IoT	Transport	Asset tracking	IoT asset tracking leverages sensors and other connected devices to enable remote monitoring and management of an asset's geolocation and movements.

Table 3

Key IoT use cases requirements and parameters

Use case	Location	Roaming	Quality of service requirement[21]	Mobile money integration	Maturity in LMICs
Mechanisation access services	Mobile	Likely	Medium	Yes	Expansion
Asset tracking	Mobile	Likely	Medium	No	Expansion
Health monitoring	Mobile	Likely	Very high	No	Expansion
Connected medical equipment	Mobile	Unlikely	Very high	No	Infancy
Disaster response drones	Mobile	Unlikely	Very high	No	Infancy
Drones for deliveries	Mobile	Possible	High	No	Infancy
Forest management	Static	Unlikely	High	No	Infancy
Wastewater network monitoring	Static	Unlikely	High	No	Infancy
Early warning systems	Static	Unlikely	Very high	No	Infancy
Smart metering	Static	Unlikely	High	Yes	Expansion

3.1 Key trends across use cases

Throughout this chapter, we highlight the differing requirements of these use cases, analysed through the common components of a deployment. Any IoT deployment will always comprise a sensing device that receives a connectivity service of some kind so that it communicates the data it gathers, and the application that performs the task needed. Notably, there is significant variation in the types of sensing devices deployed and the types of networks used to connect these devices. Table 3 outlines some of the key parameters that determine the needs of a use case.

Our analysis shows the wide range of sensing and actuating devices, gateways and cameras present in the device layer across the different use cases. These devices have a range of different requirements. Battery life is a common priority for use cases such as early warning systems (EWS) or wastewater monitoring where devices are deployed in hard-to-reach areas, making it expensive to replace hardware. In addition, these use cases and others deployed outside often require durable devices due to the conditions they face. Size is also an important consideration for sensors attached to other objects, as seen in asset tracking, forest management and other use cases. Likewise, the drones deployed for deliveries or disaster response must attest to certain size and weight requirements.

21. Quality of service refers to the difficulty of addressing key device and network requirements.

The network layer can be further analysed by looking at static and mobile assets, and where roaming is likely needed as a feature of the use case. Static assets can be supported by various technologies. For example, smart meters may use a fixed line connection (such as PSTN), a broadband/Wi-Fi connection or a cellular connection. The lack of fixed infrastructure in many countries means it is often the latter used to connect static devices, especially when they are geographically dispersed (e.g. EWS and forest management solutions).

Mobile networks are also the network of choice to support the connectivity requirements of mobile assets, unless they are located inside a single building (e.g. asset tracking in a factory), in which case fixed networks might be used. Mobile assets such as asset-tracked vehicles or mechanisation access services sometimes move between countries, meaning they require support for roaming. This is less common for static assets; however, some IoT devices such as smart meters and PAYG cooking devices are often manufactured in China and then shipped abroad. These devices are subject to location regulations on permanent roaming.

The quality of service requirements vary significantly depending on the applications, in line with security and reliability requirements. For example, the critical nature of use cases in the health sector means they must adhere to strict requirements around security and reliability. There are also differences in how IoT use cases integrate with other parts of the digital ecosystem, such as mobile money. When equipment is highly specialised – as with drones, medical equipment and EWS – the cost of IoT devices makes it harder to scale deployments. This is particularly for use cases like disaster response where funding in many LMICs is dependent on humanitarian programming budgets. The challenge of scaling IoT deployments in these areas is compounded by the complexity of networks required, particularly in terms of latency and reliability.

Overall, IoT in LMICs remains at a nascent stage of development, although some upper-middle income countries and lower-middle income countries (e.g. India) are seeing strong traction. Currently, no use case can be categorised as reaching maturity yet. However, a range of use cases have entered their expansion phase in several LMICs, including mechanisation access services, asset tracking, smart metering and PAYG cooking. These use cases have been able to grow due to several factors:

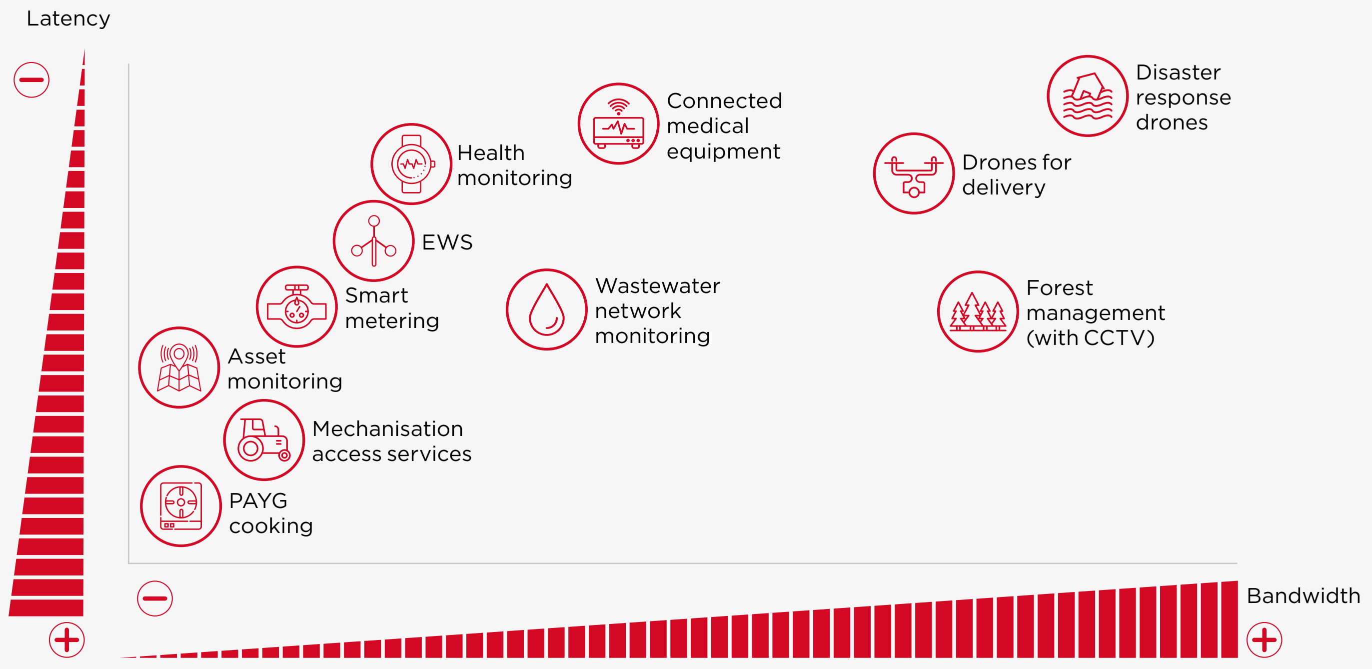
- **Economies of scale from high-income countries and China:** Hundreds of millions of asset trackers have already been deployed in advanced markets, enabling manufacturers to develop significant economies of scale. This provides IoT companies in LMICs with access to a range of low-cost devices.
- **Availability of plug-and-play solutions:** Developing proprietary hardware, software and security architectures and then managing the certification process takes several years, substantial investment and significant technical expertise. Use cases that can be deployed with minimal design time, added approval and integration will therefore scale more quickly, as evidenced by asset tracking and mechanisation access services.
- **Product-network fit:** In most instances, mechanisation access services, asset tracking, smart meters and PAYG cooking do not require superfast download speeds or extremely low latency. These applications can be supported by existing 2G, 3G and 4G networks which are widely available in most LMICs.
- **Integration of IoT into innovative business models:** Several IoT companies in LMICs have built successful business models, enabling them to scale their services. For companies delivering mechanisation access services, smart metering and PAYG cooking solutions, the presence of a robust mobile money ecosystem has been a key factor in this success. Most projects for use cases in their infancy stage rely on funding from philanthropic or donor capital or through support from the corporate social responsibility (CSR) functions of private sector organisations.

Use cases with stricter network requirements face greater challenges in reaching scale. Networks capable of meeting the requirements of use cases with strict quality of service requirements are unlikely to be in place in every location where they are needed, restricting take-up. This applies to advanced markets as well as developing ones. Likewise, use cases involving drones require operators to develop new capabilities in 5G and edge computing to deliver the necessary speeds and latencies. This is in contrast to monitoring use cases which can perform at low speeds and higher latencies.

The remainder of this section provides details of the 10 selected use cases chosen with agriculture, climate, health, humanitarian assistance, transport and utilities. We set out the benefits of deploying IoT solutions in these areas and discuss the key device and network requirements for different scenarios.

Figure 14

IoT use cases varying bandwidth and latency requirements



Source: GSMA Intelligence

3.2 Agriculture

IoT solutions are a key part of smart farming initiatives, which use on-farm and remote sensors to generate and transmit data about a specific crop, animal or practice.[22] This enables the mechanisation and automation of on-farm practices, leading to more efficient, high-quality and sustainable production of agricultural goods. Smart farming solutions can be categorised into three groups:

- **Smart crop management solutions** include remote management of water pumps, soil monitoring, crop monitoring, irrigation management and automation, greenhouse management, automatic fertiliser and pesticide application, cold storage management and logistics tracking. Examples include: Inspira Farms, Nano Ganesh and SunCulture.
- **Smart livestock management** uses IoT devices to help farmers with containment and theft prevention, health and reproduction, identification of predatory threats and long-term management. Examples include: Aquarech, eFishery and Stellapps.
- **Mechanisation access services** use digital booking systems (normally in the form of a mobile app) to enable farmers to access agricultural equipment, such as tractors, drones, threshers, tilling machines and other farm equipment. Examples include: BeatDrone, Hello Tractor and TROTRO Tractor.

Spotlight 5

eFishery and Telkomsel's smart fisheries

eFishery is a smart livestock management start-up that has developed an automatic fish feeder using NB-IoT technology from Telkomsel. It schedules fish feeding times, checks on water quality and monitors fish behaviour. This solution offers several benefits to farmers and the environment; it lowers the risk of overfeeding, reduces water pollution and enables farmers to stay updated on the fishes' condition wherever they are. For Telkomsel, it offers a new revenue source outside of traditional mobile services and acts as a proof point for other enterprises evaluating the benefits of NB-IoT. In February 2018, eFishery received a grant from the GSMA Ecosystem Accelerator Innovation Fund [24] to extend its value proposition to fish and shrimp farmers by adding more features to its product offerings, including a farm management feature and a financing dashboard that will connect farmers to financial institutions.

Mechanisation access services

Use case description: Mechanisation access service providers have reported the highest user figures among the three categories.[23] These services enable a single piece of machinery to serve hundreds of farmers who do not typically have access to such equipment, which in turn saves farmers' time and lowers their costs. For equipment owners, it reduces the time their machinery is spent idle, helping them to improve their return on investment. The IoT element of mechanisation access services comes in when agricultural equipment is fitted with monitoring devices. Examples include fuel level sensor and fuel flow meters, GPS trackers and CAN readers for monitoring engine time, speed, temperature and other parameters.

Key use case requirements:

Durability: IoT-enabled mechanisation access services share many of the same requirements as crop management and livestock management (e.g., rugged devices, support for SMS messaging and wide-area coverage).

Precision: Mechanisation access services require accurate positioning of agricultural equipment. Most services use hardware that integrates GPS, which is normally accurate to within two metres.

Roaming: Some mechanisation access services also require the ability to roam between countries, which is why companies such as Hello Tractor fit their monitoring devices with international SIM cards.[25]

22. GSMA (2021). "Digital Agriculture Maps"
23. GSMA (2022). "Assessment of smart farming solutions for smallholders in low and middle-income countries"
24. GSMA (2019) "Meet our portfolio start-ups: eFishery, Indonesia"
25. Hello Tractor: Get Technology

Spotlight 6

Hello Tractor's IoT-enabled mechanisation access services

In Kenya, Hello Tractor connects tractor owners to farmers through a mobile app, whereby tractor owners can rent their machines to smallholders in their area and farmers can pool together to rent a vehicle at affordable rates. Hello Tractor equips every tractor with a low-cost monitoring device that tracks everything related to tractor operations, from fuel consumption to tractor movements. The data collected is then transferred to the Hello Tractor app, where it is displayed in a user-friendly format. This allows tractor owners to have full visibility into tractor location, activities performed and maintenance requirements. The app also allows farmers to rate the tractor operators who have worked on their land and view the ratings of other users to help them decide which tractor owners they can rely on.

Hello Tractor was launched in 2014 and now operates in 18 countries. Each of their tractors serves up to 200 farms, and enables farmers to cut their costs by 40%, increasing their yields seven-fold in some instances.[26] The GSMA Innovation Fund are currently working with Hello Tractor to integrate early warning and weather alert services to their offering.

3.3 Climate

IoT offers significant potential in engineering innovative climate solutions, cutting across several of the areas analysed in this chapter, such as agriculture (smart crop management), humanitarian assistance (EWS) and utilities. There are also specific applications, such as natural resource management (NRM), where IoT plays a growing role in response to the climate challenge.

Natural resource management

Use case description: NRM refers to the sustainable utilisation of the planet's natural resources, such as land, water, air, forests and a diversity of plant and animal species. The use of digital technology in NRM is still nascent, but has grown steadily over the last decade. GSMA identified 131 NRM projects where digital technologies were being used, with forest management accounting for nearly a quarter of all projects.[27]

Sensors can be used to support forest management in a variety of ways, including analysing tree growth, measuring air and water temperatures, tracking vulnerable species, detecting chainsaws and optimising ranger patrol routes. This data can be combined with satellite imagery and drone footage to create a better understanding of deforestation and its impact.

Key use case requirements:

Network coverage in remote areas: The coverage gap—those living in areas without mobile broadband coverage—continues to shrink.[28] However, providing ubiquitous connectivity remains a significant challenge due to the feasibility of deploying networks in sparsely populated rural areas with difficult terrains, such as forests. Extending networks to these areas is therefore a key requirement for scaling forest management solutions.

Gateway devices: IoT-enabled forest management solutions can put a sensor on virtually anything, including animals, anti-poaching units, entry gates and tree branches, roots and surrounding soils. Many solutions will rely on a gateway that aggregates data from all the devices and then sends it to the cloud for analysis.

Bandwidth: There are a variety of innovative niche IoT projects for forest management which include recording devices that transmit sound, photographs and video from protected areas. These require high bandwidth networks to send large data files.

26. The New Stack. (2019). Hello Tractor: An App-Driven Ecosystem for Tractor-Sharing. Available at: https://thenewstack.io/hello-tractor-an-app-driven-ecosystem-for-tractor-sharing.
27. Wilson, M. (2020). "Digital Dividends in Natural Resource Management" GSMA
28. Delaporte, A., & Bahia, K., (2021). "The State of Mobile Internet Connectivity 2021" GSMA

Spotlight 7

Guarding rainforests in the Philippines

In the Philippines, mobile operator Smart Communications Huawei, non-profit Rainforest Connection (RFCx) and the government's Department of Environment and Natural Resources (DENR) are working together to test a new monitoring system that leverages connected mobile devices and artificial intelligence (AI) to prevent illegal logging and animal poaching in five protected areas. The solutions help detect the sound of human activity (e.g. chainsaws or motor vehicles) and captures data on animal patterns and behaviours.

The solution works by connecting upcycled Huawei smartphones to solar panels and microphones, allowing the RFCx system to livestream the sound of the forest 24 hours a day. The mobile devices have proven to be extremely durable. RFCx estimates that they can operate non-stop for two years without human intervention, and are less expensive and easier to power than most other types of connected devices. The recorded audio is then uploaded in real time to the cloud through wireless networks. The project in the Philippines is the first instance where RFCx has worked with an MNO to support the monitoring system.[29]

3.4 Health

The COVID-19 pandemic has magnified weaknesses and gaps in healthcare systems. Digital solutions are likely to play a key role in strengthening these systems. For example, the application of IoT in the health sector allows for medical device integration, remote monitoring in personal healthcare and treatment of diseases.

Connected medical equipment

Use case description: Equipping medical devices with connectivity enables healthcare professionals to effectively locate, monitor and manage the devices they use to provide services to patients. This is important as lost and unmaintained equipment can disrupt medical procedures, reduce the productivity of medical staff and increase healthcare costs. Moreover, when data from connected medical equipment is sent to IoT platforms, it can be analysed to identify process bottlenecks and under-utilised assets, and predict future equipment needs.

Connected medical equipment also enables medical professionals to deliver field-based services, such as imaging diagnostics delivered through wirelessly connecting ultrasound devices to specialists in clinics. For example, TeleCTG provides portable cardiotocography solutions in Indonesia that can be used by midwives and doctors to provide quality maternal health services. This can help reduce maternal mortality rates in the country.

Key use case requirements:

Range of coverage options: Deep indoor coverage is often required to connect medical equipment in hospitals, whereas wide-area coverage is more important for field-based equipment.

Device size: IoT modules must be small enough for size-constrained hardware and must be hard-wearing to function despite regular sterilisation.

Security: Medical devices must also be able to send data securely over the network to cloud-based platforms to maintain device functionality and protect user data. As the market has moved from 2G through 4G and now 5G, security has become an increasingly integral part of standards, meaning connected medical solutions are increasingly leveraging cellular connectivity.[30]

29. For more information, see Wilson, M., (2020). "Digital Dividends in Natural Resource Management" GSMA
30. Thales (2021) "Remote Patient Monitoring powered by Global Cellular IoT Connectivity"

Health monitoring at home

Use case description: Health monitoring at home enables the wider reach of healthcare delivery as services can be delivered and managed remotely. Many solutions combine IoT devices, such as wearables and clinical-grade devices, with telehealth services. This can help governments improve health outcomes, particularly in rural areas where people travel long distances to speak to medical professionals.

The growing relevance of health monitoring devices in homes can be attributed to major vendors building their wearable propositions around health and wellness, providing new or enhanced features that allow users to measure blood oxygen levels, track fitness metrics, take electrocardiograms (ECGs), check heart rates and track sleep. In addition, there are an increasing number of clinical grade devices available with features including blood pressure measurement, biomarkers for blood glucose and sweat PH sensors. This data is then sent to cloud-based platforms, which users and medical professionals can access to understand the information collected by prescribed devices.

Key use case requirements:

Durability: The importance of agriculture to several economies in LMICs means a solid, shock-resistant and waterproof design is important, particularly for farmers.

Battery life: A self-charging or long-life battery is an important feature, particularly among households with limited access to electric power.

Standalone: While smartphone penetration has risen strongly in LMICs, enabling monitoring devices to be fully operated without being paired with smartphones helps to extend the addressable market, albeit with cost trade-offs.

Security: As with connected medical equipment, security is also a crucial concern given how personal and sensitive the data being transmitted are.

Spotlight 8

Trails of wearables in Cambodia, Burkina Faso, and Kenya

Several studies have considered how these devices could improve healthcare outcomes in LMICs. For example, smartwatches can be used to monitor symptoms of infectious diseases,[31] such as Ebola. A recent study in Cambodia analysed whether health monitoring at home could support a public health programme to prevent non-communicable diseases, such as heart disease and strokes.[32] Moreover, the relationship between climate change and health outcomes has been examined in Burkina Faso and Kenya by providing wearables to trial participants.[33] Despite growing evidence of the positive relationship between health monitoring at home and healthcare outcomes, advanced countries continue to account for the majority of worldwide sales of these devices.

31. Al-Halhouli A. et al., (2021). "Monitoring Symptoms of Infectious Diseases: Perspectives for Printed Wearable Sensors" Micronmachines
32. Liverani M. et al. (2021). "User experiences and perceptions of health wearables: an exploratory study in Cambodia" Global Health and Research Policy
33. Barteit S. et al. (2021). "Feasibility, acceptability and validation of wearable devices for climate change and health research in the low-resource contexts of Burkina Faso and Kenya: Study protocol" PLoS One

3.5 Humanitarian assistance

Humanitarian needs continue to rise, driven by challenges such as disasters triggered by natural hazards.[34] IoT solutions can timely detect hazards, improve response and support humanitarian organisations responding to crises more effectively.

Early warning systems

Use case description: EWS monitor, forecast and predict hazards, assess risks and communicate and disseminate relevant information for people to take action in advance of a shock.[35] These solutions can be implemented for different types of hazards, both natural and man-made. IoT solutions are mostly used for natural hazards, including geotectonic (earthquakes, tsunamis and volcanic activity) and hydrometeorological (floods, typhoons, cyclones, hurricanes and droughts). The earlier and more accurately hazards can be identified, the more likely it is that their impact can be mitigated.

IoT solutions can be integrated with EWS to collect better quality and consistent information on a range of parameters, including CO2 emissions (to forecast volcanic eruptions),[36] vibrations (to anticipate landslides),[37] rainfall thresholds (to predict floods),[38] and soil moisture (to detect wildfires).[39] Data is then transmitted by wireless networks to an IoT platform that analyses patterns to detect hazards and transmit alerts when necessary.

With the rising availability of low-cost hardware and connectivity, progress has been made in integrating IoT solutions in EWS. However, IoT-enabled EWS are often fragmented, with inadequate coordination and data sharing between stakeholders curtailing their impact on the ground.[40]

Key use case requirements:

Reliability: The critical nature of EWS means reliability is paramount. Hardware should be designed to withstand the impact of hazardous weather conditions (e.g. protective casing or fabrication can be used on the sensor nodes).

Battery life: EWS often deploy sensors in hard-to-reach areas (e.g. on the sea surface or on a volcano), making it expensive to replace batteries. EWS sensors are often deployed in direct sunlight, therefore solar cells can be used as a source of power supply.

Coverage: EWS for wildland fires, earthquakes, tsunamis and other threats typically monitor activity over a large geographical area. This requires long-range communication between IoT sensors and gateways. The connectivity solution also requires excellent signal propagation to overcome blockages from trees, mountains and other obstacles.

Spotlight 9

Lumkani uses IoT to address the challenges of fires in urban informal settlements

Lumkani is a South African social enterprise that has developed an innovative EWS. It has installed over 20,000 fire sensors inside homes across South Africa at zero cost to users as a result of GSMA grant funding. The sensors mitigate fire risk through a networked alarm which provides live monitoring and SMS alerts to residents and their neighbours, allowing instant notification of fire.[41]

34. GSMA (2022) Mobile for Humanitarian Innovation Annual Report
35. UNDRR: Early Warning System
36. Amaliya V.F., et al. (2021). Development of IoT-Based Volcano Early Warning Journal of Physics: Conference Series Vol. 1772
37. Elavarasi, K. and Nandhini, S., (2021) Landslide Monitoring and Tracking Using IoT Sensors Journal of Physics: Conference Series Vol. 1717
38. ASEAN Australia Smart Cities Trust Fund (2020) Digital Solutions: IoT For Real-Time Flood Early Warning Systems
39. Herring B. et al. (2022). Underground LoRa Sensor Node for Bushfire Monitoring. Fire Technology
40. Aranda, C., & Humeau, E., (2022). Early Warning Systems in the Philippines: Building resilience through mobile and digital technologies. GSMA
41. GSMA (2021). Lumkani Fire Detection and Insurance

Disaster response drones

Use case description: Drones have a range of development applications when it comes to humanitarian assistance. They can be used to predict where a disaster might happen and they can also be deployed at emergency response sites to assess damage in the aftermath of sudden onset events. For example, aerial images from drones can help emergency services and humanitarian organisations make decisions on the number of personnel and equipment needed. Drones can also be equipped with thermal cameras and IoT sensors (e.g. gas and temperature sensors) to provide continuous, real-time updates.

Drones have several advantages over traditional methods of assessing disaster impact. In comparison to a fixed-wing light aircraft or helicopter, drones are more cost-effective, faster, and suitable for use in extreme weather conditions.[42] Drones also produce higher quality images than satellites and GPS surveys.

Key use case requirements:

Bandwidth: Drones equipped with real-time video monitoring systems require high bandwidth connectivity to transfer large amounts of data over the network in a short space of time. The collected data can then be processed and mapped on 3D scales.

Latency: Remotely piloted drones assessing damage after a natural disaster require low latency connectivity to enable the pilot to navigate the drone effectively.

Reliability: Reliable and secure communication networks are vital to share data collected by drones and other equipment with rescue team members.

Spotlight 10

Smart Communications and Nokia highlight the value of private networks

The damage caused by natural hazard disasters can temporarily disable mobile networks, making it even harder for humanitarian organisations to respond to crises quickly and efficiently. In this scenario, private networks provide an alternative means of connectivity that can be quickly deployed at a disaster site.[43]

Following the Porac earthquake in the Philippines in 2019 and the subsequent loss of connectivity, Smart Communications and Nokia set up a private network to help the Philippine Red Cross evaluate the surrounding buildings and infrastructure. This enabled drones to identify damage and potential hazards not visible from the ground. The technology underpinning the solution is now being used in disaster resilience contests around the world.[44]

42. Daud, S.M.S.M., et al (2022). Applications of drone in disaster management: A scoping review Science & Justice Vol 62
43. A private network is a cellular network that is built specifically for an individual enterprise or organisation without dependence on or reference to a national mobile grid.
44. GSMA (2022). "Grant project lessons and outcomes: Nokia Saving Lives"

3.6 Transport

IoT devices and modules are becoming increasingly common in the transport sector. Key drivers include the need to optimise fuel and routing systems and locate valuable assets. This analysis focuses on the use of drones for deliveries and asset tracking.

Asset tracking

Use case description: IoT asset tracking leverages sensors and other connected devices to enable remote monitoring and management of an asset's geolocation and movements. It is used across a wide variety of industries, including agriculture (e.g. tracking livestock), manufacturing (e.g. locating industrial equipment) and smart cities (e.g. monitoring manholes to prevent theft).

In the transportation sector, IoT asset tracking enables companies to monitor how their goods are being transported throughout the supply chain. Trackers and sensors can be attached to shipping containers, trailers, pallets and even individual packages. These services are an essential component of e-commerce solutions, and increasingly being applied in developing more reliable logistics systems. Some parameters are particularly important for items that must be transported under specific conditions. In these scenarios, sensors can be used to collect data on temperature, humidity, moisture and other variables. Alerts can then be set up so that action can be taken if conditions change (e.g. a rise in temperature levels that could cause items to perish).

Key use case requirements:

Device size: IoT asset tracking devices need to be compact given the space constraints in shipping containers and other methods used to transport goods.

Durability: They also need to be rugged to withstand any physical impact during loading and unloading.

Coverage and roaming: Wide-area coverage is crucial given the devices will be travelling significant distances. Furthermore, tracking assets internationally is becoming more important with new agreements such as The African Continental Free Trade Area set to boost trade flow between African countries even further. The complexities of IoT roaming therefore need to be understood.

Spotlight 11

Koolboks trial IoT to ensure cold chain compliance in Nigeria

Koolboks provides pay-as-you-go solar-powered refrigeration solutions. Koolboks' innovative product uses ice, as well as batteries, to convert the power of the sun into cooling. Thanks to this, they're cutting the cost of off-grid refrigeration by 40%. With embedded PAYG technology, Koolboks are able to offer their freezers on a lease-to-own basis, a locking device embedded within the compressor links the payments and cooling.

Koolboks, in partnership with IFC and Danone, recently trialed installing IoT devices to monitor temperature and usage of the freezers (e.g. number of times opened) in a pilot to test the applicability of maintaining the cold chain in distribution of frozen dairy products. The outcome of the pilot informed further development of Koolboks' IoT platform, with plans underway to equip all future food storage products with sensors for temperature monitoring, geolocation, and energy management by the user. The GSMA are currently supporting Koolboks to scale their solution in Nigeria.

3.7 Utilities

With growing pressure on the world's limited resources, utility companies are seeking new ways to better match supply and demand, harness cleaner energy sources and reduce costs. Mobile technology will be pivotal to achieving these objectives, underpinned by the growing role of IoT solutions.

PAYG clean cooking

Use case description: According to the World Bank, four billion people worldwide lack access to modern energy cooking facilities. This consists of 1.2 billion people with no access to cooking facilities and 2.8 billion people cooking with fuels such as solid biomass, kerosene, or coal. These fuels produce significant greenhouse gas emissions and contribute to premature deaths from household air pollution.[45,46]

Improving access to clean cooking solutions is therefore an important driver in reducing social and environmental inequalities. Two types of solutions have gained traction in LMICs in recent years: smart meters for liquefied petroleum gas (LPG) cylinders and electromagnetic induction stoves. IoT technology plays an important role in both products, as highlighted by examples such as Powerstove and Jaan Pakistan.

Key use case requirements:

Battery life: For smart meters used for LPG cylinders to function properly, their batteries must be adequately charged.

GPS functionality: Providers can locate the equipment in case customers default on payments.

Durability and safety: IoT units need to be durable as they are likely to see considerable use. Additionally, it is essential that they are tamper-proof, as there can be strong incentives to try and bypass PAYG devices and in the case of gas, this can prove dangerous.

Spotlight 12
Digital payments and clean cooking solutions in Kenya, Tanzania, and Cambodia

Circle Gas operates in Kenya and Tanzania, providing customers with a stovetop, a gas cylinder and a smart meter that monitors gas usage and sends alerts to a fleet of motorised technicians so they can replace the cylinder before it runs out.[47] This process is underpinned by mobile money, which enables customers to upload money to a digital wallet in the Circle Gas app and pay for gas through a simple transaction on their phone. Moreover, when the mobile money funds that are loaded on the embedded digital wallet run out, the smart meter ensures the tamper-proof cylinder valve automatically shuts off the gas supply.

PAYG financing is also an important aspect of electromagnetic induction stoves. With devices from the likes of ATEC costing around $200, it is not feasible for many households in LMICs to purchase these devices outright. However, PAYG financing enables customers to purchase the stove on monthly instalment plans. Mobile money API integrations enable payments to be automatically made. Most stoves lock if the customer has no credit to reduce the risk of defaults on payments.

45. Bailis R., et al (2015). The carbon footprint of traditional woodfuels. Nature Climate Change Vol 5.
46. World Bank (2020). "Infographic – Modern Energy Cooking Services"
47. The equipment is owned and maintained by Circle Gas – the customer only pays for the gas they use.

Smart metering

Use case description: To support modernisation and prepare for future increases in demand, energy and water companies are upgrading to Advanced Metering Infrastructure (AMI) using an integrated system of smart meters, communications networks and data-management systems. This enables usage data to be accurately recorded and automatically transmitted in real-time to IoT platforms where it can be analysed. Consequently, utility companies no longer have to send staff to read meters (which is expensive) or rely on customers reporting the meter reading themselves (which is often late and unreliable). In addition, smart metering solutions can help energy utilities minimise electricity theft and line losses in addition to water leaks,[48] while enabling water utilities to identify leaks and reduce their Non-Revenue Water (NRW) costs.

The data collected by smart meters inside homes can be viewed by customers on mobile apps. This allows them to have visibility into their consumption patterns, and combined with advanced analytics (AI or machine learning), the data from these meters can enable predictive analysis on the performance of networks, or the development of digital twins. Smart meters can also improve household access to energy and water. When combined with digital payments, smart meters enable utility companies to introduce PAYG offerings to connect new subscribers without risk to the utility (as they are prepaid). PAYG tariffs also give users who were previously disconnected due to high arrears the chance to reconnect to utility networks and make small daily micropayments towards their accrued debt.

Key use case requirements:

Coverage: Smart meters are normally distributed across a country, so wide coverage is needed. A network with strong propagation characteristics is also required to connect meters in hard-to-reach locations, such as deep inside buildings or in meter cabinets.

Battery life: Many meters may not be connected to mains electricity, so they require a low power connectivity solution and devices with long battery life (5+ years). The length of battery life is a key determinant of life-cycle costs, and can make or break the feasibility of a deployment.

Cost: Advanced or smart meters are perhaps the most prominent case of massive IoT. Given that most deployments will involve hundreds of thousands, if not millions, of devices, the unit costs are critical.

Spotlight 13
Bridging the energy gap through mini-grids in Nigeria

Mini-grids are decentralised, independent power networks that can function apart from the national grid. They occupy a 'sweet spot' between national grid extensions and standalone solar home systems.[50] IoT solutions are a key catalyst for the mini-grid ecosystem. Smart metering solutions enable mini-grid providers to remotely monitor and manage energy production, operations, and consumption. The ability to remotely identify and troubleshoot problems greatly reduces operating costs, and enables companies to customise their service offering in line with evolving customer behaviour.[51] Smart metering can also facilitate digital payment collection, enabling prepaid PAYG services.

Odyssey's end-to-end investment and asset management platform enables funders, governments, regulators, and project developers to partner on mini-grid projects. In Nigeria they are collaborating with the Rural Electrification Agency of Nigeria (REA) under the Nigeria Electrification Project (NEP) in a project that exemplifies the catalytic role IoT can play. The NEP was established in 2018 and is one of the most ambitious off-grid rural electrification projects in history. Odyssey's collaboration under NEP enables efficient results-based financing, with per-connection subsidies deployed only after established proof that customers have been connected to reliable power.[52,53]

48. See for example, GSMA (2020) "Partnering to minimise electricity theft and line losses in Pakistan – Jazz, CISNR and PESCO"
49. Bauer, G.K., (2019). "Mini-grids, macro impact?" GSMA.
50. GSMA (2019). "Mini-grids, macro impact?"
51. Engelmeier, T. (2020), "How data and digital solutions are changing the mini-grid business model", Mini-Grids Partnership
52. Odyssey (2021). "Using Odyssey to Implement Big Data Solutions for one of the most Ambitious Off-Grid Rural Electrification Programs in History"
53. GSMA (2020). "Innovative Data for Urban Planning"

Wastewater network monitoring

Use case description: Management of most sewer networks is often more reactive than proactive, especially with response to blockages, infiltration and overflows.[54] Mixing wastewater with such events causes serious environmental damage and public health concerns. Thus, increasing regulations on sewer overflow and changing weather conditions is driving the adoption of smart technology. Moreover, the presence of COVID-19 in faeces raised the potential to survey sewage water for epidemiological monitoring, also referred to as wastewater-based epidemiology (WBE) or as environmental surveillance.[55] Together with clinical data, WBE could provide critical monitoring of virus transmissions like poliovirus, COVID-19 and others within a community.[56]

IoT-enabled devices help in both wastewater monitoring as well as wastewater management, including identifying water treatment processes, managing treatment plants and detecting harmful chemicals in the water. Sensors can be installed to measure parameters, including water levels, flow, temperature and composition. This enables the remote monitoring of thousands of miles of sewer networks. Real-time data can be provided on leakages, damages and blockages, which informs efficient wastewater management and predictive analysis. Several countries are now using sensors across their wastewater networks.[57]

There are multiple options available when assembling wastewater monitoring IoT solutions, ranging from buying a ready-to-use solution from an IoT company to developing a bespoke solution that integrates components from different providers. The latter option demands higher technical expertise and investment.[58] Aqua Robur, Detectronic and Xylem are some of the solutions available in the market.

Key use case requirements:

Durability: Devices need to be compact and rugged to cope with being deployed in water systems.

Battery life: Devices need long battery life as they can be difficult to deploy and access.

Coverage: Networks need to have strong propagation characteristics to reach devices deployed deep underground.

Spotlight 14
IoT-enabled wastewater monitoring in India

In India, a few local municipalities like Vishakhapatnam, Lucknow and Gurugram have begun installing sensors to build IoT-based smart sewer systems. For example, Gurugram has deployed a sensor-based monitoring system that detects the level of discharge or flow in the manhole and sends a message if it reaches the overflow level.[59] The municipality aims to prevent overflows and to receive information in advance to prepare themselves for the next steps. This is crucial in reducing costs as most of the time blockages and overflows are cleaned by humans entering the manholes and sewer pipes.

54. Drenoyanis, A. et al (2019). "Implementation of an IoT Based Radar Sensor Network for Wastewater Management" Sensors
55. Medema, G. et al (2020). "Presence of SARS-Coronavirus-2 RNA in Sewage and Correlation with Reported COVID-19 Prevalence in the Early Stage of the Epidemic in The Netherlands." Environmental Science & Technology Letters
56. Bivins, A et al (2020). "Wastewater-Based Epidemiology: Global Collaborative to Maximize Contributions in the Fight Against COVID-19" Environmental Science & Technology
57. Drenoyanis, A. et al. (2019) "Implementation of an IoT Based Radar Sensor Network for Wastewater Management" Sensors
58. Process & Control (2021). "A quick guide to incorporating IoT in your wastewater treatment plant"
59. Times of India (2021). "Gurugram's sewage overflow will be monitored by 4 sensors"

4 Trends shaping IoT deployments

The IoT market will continue to develop at pace, both globally and within the context of LMICs. This chapter analyses forward-looking trends—identified through our research—which are building momentum and shaping the outlook for the IoT sector in LMICs across the next decade.

Enterprise IoT will grow at a much faster rate than consumer IoT

During the 2020s, enterprise IoT connections will grow at a much faster rate than consumer IoT connections, as businesses step up their focus on remote access and automaton. Growth in the adoption of IoT connections in the enterprise segment across Sub-Saharan Africa will be driven by smart utilities and smart buildings.

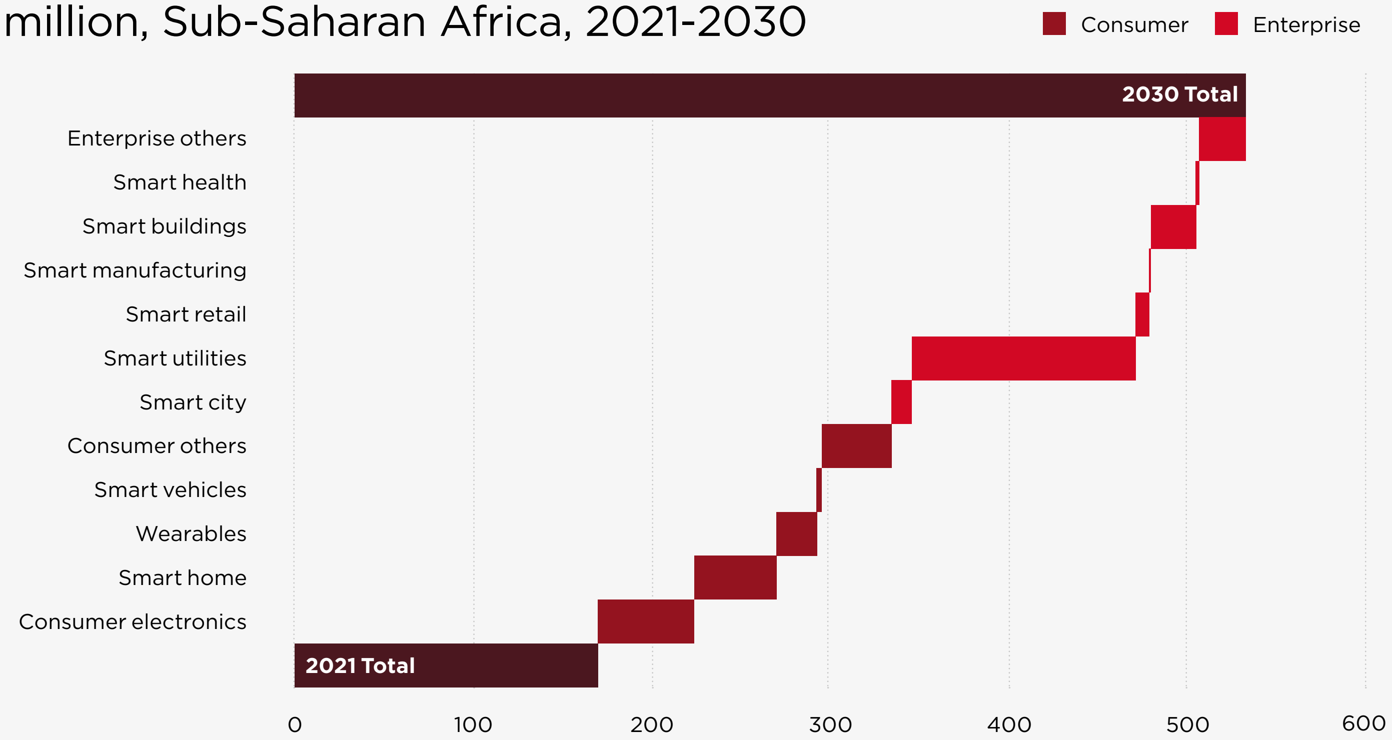
The pace of 2G and 3G network shutdowns will accelerate

The pace of 2G/3G network shutdowns is increasing as operators look to optimise their network operations and costs, and to refarm spectrum for 4G and 5G. Mobile operators in South and Southeast Asia are likely to retire legacy networks before their counterparts in Sub-Saharan Africa, due to the higher penetration of 4G services in South and Southeast Asia. At least one operator in Bangladesh, Cambodia, India, Indonesia, Malaysia, Nepal, Sri Lanka and Thailand has retired a legacy network (or announced plans to do so). In contrast, Telkom South Africa is the only operator in Africa to have retired a legacy network, having shut down its 2G network in 2020 in addition to 80% of its 3G network as of January 2022.

IoT devices frequently have a long device life-cycle and are in hard-to-reach locations, which makes the upgrade process troublesome. It is therefore important that hardware providers know which networks will be available in which countries and for how long. Without this information, their devices could stop working if they only work on 2G/3G, or may will face increased costs from over-specifying their devices to ensure avoiding redundancy.

Figure 15

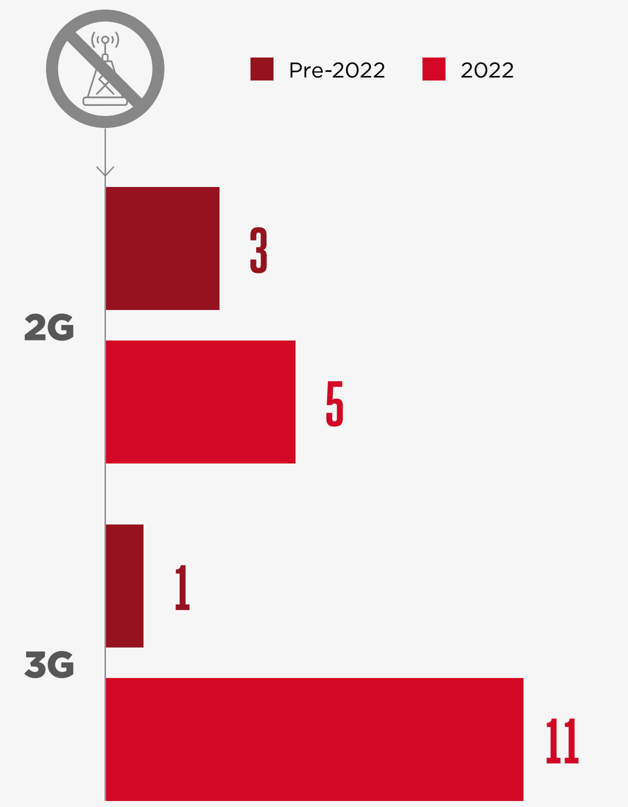
Total IoT connections net additions, million, Sub-Saharan Africa, 2021-2030



Source: GSMAi

Figure 16

Number of completed and planned 2G and 3G network sunsets in South and Southeast Asia and Sub-Saharan Africa



Note: Data is for LMICs only. Number of generation shutdowns as opposed to technology migration within the same generation of technologies. 2022 includes estimates based on operators' announced plans for shutdowns.

Source: GSMA Intelligence

5G will rollout gradually across LMICs, helping to enhance IoT applications

As of Q2 2022, 195 operators in 75 markets had launched mobile 5G.[60] While 5G deployments have been dominated by operators in high-income markets, momentum is starting to build in lower income regions. For example, four LMICs in Sub-Saharan Africa (Kenya, Madagascar, South Africa and Togo) and five in South and Southeast Asia (Indonesia, Laos, Malaysia, Philippines and Thailand) have launched commercial 5G mobile service. This figure will increase in the coming years with several operators in LMICs formally announcing launch plans for 5G.

The uneven rollout of 5G could have consequences for multiple IoT use cases, such as those highlighted in chapter 3. For example, 5G's enhanced capabilities in terms of higher speeds and lower latency can support drone applications for disaster response and medical deliveries. However, as only a limited number of LMICs have launched 5G, the pace of adoption for these use cases may vary between countries. In addition to upgraded connectivity speeds compared to previous network generations, 5G provides several other enhancements, including improved reliability and higher capacity.[61]

The rise of Mobile Virtual Network Operators (MVNOs) as IoT connectivity providers

MVNOs offer focused services for IoT by relying on one or more MNO networks or non-cellular networks (e.g. Sigfox) coverage. Prime examples of IoT-focused MVNOs are Aeris Communications, BICS, EMnify, Eseye, Kore Wireless, Wireless Logic, Soracom and 1NCE. A number of IoT MVNOs have received considerable investment in recent years. EMnify received a $57 million investment in 2021 to accelerate its global market expansion.[62] In addition, Monogoto, which provides worldwide IoT connectivity, received investment in the same year from Telefónica Tech and Singtel to bolster its expansion plans.[63] Interest in IoT MVNOs is likely to continue to rise, with several players reporting strong connection growth.

Typical services offered by MVNOs are SIMs and eSIM solutions for connected devices and connectivity management (e.g. device authentication, device provisioning, roaming, multiple networks single pane of glass type of devices management, and value-adding integration services). Some MVNOs, such as 1NCE and Soracom, are offering cloud-native IoT platforms so that their customers can access connectivity services through the likes of Amazon AWS and Microsoft Azure in a faster and more efficient way.

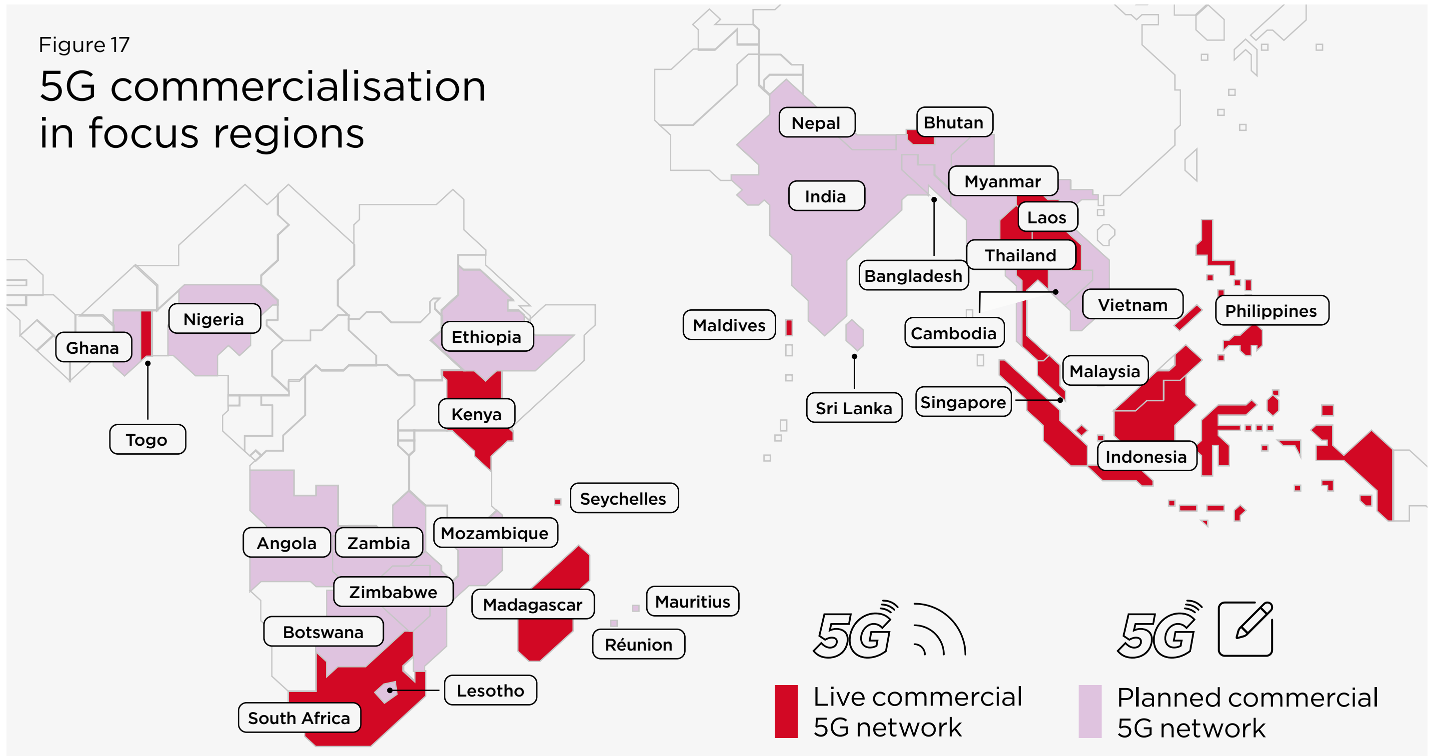
Demand for private networks will grow, but activity is likely to remain concentrated in high-income countries

Public cellular networks have been the primary option for IoT connectivity, however they have been designed primarily for consumer use. This raises some potential issues. Firstly, enterprises have to use the same spectrum as consumers,

60. Iji, M. et al. (2022). "5G in context, Q2 2022" GSMA Intelligence
61. Capacity is the amount of traffic that a network can handle at any given time.
62. EMnify (2022). "EMnify Raises $57M (€50M) in Series B Funding from One Peak"
63. CTech (2021). "Monogoto raises $11 million for cellular IoT connectivity platform"

Figure 17

5G commercialisation in focus regions



Data correct to 30 June 2022. For updates, see **gsmaintelligence.com**

Note: Status assigned where an operator has stated a commitment/timeline (Planned) or announced commercial 5G launched (Live). Status defined as live where at least one operator has commercially launched 5G services.

Source: GSMA Intelligence

which can impact service quality (e.g. network congestion). Secondly, it means that networks might not be available in areas where enterprises operate but people do not live. These issues are driving interest in private networks, which can be defined as cellular networks built specifically for an individual enterprise or organisation without dependence on or reference to a national mobile grid. Private networks offer more certainty in terms of network performance, albeit with trade-offs in terms of higher costs.

According to the GSMA Intelligence Enterprise in Focus survey, around 20% of enterprises in LMICs believe they need private networks. Demand is highest in the utilities and manufacturing sectors. Other sectors (e.g. transport) tend to have wider coverage footprint goals, which would make private networks uneconomical. Most cellular private network deployments so far have been in high-income countries, reflecting the high costs involved and the nascent stage of the market globally. While cellular private networks are still a long way off in many countries, more deployments are starting to happen in upper-middle income countries. For example, EDOTCO has deployed a private network at Langkawi International Airport in Malaysia. This supports applications such as asset tracking for luggage, air quality monitoring and facial recognition. Furthermore, MTN is building private networks for ports and mining in South Africa to give enterprises greater control over their connectivity.

A shift towards local manufacturing to capture value

IoT devices such as sensors and gateways can represent a significant proportion of overall IoT costs. This is driving many LMICs to consider whether it is possible to develop low-cost domestic manufacture capabilities to make solutions more affordable for individuals and enterprises. For example, Mojec International established an electricity meter plan in Nigeria with a production capacity of over 2.4 million meters per year, designed to serve local African markets.[64] Similarly, in a GSMA supported deployment in Sri Lanka between Dialog Axiata, LECO and the University of Moratuwa, a smart grid pilot used

64. TechEconomy (2022). "Mojec Using Smart Metering Technology to Solve Nigeria's Power Problems"

locally manufactured meters. Other large LMICs such as India also have a growing ecosystem of local device manufacturers. For smaller markets, it is likely to be harder to build such an ecosystem, given potential for economies of scale.

Governments can play a role in incentivising local production of devices and hardware. Examples include governments becoming early adopters of locally manufactured devices themselves (e.g. IoT deployments within government-owned buildings and enterprises), educating the market about IoT, developing educational programmes to improve the skills of the workforce in areas such as engineering, and developing financing schemes and incentives for companies to set up local manufacturing facilities. However, even with these types of initiatives, it might be challenging to produce hardware at the same cost as manufacturers in China and other established IoT markets such as Europe and the US. It is therefore important for government to consider additional benefits to the local economy from building local manufacturing, such as increased employment, while also maintaining relationships with international suppliers.

IoT deployments will grow in sophistication, creating opportunities for software providers and application developers

As the number of IoT devices in South Asia and Sub-Saharan Africa proliferate and as IoT networks expand, there will be a need to manage larger IoT deployments in terms of the number of devices and growing complexity. Currently, system integrators are driving device deployments and interactions with end users, including performing tasks such as provisioning of devices (getting the devices connected to the IoT network) from connectivity providers. Besides growing IoT deployments, use cases will move beyond basic monitoring to providing actionable insights to end users. This is where IoT vendors will be pushed to diversify their offerings beyond just connectivity-only or devices-only. In bigger LMICs markets, for example in India, mobile operators already act as IoT solutions providers. In cases where operators are active in digital payments and mobile money, there can be integration with IoT applications, such as payment for utility bills or monitoring of energy consumption.

As IoT deployments increase in complexity, the market offers opportunities for other technology companies to build IoT platforms that manage diverse connectivity and applications requirements, such as software providers that can add analytics capabilities on top of an IoT solution, or mobile applications developers that can offer consumer-facing applications for monitoring energy savings. Where customers need end-to-end solutions, they will also expect seamless support services and a single point of contact. In the case of mobile operators, for example, partnerships will be important to enhance their offerings and ability to support IoT customers.

The investment outlook could become uncertain, driving more IoT start-ups to consider alternative funding mechanisms

In recent years, there has been strong growth in tech investment across the focus regions.[65] This is helping IoT start-ups to scale their solutions. For example, Zipline raised $250 million in 2021 to build out the infrastructure in drone-delivery service in Ghana and Nigeria, and M-KOPA raised $75 million in 2022 to expand its solar power home systems and other PAYG consumer electronic products into more markets in Sub-Saharan Africa.[66,67] However, global macroeconomic trends threaten to curtail tech investment. There are already signs investment is slowing in Asia,[68] and while trends in Sub-Saharan Africa remained strong in the first half of 2022, investment on the African continent also slowed in the second half of the year.

Consequently, it is likely that tech start-ups will pursue alternative funding mechanisms. Climate-related IoT start-ups are particularly well-placed here, as the data they collect can allow them to explore opportunities such as voluntary carbon credit markets. For instance, ATEC's eCook stove uploads data on cooking time to a central dashboard that can be verified by a third party and converted into Gold Standard certified carbon credits. These credits can then be sold to ATEC's international corporate partners, which subsidise the monthly instalments paid by eCook users. Moreover, Kenya's SunCulture is exploring the possibility of seeking funding from these carbon offset marketplaces to lower the cost of their solution for smallholder farmers.[69] The Taskforce on Scaling Voluntary Carbon Markets (TSVCM) estimates that demand for carbon credits could increase by a factor of 15 or more by 2030 and by a factor of up to 100 by 2050.[70] Overall, the market for carbon credits could be worth upward of $50 billion in 2030. This could be a particularly important source of funding for IoT start-ups in smaller countries within the focus region, given the majority of tech funding has been concentrated in major markets such as Kenya, India, Indonesia, Malaysia, Nigeria and South Africa.

65. See, for example, Partech Partners (2022). "2021 Africa Tech Venture Capital Report" and Cento (2022). "Southeast Asia Tech Investment – 2021"
66. Tech Crunch (2021). "Zipline raises $250m at $2.57b valuation to build out its instant logistics service"
67. Tech Crunch (2022). "M-KOPA raises 75m as it clocks 2 million customers across four African markets"
68. Bloomberg (2022). "Africa Defies Global Trend With Funding for Startups Surging"
69. Loukos, P & Arathoon, L., (2022). "Assessment of smart farming solutions for smallholders in low and middle-income countries" GSMA
70. Blaufelder, C., et al. (2021). "A blueprint for scaling voluntary carbon markets to meet the climate challenge" McKinsey & Company

Policymakers in many countries are likely to introduce new regulations for emerging IoT use cases, such as drones

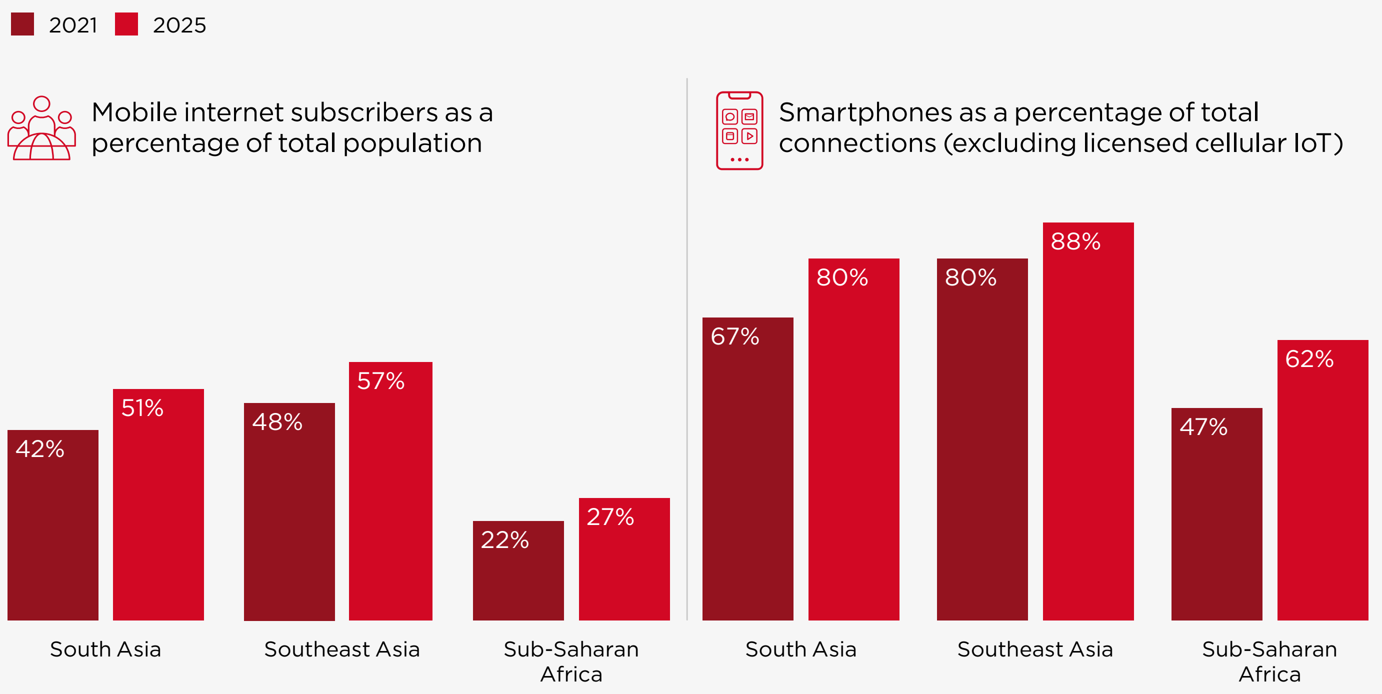
The rapid development of the IoT market means regulators are struggling to keep pace. Drones have become a key test case for many regulators, as the solution poses so many questions related to safety and privacy. For example, most telecoms regulators are yet to grant spectrum licences that allow drone flights beyond distances outside the normal visible range of the pilot. This is important given that mobile networks are vital for transmitting and sharing data pertaining to drones, such as flight paths, authorisation and traffic management.

Regulatory efforts over the next few years are likely to focus on creating frameworks that will allow the drone sector to develop and innovate while also limiting risks related to safety, privacy and data protection. The fact that drones fly across borders adds another layer of complexity, meaning collaboration between policymakers in different countries is required. Developing new rules for emerging use cases is an important step forward to give stakeholders, such as connectivity providers, hardware manufacturers and IoT start-ups, more certainty which is important due to the long-term nature of their investments. In turn, this should help to accelerate rollout of IoT services.

The scaling of other digital technologies will spur IoT growth

IoT services require mobile coverage and internet connectivity. As highlighted in chapter 2, the IoT market has evolved to provide an increasingly rich array of connectivity technologies to support the demands of IoT applications in LMICs. Smartphone adoption is also a key enabler. Although some IoT solutions are designed for feature phones through the use of USSD or SMS, the rich interface of smartphones provides a much more user-friendly experience to access data and other insights on IoT platforms. The wide spread of digital payments (in particular, mobile money services) can also support IoT growth, particularly use cases that leverage on PAYG business models such as SHS and PAYG cooking devices. This highlights how digital payments can improve access to services such as water and energy by giving people the ability to pay for what they use as they need it.

Figure 18
Mobile internet subscribers and smartphone connections



Source: GSMA Intelligence

5 Towards a thriving ecosystem

The next decade offers enormous opportunity to test and scale innovative IoT solutions.
A convergence of developments in the supporting network technologies, a growing and thriving innovation ecosystem, and accelerating levels of digital development in populations and institutions means that deployments with impact are increasing in reach in many markets. Harnessing this opportunity will look very different market-by-market, however there are some common supportive actions that different key stakeholder groups can take to accelerate adoption and impacts.

Mobile operators

- **Focus on selected verticals:** LPWA networks open up a range of new opportunities for operators in IoT. However, it is unrealistic for operators to provide solutions in every vertical market. To maximise their chance of success, they should weigh up the technical and commercial challenges of entering new sectors against their existing competencies and assets, such as channels to market and staff who are well informed of existing trends.

- **Establish strategic partnerships:** IoT is a nascent area for most operators in LMICs. Most use cases require a mixed set of skills and resources, and a partnership-based model. Operators should scout regional and local tech hubs to identify relevant start-ups or build their own IoT-centric incubators (e.g. Orange 5G Lab Dakar, and XL Axiata's X-CAMP in Indonesia). Other examples include strategic partnerships with universities, such as Dialog and the University of Moratuwa's Mobile Communications Research Laboratory. Acquisitions of IoT companies can also be considered to expand operator presence but this is a more expensive and challenging option versus partnering.

- **Select an appropriate pricing model:** Pricing for IoT ought to differ from traditional telecoms pricing because of the different traffic profile, set of services and performances required, in particular, for licensed LPWA the low data volumes. Instead of billing data consumption per device, charging access fees for the device/per device better reflects the network resources used.

- **Make best use of established industry guidelines:** where available, it is recommended operators leverage the guidelines from industry. For example, the GSMA IoT Deployment Guide,[71] the Improving Energy Efficiency for Mobile IoT Whitepaper[72] and GSMA Roaming resources.[73] Sharing the network parameter setting for roaming is of particular importance to the developers of IoT services.

Hardware providers

- **Adopt strong security hygiene:** Strong security hygiene throughout the lifecycle of the device increases the confidence of customers to implement IoT solutions. Some security recommendations are easy tasks; from making sure devices do not have default passwords and that are regular updated to requiring encryption of devices that are suitable for the service and kept up to date.

- **Develop joint go-to-market solutions:** Hardware providers can partner with mobile operators to offer a joint go-to-market solution. This is particularly important in nascent markets where neither party has the full skillsets required and customer awareness is low. For instance, Celcom Malaysia partnered with Aerodyne to integrate connectivity into Aerodyne's drone portfolio.

- **Design with longevity at heart:** In some cases, connected devices (such as smart meters) stay in the field for almost a decade. Consistent designs are needed so that the modules device original equipment manufacturers (OEMs) embed or deploy will not have to be changed every couple of years. Implementing efficient remote management system are also central to ensuring software and firmware can be updated when needed.

Enterprises, utilities, and other service providers

- **Define the desired outcome:** Before embarking on an IoT deployment, enterprises must know what outcome they are trying to achieve in order to judge the success of the project (e.g. a reduction in unplanned maintenance, improved customer satisfaction). This data must be readily available and easily analysed to ensure targets are met. IoT's place in the business model must also be carefully appraised.

- **Start small, dream big:** A small-scale pilot is a good way to ensure network performance, device installation, data security and other factors are fit for purpose and that every stakeholder is clear on their role in the project. Once this has been established, enterprises can move onto larger scale deployments.

- **Take stock:** It is crucial for enterprises to have a good understanding of their existing IoT devices inventory, including device type, brand, location

71. GSMA (2022) "Mobile IoT Deployment Guide – October 2022"
72. [footnote: GSMA (2022) "GSMA Whitepaper – Improving Energy Efficiency for Mobile IoT"
73. See https://www.gsma.com/iot/mobile-iot/roaming/

and size. This will help enterprises build realistic timelines and accurate costs into any transition project for replacing devices (e.g. due to the retirement of legacy networks).

— **Build and maintain consumer trust:** Those engaging with end-customers have a social responsibility to ensure that customers provide informed consent. This includes ensuring that customers are informed about the capabilities and functions of the devices used, as well as how the data are managed and used.

Policymakers

— **Provide certainty:** The nature of IoT (where devices can be deployed for up to 10 years without being replaced due to the length of the battery life) means companies require certainty when it comes to regulation. This is particularly important for issues such as permanent roaming, which remain unclear in many LMICs.

— **Lead on security:** Going to market with an IoT solution without enough consideration of security can result in messy retrofitting and patching when security flaws appear. Regulators can design IoT regulation including security at the early stages of the market, with the potential to develop policy at a similar pace to the IoT market. Industry-led IoT security guidelines and best practices from the GSMA or ETSI provide a much-needed initial step for key stakeholders in the value chain.[74] To develop consumer trust, businesses need to build their IoT operations based on privacy respecting principles, such as the published GSMA Mobile Privacy Principles.[75]

— **Reduce barriers to adoption:** IoT devices need a different regulatory framework to smartphones, for example, since they generate lower average revenue per connection. High taxation will inhibit adoption. Regulations should aim to be technology-neutral rather than catering to specific technologies, as the pace of technological advancement will always move faster than regulation.

— **Lead on deployments:** In cases where government entities are also major service providers, for example in centralised energy and water, there is the opportunity for public procurements to act as an accelerator of IoT adoption through large-scale deployments.

74. See, for example: https://www.gsma.com/iot/iot-security/iot-security-guidelines
75. GSMA (2016). "Mobile Privacy Principles"

Financing partners

— **Take a long-term view:** It can take time for IoT solutions to reach scale, as they need to be adequately tested and trialled before reaching the commercialisation stage. Interview participants also noted that there can often also be delays in finalising contracts with buyers of IoT services, particularly when it comes to dealing with large companies and public sector organisations. Patient capital from early investors is therefore important to attract further investment and scale IoT solutions.

— **Seize the opportunities to innovate:** New technologies present new opportunities. The combination of IoT and mobile payments has already unlocked a new wave of asset financing models through PAYG. Though this is only the start, connected productive assets offer the possibility of a broader range of revenue share models, and with a lower risk profile and the combination of new data sources with digital payments, credit risk models can draw on a broader range of data.

— **Transfer skills and networks as well as funds:** In addition to providing financial support, financing partners can add value to IoT start-ups in other ways, such as providing access to their network of partners and offering strategic advice in marketing, operations and technology. It is important that both parties are clear from the outset on what level of engagement and support can be expected.

Development actors

— **De-risking capital can leverage impact:** Donor funding can play a catalytic role in spurring IoT innovation, especially in low-income countries where the IoT ecosystem is still at an early stage, and 'space to fail' is needed. This is particularly important for IoT use cases that are often overlooked by private sector investors, such as those in water and sanitation. That said, donors engaging in these programmes need to take care not to distort the markets they are engaging in, or crowd out other sources of funding.

— **Invest in ecosystems as well as enterprises or solutions:** Development actors, particularly multilateral institutions, can unite governments and private-sector organisations, such as connectivity providers, hardware providers and start-ups in ways few other actors can through brokering connections and investing in long-term programmes. Collaborations like this can be an effective way to share knowledge and upskill workforces.

Annex A: **Annotated bibliography of key resources**

This annotated bibliography is intended as a resource for readers new to IoT who want to explore the topic further. It contains details for some, but not all, of the research cited in this report. It includes a brief summary of what is in each resource, and links to the paper.

Airbus (2018). "The Great Enabler: Aerospace in Africa." This paper provides a comprehensive look at how aerospace technology can enable social and economic development in Africa. It covers the use of aerospace technology in improving access to basic healthcare, enhancing food security, making agriculture more competitive and sustainable, promoting education, training and innovation. The paper looks extensively at the drone market, including drone regulation.

AMDA (2022). "Benchmarking Africa's Mini-Grids Report." This report provides insights into the commercial performance of micro-grids in Sub-Saharan Africa. It also provides advice and recommendations to industry players and governments on scaling micro-grids.

Analysys Mason (2016) "IoT: Seven areas for regulators and policy makers to consider." The potential for IoT to have a positive economic, societal, and environmental impact worldwide is substantial, but its development also raises new questions to be addressed by regulators and policy makers. This report identifies seven key areas of interest for regulators reviewing IoT.

Asian Development Bank (2017). "The Internet of Things in the Power Sector: Opportunities in Asia and the Pacific." This report looks at the problems faced by Asia's power sector, which is struggling to keep up with high demand growth rates. It explores the potential of IoT to support the sector and provides case studies on the use of IoT in the energy sector from outside of the region.

Asian Development Bank (2018). "Smart Metering Road Map for Nepal." This report summarises the proposed activities and plans for the Nepal Electricity Authority on the implementation of a smart electricity grid. It also explains the guiding principles, decision framework, and methodology used to manage the transition to new technologies.

Bisaga, I et al. (2019). "Scalable off-grid energy services enabled by IoT: A case study of BBOXX SMART Solar." This case study shows how IoT can be used to tackle development challenges by using the case study of BBOXX (a Solar Home Systems provider).

Counterpoint Research (2018). "LPWANs Will Co-Exist, No War Brewing Between Cellular and Non-Cellular." This report argues that the IoT market has enough opportunity for all forms of cellular and non-cellular LPWANs. A few years ago, cellular LPWANs lagged behind the non-cellular LPWANs and created an opportunity for non-cellular propriety technologies such as Sigfox, LoRa, Weightless, Ingenu, etc., which originated from the EU and spread to other parts of the world. However, in the recent past, cellular LPWANs have gained ground, with a push from network operators such as Vodafone and China Mobile and spearheaded by Huawei.

Daud, S. et al. (2022)."Applications of drone in disaster management: A scoping review." This paper provides a comprehensive scoping review of drone applications in disaster management. Based on articles identified, drone application in disasters are classified into four categories; (1) mapping or disaster management, which has shown the highest contribution, (2) search and rescue, (3) transportation and (4) training. The paper anticipates that with sufficient development, the application of drones appears promising and will improve their effectiveness, especially in disaster management.

Frost & Sullivan and Government of Nepal, Ministry of Communication and Information Technology (2019). "2019 Digital Nepal Framework." This report looks at how Nepal can leverage the potential of digital technologies to drive accelerated economic growth. It considers the role of technology in multiple sectors, including energy and urban infrastructure.

GSMA (2022). "Early Warning Systems in the Philippines: Building resilience through mobile and digital technologies." This report highlights how mobile and digital technologies, such as IoT, big data and AI, play an important role in EWS in the Philippines. However, the implementation of these solutions has been extremely fragmented, with overlapping solutions, inadequate coordination and data sharing between stakeholders, and a lack of impact forecasting at the local level. The report also looks at the use of IoT in EWS in other countries, such as Cambodia.

GSMA (2022). "India: on the road to a digital nation." This report looks at the concerted efforts India is making to integrate digital technologies and services into every sector of the economy. It explores how this has the potential to reshape the economy by enabling new operating models for businesses and transforming the way citizens interact with the society and environment around them.

GSMA (2022). "The State of Mobile Internet Connectivity Report 2022." This report provides the mobile industry and other stakeholders with a comprehensive overview of the trends in global connectivity, as well as insights on key barriers to mobile internet adoption and use.

GSMA (2022). "Three lessons from Nokia Saving Lives, GSMA-funded innovation project." This blog post shares three key lessons from the GSMA's Mobile for Humanitarian Innovation Fund's project with Nokia Saving Lives (NSL) in the Philippines, which deployed drones for disaster response. These lessons include the importance of navigating local policies and regulations, as well as ensuring the ongoing availability of experts to implement the technical solution.

Elavarasi, K. and Nandhini, S. (2021). "Landslide Monitoring and Tracking Using IoT Sensors." This paper looks at how IoT sensors can be used to anticipate landslides. It focuses on the types of sensors that can be used, including vibration sensors, soil moisture sensors, accelerometer sensors and temperature sensors.

GSMA (2021). "Cross-Border Data Flows: The impact of data localisation on IoT." To unlock the potential of IoT, mobile operators and other players in the IoT ecosystem need business models and technologies that will work anywhere in the world and allow data to flow. However, some countries, concerned about digital sovereignty, are considering the imposition of localisation requirements that would have the effect of restricting international data flows and fragmenting the digital world. In this report, the GSMA presents evidence-based research that quantifies the impacts of hypothetical localisation requirements in three countries in the context of IoT.

GSMA Intelligence (2022). "Mobile network sunset: trends, regional variations and implications for IoT." This report discusses the reasons why MNOs are looking to retire 2G/3G networks, concluding that there is no single motive for legacy network retirements. It also highlights regional and operator group variations when it comes to the timeframe for network sunsets, as well as the implications for IoT use cases such as remote monitoring and remote healthcare.

GSMA Intelligence (2021). "Radar: Connectivity from the sky." Satellite broadband continues to undergo a period of reinvention through the LEO constellation model that re-emerged five years ago. Survey data from enterprise verticals suggests that 15–25% of businesses—ranging from SMEs to corporates—already use satellite connectivity as a primary or back-up access technology. Public sector agencies, manufacturing groups and healthcare facilities are the highest adopters of satellite outside of the maritime, aviation and logistics sectors. Interestingly, those in utilities demonstrated the highest spike in intention to use satellite, reflecting their need for IoT connectivity in off-grid areas.

GSMA Intelligence (2021). "IoT market update: assessing disruption and opportunities, forecasting connections to 2030." GSMA Intelligence forecasts that total IoT connections will more than double between 2021 and 2030, reaching 37.4 billion from 15.1 billion in 2021. The report captures some of the key trends driving the IoT industry, including the digitisation of enterprises across vertical sectors, supply chain challenges and the impact of COVID-19.

GSMA Intelligence (2020). "Enterprises speak: IoT gets real." This analysis presents the findings of the latest GSMA Intelligence IoT enterprise survey of almost 2,900 enterprises. It shows that almost two thirds of enterprises have deployed IoT as part of broader digital transformation initiatives. This figure is even higher in LMICs such as Indonesia (80%) and South Africa (70%).

GSMA Intelligence (2022). "Industry pathways to net zero: Decarbonisation in transport." The transport sector accounts for around 16% of global CO2 emissions, equivalent to 8.6 gigatonnes (Gt) in 2020. Achieving 50% reductions in emissions in each of the next three decades to reach net zero by 2050 means removing 4.3 Gt of CO2 from total annual transport-related emissions over the next 10 years. This analysis focuses on the role that mobile and digital technology can play in helping companies in the transport sector lower emissions. It provides illustrations of use cases mapped to the broad technology groups of IoT, cellular connectivity, and cloud and analytics.

GSMA Intelligence (2020). "IoT revenue: state of the market 2020." The global IoT market will be worth $900 billion in revenue by 2025 - an almost threefold increase on 2019. However, connectivity is just a fraction of the overall opportunity. Applications, platforms and services account for the bulk of the value in IoT solutions, which drives the majority of IoT revenue. This report highlights the key drivers of market growth and delves into the thinking behind the forecasts.

GSMA Intelligence (2021). "Licensed LPWA: scaling IoT in the 5G era." This report analyses the growth of licensed LPWA versus unlicensed LPWA. It also presents recommendations in areas such as pricing, use cases and developer relations for operators looking to scale LPWA.

GSMA Intelligence (2022). "Mobile operators look to the skies with connected UAV opportunity." Unmanned/uncrewed aerial vehicles (UAVs), or drones, continue to be a promising future means of transporting goods and people and enabling transformational applications. However, most UAV-based services are confined to visual line of sight (VLOS) flights, meaning operation is only allowed in close proximity to the pilot (typically up to two kilometres). For commercial use cases to scale, automation and beyond visual line of sight (BVLOS) flights are needed, for which mobile connectivity is a key enabler, as highlighted by this report.

GSMA Intelligence (2020). "Satellite aims for blast-off in IoT." For many years, L-Band satellite transmissions have serviced a range of verticals, including logistics, agriculture, and aerospace. Pricing has remained prohibitively expensive, which has inhibited the widespread use of satellite technology. The playing field is now changing though, following the recent regulatory approval of LEO constellations from SpaceX and OneWeb, along with the entrance of Amazon as a competitor.

GSMA Intelligence (2021). "Saying goodbye to legacy networks, but what's next for IoT?" This report provides a set of recommendations for MNOs and enterprises regarding the closure of 2G/3G networks. It also gives examples of best practice within the industry. For example, Telstra's 2G and 3G network shutdown relies heavily on its IoT/M2M Certification Program. Since December 2018, Telstra has no longer accepted 3G-only devices into the Program, in preparation for its 3G WCDMA network shutdown in June 2024. Telstra also requires new IoT/M2M cellular-capable devices to support 4G-LTE and VoLTE, if voice is required to support remote firmware upgrade capability.

GSMA Intelligence (2021). "Scaling digital platforms through partnerships: The value of collaboration between mobile operators and digital platforms in emerging technologies." This report highlights the value of partnerships between MNOs and companies looking to scale, where there are benefits for both parties. It also provides an update to the GSMA's haves/ needs frameworks, which shows that mobile operators and start-ups possess certain 'haves' and 'needs' when it comes to scale and innovation.

GSMA Intelligence (2022). "The changing shape of smart cities: new trends and new roles for operators." *[paywall content]* Smart cities are not new, but recent developments indicate a shift to smart and sustainable cities where digital technology is used for multiple purposes, including environmental aspects. This report highlights the need for closer collaboration between city stakeholders throughout the entire smart city life cycle, from the initial assessment to strategy design and implementation. Operators are increasingly involved in smart city projects. For some, their role is moving beyond providing connectivity to become smart city solution providers.

Herring B., et al. (2022). "Underground LoRa Sensor Node for Bushfire Monitoring." This paper considers the feasibility of an underground LoRaWAN bushfire temperature sensing node. The device suffered no significant increase in signal loss under any of the conditions tested, including 100mm of damp and wet soil and smoke and radiation interference from fires. The paper therefore concludes that LoRaWAN is an effective technology for a bushfire warning system.

Idoko, E., et al. (2021). "Determinants of Smart Meter on Sustainable Energy Consumption Behavior: A Developing Country Perspective." This paper considers the influence of smart meters on sustainable energy consumption behaviour among residents in suburban Nigeria, highlighting the positive correlation between smart meter adoption and environmental concern.

IEEE Spectrum (2021). "In the air with Zipline's medical delivery drones." Long-form article analysing the deployment of Zipline's delivery drones in Rwanda. It covers the technical solution and challenges of building a drone-based delivery service, and explains why Rwanda and the health sector are particularly well-suited to drone-based delivery services.

International Energy Agency (2022). "Enhancing Indonesia's Power System." This report analyses Indonesia's efforts to reform its energy sector. It also considers whether a higher share of solar-powered micro-girds could fill Indonesia's energy gap and help meet the 2025 renewables target.

ITU (2016). "Harnessing the Internet of Things for Global Development." This report explores the current use and potential of IoT technologies in tackling global development challenges, highlighting specific instances where IoT is helping to solve some of the world's most pressing issues. It presents recommendations on what is required for IoT to reach billions of people living in LMICs.

Kumar, N and Mallick, P. (2018). "The Internet of Things: Insights into the building blocks, component interactions, and architecture layers." This paper summarises IoT, IoT building blocks, components and their interactions along with architecture layers (Three Layer, Five Layer, Six Layer, Seven Layer).

Lopez-Vargas A., et al. (2021). "IoT for Global Development to Achieve the United Nations Sustainable Development Goals: The New Scenario After the COVID-19 Pandemic." This paper explores the new challenges faced by developing countries after COVID-19's emergence. It then looks at IoT's impact on the sustainable development goals (SDG) in a post-Covid world, including IoT's impact on agriculture, health and utilities.

LoRa Alliance (2020). "2021 End of Year Report." This is an annual report published by the LoRa Alliance. It provides data on LoRaWAN certified products and LoRaWAN coverage, as well as updates on regulation and the LoRaWAN ecosystem.

LoRa Alliance and ABI Research (2019). "LoRaWAN and NB-IoT: competitors or complementary?" This whitepaper examines the similarities and differences between LoRaWAN and NB-IoT. Co-authored by the LoRa Alliance—the association set up to promote the global adoption of the LoRaWAN standard—the report stresses LoRaWAN's unique benefits. The whitepaper concludes with potential use cases where both LoRaWAN and NB-IoT will operate together to provide the greatest value for customers.

MasterCard Foundation (2018). "Pay-As-You-Go and the Internet of Things: Driving a New Wave of Financial Inclusion in the Developing World." PAYG business models are emerging around the globe to give people the ability to pay for what they use, as they need it. Solar energy providers have been early adopters of PAYG, expanding electricity access to underserved communities through flexible payment plans. The PAYG model can also scale outside of energy. This report discusses the relationship between OAYG models and financial inclusion.

Li, X., et al. (2020). "Performance monitoring of African micro-grids: Good practices and operational data." This report highlights the importance of performance monitoring for micro-grids, focusing on the operations phase of micro-grid projects, as that is when the bulk of the data is generated and most performance monitoring benefits are realised.

Ndunguru, E., (2021). "Increasing Access to Clean Cooking: The Practicality of Pay-Go in Promoting Adoption of Bottled Gas in Kinondoni, Dar Es Salaam, Tanzania." This study evaluates the practicality of PAYG cooking solutions. It covers execution, usefulness and challenges; and its implications on household energy sector development. The study was conducted in Dar es Salaam, Tanzania between 2018 and 2020.

Nyaaba, A. and Ayamga, M., (2021). "Intricacies of medical drones in healthcare delivery: Implications for Africa." This paper looks at the various medical supplies delivered by drones, the challenges to the successful use of medical drones (e.g. regulation, cost, privacy concerns) and the potential benefits of medical drones, ranging from reducing response times during health emergencies thus helping to save more lives, to being environmentally friendly as the CO2 emissions levels are lower than conventional delivery by trucks and cars.

OpenGov (2022). "Smart Grid Systems to power Indonesia." This blog evaluates the smart grid concept in the context of Indonesia's Industry 4.0 initiative. It highlights the benefits of smart grid technology, while analysing implementation challenges such as investment costs and logistics.

Patel, A. (2020). "5 Layer Architecture of IoT." IoT solutions are made up of various building blocks that can be organised into three, five or seven layers, depending on the IoT architecture selected. This piece explores the roles and functional features of the different layers.

Phuyal, S., et al. (2021). "Internet of Things in Power Industry: Current Scenario of Nepal." This paper focuses on the current status, technical requirements, applications and the scope of IoT in Nepal's energy market. It includes analysis on smart metering and smart grids, as well as centralised and distributed power systems.

Rejeb, A., et al. (2022). "The Interplay between the Internet of Things and agriculture: A bibliometric analysis and research agenda." This paper provides a review of studies on IoT and agriculture and analyses how IoT can benefit the agricultural sector. Section 5.2 offers insights into the main IoT challenges in agriculture.

Renewable Energy World (2020). "The role of microgrids in India." This article looks at the challenges of connectivity in rural areas of India to the central grid, before evaluating the case for solar-powered microgrids in these locations. The article also considers the role of the public and private sector in India in driving the deployment of microgrids.

Rural Electrification Agency (2018). "The Off-Grid Opportunity in Nigeria." This report highlights the size of the opportunity for mini-grids and solar home systems in Nigeria. It also discusses the role of the private sector and the Rural Electrification Agency in developing the country's off-grid power markets, as well as what conditions are conducive to create an enabling environment for mini-grids.

Sarrab, M. et al. (2020). "Development of an IoT based real-time traffic monitoring system for city governance." This research proposes an IoT-based system model to collect, process and store real-time traffic data. The objective is to provide real-time traffic updates on traffic congestion and unusual traffic incidents through roadside message units.

Schaefer, M., et al (2020). "Low-cost UAV surveys of hurricane damage in Dominica: automated processing with co-registration of pre-hurricane imagery for change analysis." This paper discusses using unmanned aerial vehicle (UAV) surveys to collect aerial imagery based on experiences from Dominica. It recommends that countries at high risk from natural disasters develop capacity for low-cost UAV surveys, building teams that can create pre-disaster baseline surveys, respond within a few hours of a local disaster event and provide aerial photography of use for the damage assessments carried out by local and incoming disaster response teams.

Shrestha, A., et al. (2020). "Status of Micro/Mini-Grid Systems in a Himalayan Nation: A Comprehensive Review." Around 22% of the Nepalese population does not receive electricity through the national power utility and is forced to identify alternative approaches to electrification. This piece looks at the role mini-grids are playing in providing electricity to households in Nepal, including the use of Mini-Hydropower Plants (MHPs).

Shupler, M., et al. (2021). "Pay-as-you-go liquefied petroleum gas supports sustainable clean cooking in Kenyan informal urban settlement during COVID-19 lockdown." This paper considers the impact of COVID-19 on the PAYG LPG market based. It shows that in Nairobi, 95% of study households continued using PAYG LPG during COVID-19 lockdown, with consumption increasing from 0.97 to 1.22 kg/capita/month.

Sierra Wireless (2020). "Connected Industrial Purifiers: How the Industrial IoT is Enhancing Air and Water Purification." This paper highlights the growing use of IoT for water purification. These solutions use technologies including the dominant reverse osmosis method, along with ultraviolet purifiers which can kill pathogens. They have many applications, spanning sectors including municipal water treatment, manufacturing and laboratories.

Sierra Wireless (2021). "How to Manage the Impending 2G/3G IoT Sunset for Asset Tracking." This paper highlights the trend of retiring 2G/3G networks. It argues that the transition will be especially challenging for end-to-end asset tracking solutions and offers four essential steps for companies to take to navigate the impending 2G/3G shutdown.

Sierra Wireless (2020). "Unlock the Potential of Smart Metering with Cellular LPWA." The report highlights the potential for smaller utilities with limited operating budgets to use cellular to deploy advanced metering infrastructure without having to build and maintain their own network.

Smart Energy International (2021). "India's smart meter rollout – 250 million meters by 2025." This is an interview with the Managing Director and Chief Executive Officer of IntelliSmart Infrastructure, the JV leading India's smart metering initiatives. The article discusses the current status of India's smart meter market from both a supply and demand perspective.

Bhattarai, T., et al. (2022). "Applications of smart grid technology in Nepal: status, challenges, and opportunities." This paper evaluates the current energy situation in Nepal, before presenting the smart grid as a solution to existing and future energy issues.

Tony Blair Institute for Global Change, (2021). "Power Africa Success Story: Nigeria's Tariff Reform Delivers Major Financial and Environmental Benefits." This blog analyses Nigeria's energy sector and considers how the Nigerian government, working alongside the private sector, can address challenges such as inadequate power supply. The blog highlights the benefits of tariff reform, while also discussing implementation challenges.

Amailiya, V.F., et al. (2021). "Development of IoT-Based Volcano Early Warning." This paper discusses the hardware and connectivity requirements for an IoT-based EWS for volcanoes. The proposed solution uses temperature, gas and humidity sensors in addition to a thermistor and accelerometer. A solar panel is used as the power supply.

Wharton School of the University of Pennsylvania (2019). "How Trendsetters Shaped India's Massive Sanitation Campaign." This paper considers the impact of the Swachh Bharat Mission (SBM), which is the Indian government's largest sanitation programme to date. It also analyses the factors behind the programme's success.

World Bank (2017). "Internet of things: the new government to business platform - a review of opportunities, practices, and challenges." This report focuses on the role of the public sector in IoT deployments. It highlights that IoT deployments have made headway; but there remain a few gaps. Most government agencies are still relatively unfamiliar with IoT and its relevance to their immediate functions. Many governments are also unsure about how to implement initiatives that include an IoT component. However, most agencies expressed a keen desire to learn about initiatives in other governments, what had worked or not, and how that might affect their plans.

Zipline (2021). "Protecting Ghana's Election: Instant Agility with Zipline's Autonomous Delivery Network." A short case study on Zipline's role in providing emergency PPE for Ghana's polling stations, highlighting Zipline's solution and its impact. The piece also discusses the benefits of using drones for delivery versus traditional ground delivery.

Annex B: **Connectivity data**

Country	Sub-region	Income Status	2G	3G	4G	5G	LTE-M	NB-IoT	LoRa WAN	Sigfox
Burundi	Central Africa	Low Income	Yes (55%)	Yes (40%)	Yes (25%)					
Cameroon	Central Africa	Lower middle income	Yes (97%)	Yes (95%)	Yes (68%)					
Central African Republic	Central Africa	Low Income	Yes (56%)	Yes (60%)						
Chad	Central Africa	Low Income	Yes (86%)	Yes (95%)	Yes (48%)					
Congo, Dem. Rep.	Central Africa	Low Income	Yes (75%)	Yes (67%)	Yes (52%)					
Congo, Rep.	Central Africa	Lower middle income	Yes (88%)	Yes (98%)	Yes (74%)					
Equatorial Guinea	Central Africa	Lower middle income	Yes (97%)	Yes (65%)	Yes (4%)					
Gabon	Central Africa	Lower middle income	Yes (97%)	Yes (95%)	Yes (90%)					
Sao Tome and Principe	Central Africa	Lower middle income	Yes (94%)	Yes (99%)						
Comoros	East Africa	Lower middle income	Yes (92%)	Yes (90%)	Yes (65%)					Yes
Djibouti	East Africa	Lower middle income	Yes (90%)	Yes (77%)	Yes (29%)					
Eritrea	East Africa	Low Income	Yes (85%)	Yes (39%)						
Ethiopia	East Africa	Low Income	Yes (97%)	Yes (99%)	Yes (96%)	Yes				
Kenya	East Africa	Lower middle income	Yes (96%)	Yes (99%)	Yes (98%)	Yes		Yes		Yes
Madagascar	East Africa	Low Income	Yes (80%)	Yes (88%)	Yes (66%)	Yes				
Mauritius	East Africa	Upper middle income	Yes (99%)	Yes (99%)	Yes (99%)	Yes				Yes
Rwanda	East Africa	Low Income	Yes (100%)	Yes (99%)	Yes (99%)					
Somalia	East Africa	Low Income	Yes (80%)	Yes (79%)	Yes (53%)					
South Sudan	East Africa	Low Income	Yes (69%)	Yes (68%)	Yes (51%)					
Tanzania	East Africa	Lower middle income	Yes (95%)	Yes (80%)	Yes (51%)					
Uganda	East Africa	Low Income	Yes (98%)	Yes (92%)	Yes (72%)					

Country	Sub-region	Income Status	2G	3G	4G	5G	LTE-M	NB-IoT	LoRa WAN	Sigfox
Bangladesh	South Asia	Lower middle income	Yes (100%)	Yes (99%)	Yes (98%)			Yes		
Bhutan	South Asia	Lower middle income	Yes (98%)	Yes (90%)	Yes (85%)	Yes				
India	South Asia	Lower middle income	Yes (99%)	Yes (90%)	Yes (99%)			Yes	Yes	Yes
Maldives	South Asia	Upper middle income	Yes (100%)	Yes (100%)	Yes (100%)	Yes				
Nepal	South Asia	Lower middle income	Yes (93%)	Yes (90%)	Yes (79%)					
Pakistan	South Asia	Lower middle income	Yes (89%)	Yes (90%)	Yes (90%)			Yes		
Sri Lanka	South Asia	Lower middle income	Yes (99%)	Yes (96%)	Yes (96%)		Yes	Yes		
Cambodia	Southeast Asia	Lower middle income	Yes (99%)	Yes (90%)	Yes (98%)					
Indonesia	Southeast Asia	Lower middle income	Yes (99%)	Yes (94%)	Yes (96%)	Yes		Yes	Yes	Yes
Lao PDR	Southeast Asia	Lower middle income	Yes (95%)	Yes (90%)	Yes (98%)	Yes				
Malaysia	Southeast Asia	Upper middle income	Yes (97%)	Yes (0%)	Yes (97%)	Yes		Yes		Yes
Myanmar	Southeast Asia	Lower middle income	Yes (97%)	Yes (95%)	Yes (91%)					
Philippines	Southeast Asia	Lower middle income	Yes (99%)	Yes (93%)	Yes (99%)					
Thailand	Southeast Asia	Upper middle income	Yes (99%)	Yes (98%)	Yes (98%)	Yes	Yes	Yes	Yes	Yes
Timor-Leste	Southeast Asia	Lower middle income	Yes (97%)	Yes (95%)	Yes (89%)					
Vietnam	Southeast Asia	Lower middle income	Yes (100%)	Yes (97%)	Yes (98%)			Yes		
Angola	Southern Africa	Lower middle income	Yes (90%)	Yes (92%)	Yes (41%)					
Botswana	Southern Africa	Upper middle income	Yes (98%)	Yes (98%)	Yes (99%)					Yes
Eswatini	Southern Africa	Lower middle income	Yes (98%)	Yes (90%)	Yes (53%)					
Lesotho	Southern Africa	Lower middle income	Yes (99%)	Yes (97%)	Yes (79%)					
Malawi	Southern Africa	Low Income	Yes (86%)	Yes (95%)	Yes (82%)					
Mozambique	Southern Africa	Low Income	Yes (85%)	Yes (71%)	Yes (58%)					
Namibia	Southern Africa	Upper middle income	Yes (100%)	Yes (80%)	Yes (55%)					Yes
South Africa	Southern Africa	Upper middle income	Yes (100%)	Yes (100%)	Yes (99%)	Yes		Yes	Yes	Yes
Zambia	Southern Africa	Lower middle income	Yes (98%)	Yes (88%)	Yes (84%)					
Zimbabwe	Southern Africa	Lower middle income	Yes (93%)	Yes (88%)	Yes (39%)	Yes				

Country	Sub-region	Income Status	2G	3G	4G	5G	LTE-M	NB-IoT	LoRa WAN	Sigfox
Benin	West Africa	Lower middle income	Yes (98%)	Yes (98%)	Yes (49%)					
Burkina Faso	West Africa	Low Income	Yes (98%)	Yes (66%)	Yes (57%)					
Cabo Verde	West Africa	Lower middle income	Yes (99%)	Yes (92%)	Yes (70%)					
Cote d'Ivoire	West Africa	Lower middle income	Yes (98%)	Yes (93%)	Yes (77%)					Yes
Gambia, The	West Africa	Low Income	Yes (98%)	Yes (75%)	Yes (60%)					
Ghana	West Africa	Lower middle income	Yes (99%)	Yes (98%)	Yes (94%)					
Guinea	West Africa	Low Income	Yes (92%)	Yes (92%)	Yes (76%)					
Guinea-Bissau	West Africa	Low Income	Yes (99%)	Yes (99%)	Yes (66%)					
Liberia	West Africa	Low Income	Yes (99%)	Yes (100%)	Yes (52%)					
Mali	West Africa	Low Income	Yes (100%)	Yes (99%)	Yes (93%)					
Mauritania	West Africa	Lower middle income	Yes (97%)	Yes (67%)	Yes (4%)					
Niger	West Africa	Low Income	Yes (92%)	Yes (71%)	Yes (47%)					
Nigeria	West Africa	Lower middle income	Yes (91%)	Yes (99%)	Yes (75%)			Yes	Yes	Yes
Senegal	West Africa	Lower middle income	Yes (99%)	Yes (100%)	Yes (86%)					Yes
Sierra Leone	West Africa	Low Income	Yes (86%)	Yes (88%)	Yes (75%)					
Togo	West Africa	Low Income	Yes (98%)	Yes (97%)	Yes (71%)	Yes				

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