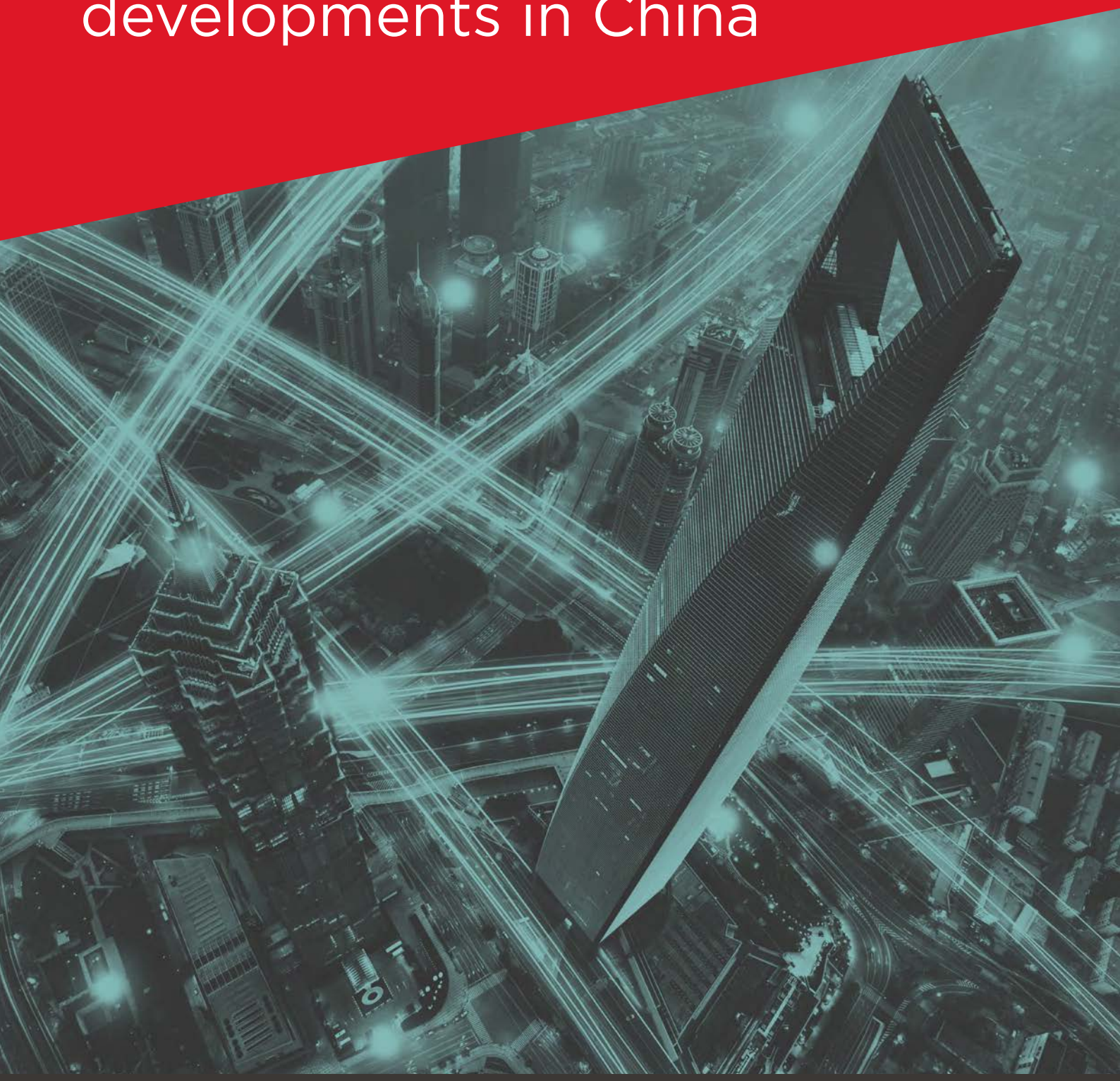
Edge computing in the 5G era

Technology and market developments in China



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The ECC is the world's largest alliance organisation to focus on edge computing with more than 260 industrial and academic members. Six industry entities have joined together to establish the Edge Computing Consortium (ECC): Huawei Technologies Co., Ltd., Shenyang Institute of Automation of the Chinese Academy of Sciences, China Academy of Information and Communications Technology (CAICT), Intel Corporation, ARM Holdings, and iSoftStone Information Technology (Group) Co., Ltd. The ECC is dedicated to advancing cooperation among industry resources from government, vendor, academic, research, and customer sectors, and pushing forward the sustainable development of the edge computing industry.

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About this report

This report looks at current and future developments in the edge computing ecosystem across several perspectives: technology, use cases, market outlook, opportunities, business model, and policy and regulation. The report offers a global view before focusing on China.

While edge technology can be deployed on (and integrated with) any mobile or fixed network, 5G is the access technology that will drive most edge use cases. This report focuses on edge computing in 5G networks, helping address critical questions for edge stakeholders in China.

To build an understanding of how the Chinese ecosystem views the development of edge computing and the associated opportunity, we conducted a survey on edge computing in China. This allowed us to gather the latest insights and views from key companies in the nascent ecosystem, including the three mobile operators, telecoms network vendors, cloud and edge specialists, technology players, and companies from a number of vertical industries. Survey results are presented in aggregate.

The GSMA appreciates the important insights provided by the following:

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Defining edge computing

In this report we use the term 'edge computing' to refer to a range of edge technologies (hardware and software) that enable storage, computing, processing and networking closer to the device generating or consuming the data than in a traditional, fully cloud-based model. These technologies include edge nodes, on-premise edge, cloud edge, edge cloud, edge gateways, edge workloads and edge applications. In the context of a mobile network, 'closer' is a relative term that could span from marginally nearer (i.e. in the transport network) to sited with the customer – whether within a user device or at their premises.

Contents

1 Executive Summary

Edge computing is gaining unprecedented attention worldwide as the industry moves into the 5G era

Edge computing is moving from concept to early-stage deployments as new use cases demand a more decentralised approach to computing and networking than a traditional, fully cloud-based model. Operators, network vendors and cloud companies are conducting trials and launching early commercial products in the US, Europe, China and developed markets of Asia Pacific. Current trials mostly use 4G or early 5G networks, but the expectation in the wider mobile ecosystem is to leverage the gradual rollout of 5G for edge deployments on a larger scale.

The move of part of the computing power from the cloud to the edge could to a large extent be seen as an operator-centric technology shift, which builds on previous developments such as the softwarisation and virtualisation of networks and plays into 5G deployments. Following industry-wide efforts to define MEC and the associated standards, MEC technology is increasingly being explored across various industry applications, with the expectation that 5G and MEC will drive greater integration between connectivity and computing.

While progress on edge computing trials continues, there are still critical questions to address around the most viable location of the edge, the magnitude of edge investment needed, and the actual business models.

China offers a distinctive outlook: leading on edge computing, 5G and Internet of Things

Judging from the pace of edge trials and early deployments, it is clear that the Chinese ecosystem is looking to play a leading role in the development of edge computing. Many companies are involved, with the three operators and major network vendors such as Huawei, ZTE, Nokia and Ericsson making the greatest effort to drive edge developments. Ecosystem cooperation is also growing, driven by the work of both local organisations (ECC, CAICT, CCSA, 5G DNA) and global organisations (ETSI, 3GPP, GSMA).

The government's ambition to make China a leading country in new technologies and Industry 4.0 is a major force in driving forward digital evolution, supporting developments in 5G and IoT. China is the largest and most developed IoT market in the world, and all three operators have bold 5G plans, including the rollout of standalone 5G networks from 2020. Leading on 5G and IoT creates a favourable environment for edge computing deployments, positioning mobile operators at the heart of it.

Technology perspective in China: the certainty of 5G; the uncertainty of edge location

While there is unanimous agreement that 5G will be the key access technology to drive edge computing deployments in China, views differ on the actual location of the edge and the magnitude of edge technology needed to serve use cases across industries.

Many surveyed companies indicated that the edge should be located on-premise for key applications in smart factories, smart ports and smart campuses, to provide the best combination of ultra-low latency, real-time processing and analytics, network reliability and security. Deploying edge infrastructure at the district or city level can be a more cost-effective solution to cover a wider range of use cases, including smart cities, autonomous vehicles, cloud/edge immersive gaming and other services accessed and consumed on mobile. In such scenarios, the rapid rollout of 5G by the Chinese operators, combined with network slicing, would provide the network capabilities required.

There is no one-size-fits-all answer to where the edge should be located. A number of factors will determine the location, including the specific requirements of the various edge use cases (latency, bandwidth, real-time analytics, volumes of data transferred, security), technology (edge configuration, distance from cloud and devices) and business aspects (actual demand, economics).

Use cases in China: autonomous driving, smart manufacturing and gaming will lead the way

Edge computing is most suitable for use cases that require at least one (possibly all) of the following: ultra-low latency (usually less than 10 milliseconds of round-trip time); real-time processing for real-time computing, rendering and analytics; high-volume data transfers; and deterministic networking. Beyond technical requirements, security and data protection are also key factors in the drive towards edge computing. Several use cases require these network capabilities, but timelines for ramp-up differ.

- **Truly autonomous vehicles** have the greatest need for edge computing according to surveyed companies. However, ramp-up will likely occur in 2023–2025 in China as the move to level 4 or 5 of vehicle autonomy requires further developments in legislation and vehicle technology, and significant road infrastructure investment.
- **Industry 4.0** offers a promising range of edge use cases. China's economy is highly reliant on the industrial sector (accounting for 41% of GDP), making productivity increases essential. The shift to automate processes depends on low-latency connectivity to satisfy precision thresholds and real-time analytics. Achieving that will require a combination of 5G, slicing and edge infrastructure sited in proximity to (or ideally inside) factories. Smart factories and ports are already seeing good momentum.
- **Gaming and e-sports, powered by edge and AR/VR,** will likely gain momentum in 2021–2022, but this requires deployment of edge infrastructure more widely. Given the real-time nature of gaming, the latencies required for a solid user experience align with 5G and workloads at the edge. Cloud functionality may be too far away for some of the more immersive applications, and locating all the computing capabilities in the device would not be practicable from a real-estate and design perspective. Considering the content involved, storing content at the edge will also drive backhaul efficiencies. In-venue live entertainment (smart stadia) and on-location TV production and broadcasting could also benefit from 5G and edge computing capabilities, without requiring extensive, wide-coverage edge deployment.

Edge computing introduces new opportunities and challenges for the Chinese ecosystem

Nearly 90% of surveyed companies see edge computing as an opportunity to generate incremental revenue in the 5G era. However, different companies come at edge computing from different angles in terms of opportunities and challenges.

- **Operators –** For China Mobile, China Telecom and China Unicom, edge computing plays into 5G's strengths, as a further layer to target the digital transformation of industries and enterprises, pushing the boundaries beyond connectivity. Operators have a smaller presence in the cloud market than Alibaba and Tencent, so extracting new use cases from network slicing and the integration of cloud, edge and core telecoms networks offers more promise. Opening up the 5G network itself to third-party developers is another opportunity, with the aim of catalysing an ecosystem of 5G service development at the edge of the network.
- **Telecoms network vendors –** As the integration of new technologies such as edge computing and artificial intelligence (AI) into core and access networks grows in scale and complexity, Huawei, ZTE, Nokia, Ericsson and other network vendors will increasingly be seen as key partners for Chinese operators and cloud companies looking to deploy edge computing – in particular, the 3GPP-compliant edge computing based on existing telecommunications infrastructure. The challenge for vendors is to design not only truly seamless, end-to-end network transformation solutions, but also to develop a new B2B2B approach (vendor–operator–enterprise) on a larger scale, to help bridge the ICT and vertical industry worlds.

- **Major cloud providers –** For Alibaba, Tencent and other cloud companies, edge technology is an extension of their cloud capabilities and offerings. These companies have established experience working with Chinese enterprises from all industries, and extensive cloud resources to build on. However, an edge computing ecosystem increasingly built around 5G poses new challenges, taking cloud companies to a new world of distributed computing that involves mobile connectivity and devices at larger scale, and requires deep edge/cloud orchestration. At the same time, cloud providers are looking to leverage and integrate edge computing into their internet-based consumer services, such as cloud gaming.

Business model for Chinese operators: still work in progress

Chinese operators will likely deploy edge computing in three phases, reflecting the gradual rollout of 5G networks and the speed of the digitisation of industries and enterprises.

- **Wave 1 (2018–2020) –** trials and bespoke small-scale deployments. In this phase, edge deployments are mostly private implementations, designed to serve the requirements of smart ports, smart campuses and smart factories, with edge infrastructure largely sited on-premises. Market education is key to bring enterprises on board.
- **Wave 2 (2021–2023) –** ramp-up. As Chinese operators deploy 5G networks at scale (GSMA Intelligence forecasts over 60% population coverage by the end of 2023), edge use cases such as autonomous driving, sporting events and gaming are increasingly explored, with edge infrastructure deployed close to aggregation points of base stations, at district or city level or in regional data centres.
- **Wave 3 (2024 and beyond) –** mainstream. The maturity of 5G, lower cost of 5G devices and more established collaboration between the mobile industry and enterprises drive edge deployments on a larger scale. Further technology developments in autonomous driving and smart manufacturing create a more favourable environment and the need for edge deployments. The economics of edge computing improve as a result of larger scale; upgrades are made to increase efficiency (such as nano-processing); and market acceptance grows.

Revenue models for edge computing are still work in progress. Providing edge use cases with connectivity only would be a low-revenue scenario for the Chinese operators. A more interesting – and likely – development would see operators deploying and managing the edge infrastructure required by use cases and supplying the connectivity, devices and IT services needed. There is also an option to offer edge hosting/co-location to other companies. Moving up the value chain, operators could opt for a full-stack model (connectivity, devices, IT services, platforms and analytics), becoming an integrated partner in overseeing the edge-related operations of their enterprise customers. Owning the lead platform means operators can offer edge IaaS and edge PaaS solutions to third parties, in combination with the connectivity required, billing and network-related information essential for end-user applications. This is where the highest value exists, but it is also where the competition is greatest, with cloud and ICT companies targeting the same opportunity.

Advancing edge computing developments and scale in China: what needs to be done

Recent progress in edge computing, coupled with clear intent of the Chinese ecosystem to be at the forefront of the new technology, offers a solid base to build on. However, much work needs to be done to realise the long-term potential of edge computing. We have identified seven key actions that should help drive edge developments and adoption in China over the next five years. Many of these actions involve the edge computing ecosystem as a whole, while some are specific to individual categories of company.

Technology developments

- Clarify the most suitable deployment model for edge computing, and drive edge standardisation
- Integrate edge computing into the wider 5G network investment roadmaps
- Address the issue of high energy costs related to cloud/edge computing and, more broadly, 5G networks

Market acceptance

- Take industry collaboration to the next level, expanding edge computing discussions with vertical industries
- Leverage enterprise awareness of edge computing to promote new trials and deployments
- Increase focus on media & entertainment and smart cities

Policy and regulation

- Establish clear and focused regulation that recognises the unique nature and challenges of edge computing

Edge computing in China: the market in numbers

$180 billion

5G capex

Chinese operators will invest up to $250 billion in mobile capex between 2018 and 2025, of which $180 billion will be on 5G networks. Nearly 20% of global 5G network investment will be in China.

1.9 billion

Licensed cellular IoT connections

China is by far the largest and most developed IoT market in the world. By 2025, it will be home to 1.9 billion licensed cellular IoT connections. Three quarters of Chinese enterprises have already deployed IoT – the highest proportion globally.

53%

Enterprise interest in exploring the capabilities of edge computing

The GSMA Intelligence IoT Enterprise Survey reveals that around half of Chinese enterprises find edge capabilities compelling for their future IoT deployments, compared to less than 40% for enterprises in the US and Europe.

4.9

Importance of edge computing for truly autonomous vehicles

The Chinese ecosystem (i.e. surveyed companies) agrees that self-driving vehicles (with level 4 and 5 autonomy) have the greatest need for edge computing among the nearly 50 use cases analysed, with a score of 4.9 (on a range of 1 to 5). However, ramp-up will likely occur in 2023–2025.

~90%

Expectation that edge computing will help generate incremental revenue

Nearly 90% of the companies participating in the survey see edge computing as an opportunity to generate new revenues in the 5G era. Two thirds expect to generate value from operational efficiencies.

7

Actions needed to drive edge computing developments and scale

The seven actions can be divided into three main categories: technology developments, market acceptance, and policy and regulation. Most actions involve all edge computing stakeholders in China.

2 Context and global trends in the drive towards edge computing

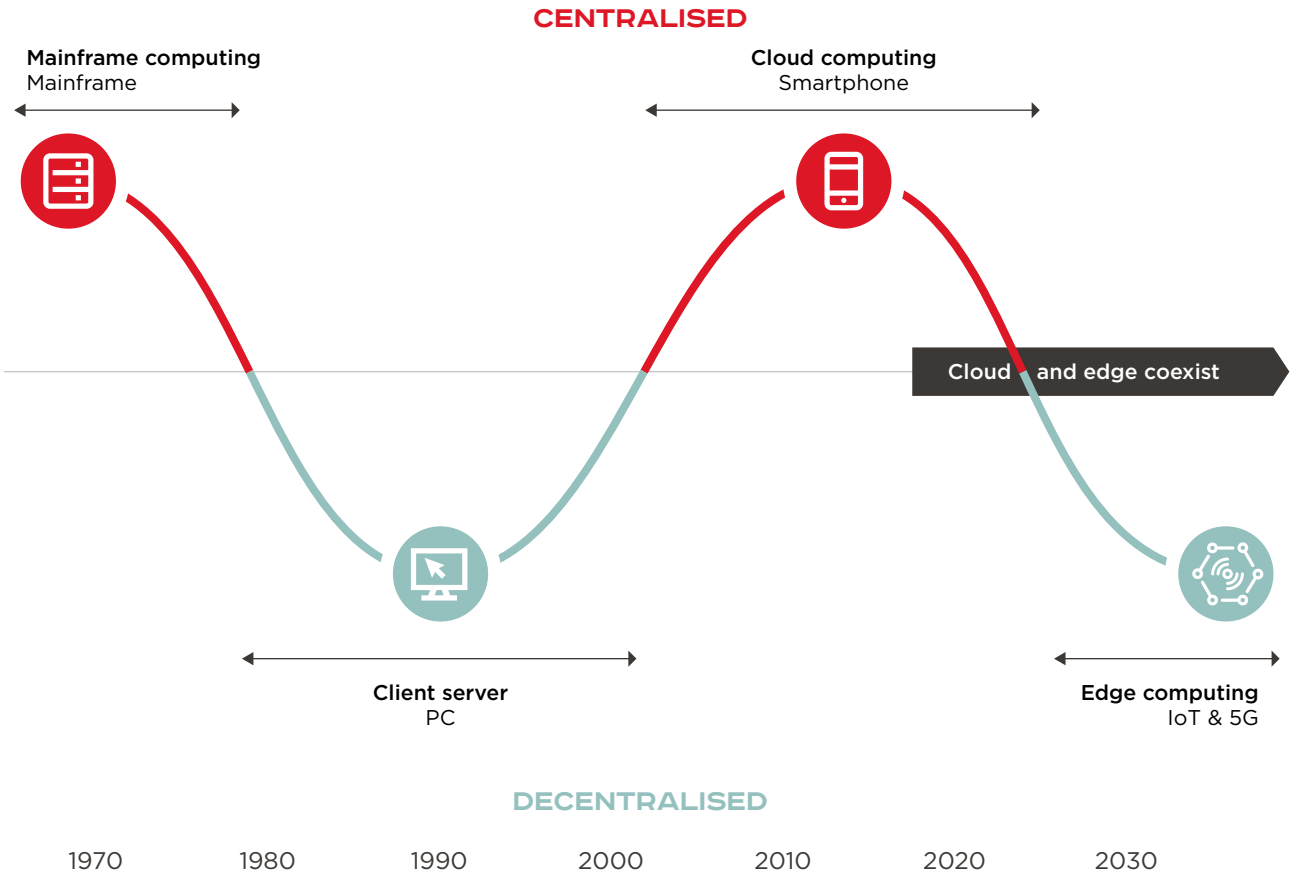
2.1 Drivers towards the edge

Over the last 40 years, computing power and processing have alternated between cycles of centralised and decentralised architectures. The mass-market adoption of the internet, enterprise IT and smartphones in the 2000s catalysed a wave of cloud computing, anchored in large centralised server farms. A handful of companies emerged to lead in this space – the so-called hyper-scale cloud computing players – Amazon (AWS), Microsoft and Google. More recently, other companies have entered the market and are scaling rapidly, including IBM, Oracle and the Chinese companies Alibaba and Tencent.

While it is difficult to define hard boundaries, there are now clear signs that a new wave – edge computing – is developing. This would mark a shift back towards decentralisation, with computing power and resources deployed 'nearer' to customers. At its heart it represents a pivot from a network-centric service model to a more workload-centric model, with localisation the key principle. This is not an either/or scenario. The centralised cloud data centres will remain and indeed will likely expand in overall capacity, but new demands (such as from IoT and enterprise) and in particular the potential for ultra-low latency services in the 5G era are drawing computing back towards the end user.

Figure 1

Computing cycles through time

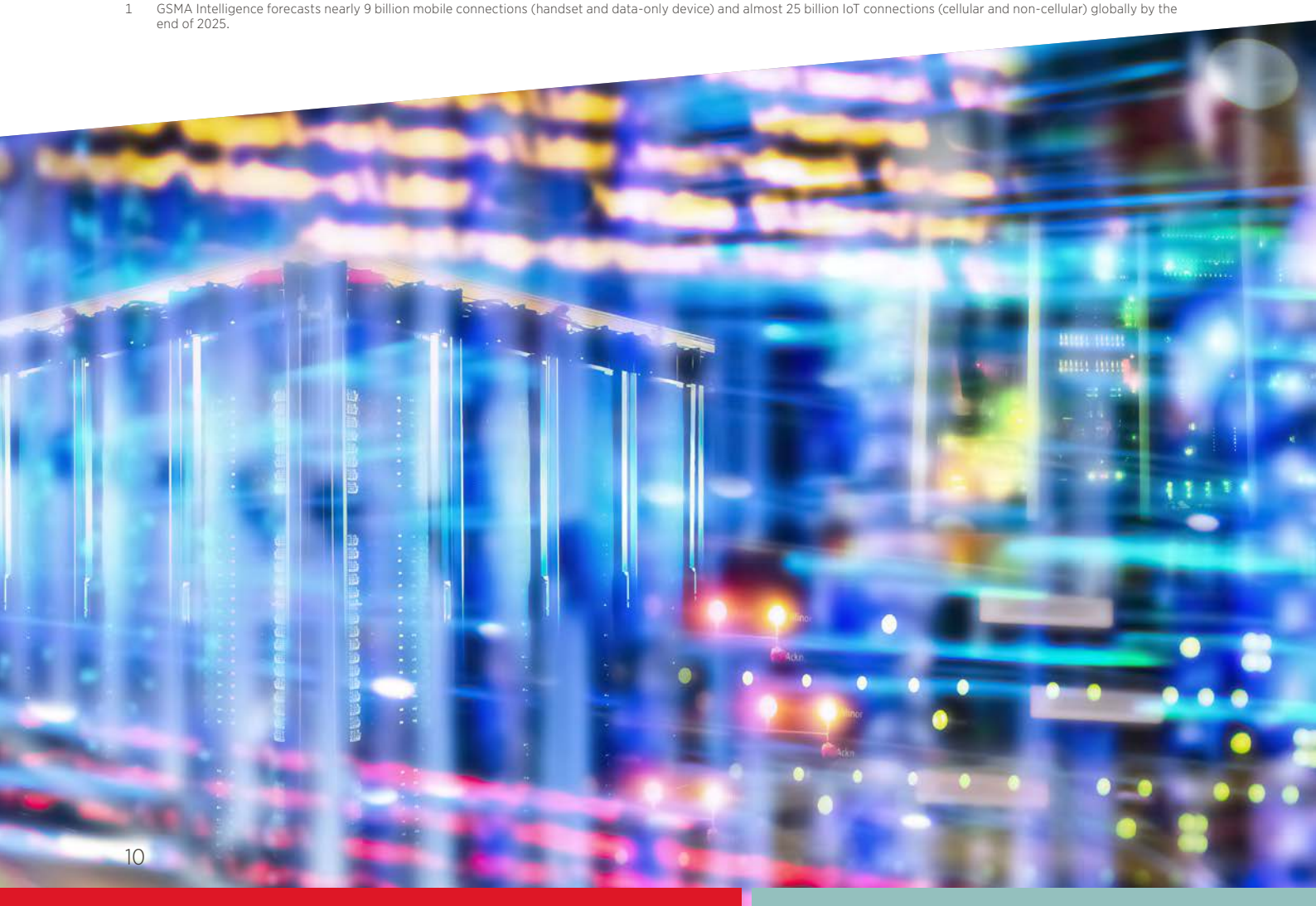


Source: GSMA Intelligence

A number of factors point towards the development of edge computing:

- **Capacity –** The increasing amounts of data produced by the plethora of connected devices will require significant bandwidth and backhaul capacity if transferred to cloud services in a more centralised location.[1] Edge computing and local data processing would reduce the amount of data needed to be transferred.
- **Cost –** Related to the issue of bandwidth, there is also a cost involved in sending large amounts of data over long distances. In addition, much of the data produced by many devices may be of little relevance and therefore would not need to be transported to centralised processors.
- **Analytics –** Data is a fundamental asset in the digital economy. The ability to turn it into real-time (or near real-time) analytics and actions will increasingly require a move of processing and computing closer to the device generating or consuming the data.
- **Security –** Many companies may not want sensitive data to leave their sites or their own servers. National laws and regulations around data privacy can also be a factor.
- **Latency –** Although 5G offers the promise of much lower latencies compared to 4G, extremely low latencies can be difficult to sustain over longer distances and with multiple network 'hops'.
- **Resilience –** Edge computing can potentially offer more possible communication paths than a centralised model. This distribution means resilience of data communications is more assured.

1 GSMA Intelligence forecasts nearly 9 billion mobile connections (handset and data-only device) and almost 25 billion IoT connections (cellular and non-cellular) globally by the end of 2025.



2.2 Defining the edge

The general move to more localised and distributed computing is a trend impacting the overall ICT ecosystem. From the perspective of the telecoms industry, or more specifically mobile operators, it was initially referred to as mobile edge computing (MEC). The European Telecommunications Standards Institute (ETSI) defines MEC as follows:

> **Mobile edge computing provides an IT service environment and cloud-computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers.**

In 2017, the definition of MEC was amended to 'multi-access edge computing', reflecting the reality that edge deployments could in practice utilise a range of access technologies, including fixed networks. While the focus of this report is on the potential for edge computing in 5G networks, the outlook for edge adoption does not rest exclusively on the future development of 5G.

MEC brings network capabilities closer to end users, allowing operators to increasingly open their networks to third parties, and enterprises to build private network environments such as in smart factories, smart ports and smart hospitals. These business scenarios usually involve various applications, requiring the network to provide ultra-low latencies and strong processing, computing and storage capabilities at the edge. Data is processed, saved and delivered locally, without having to be hauled back to the network centre. 5G MEC also supports connectivity and computing integration to provide more efficient interactions with end users.

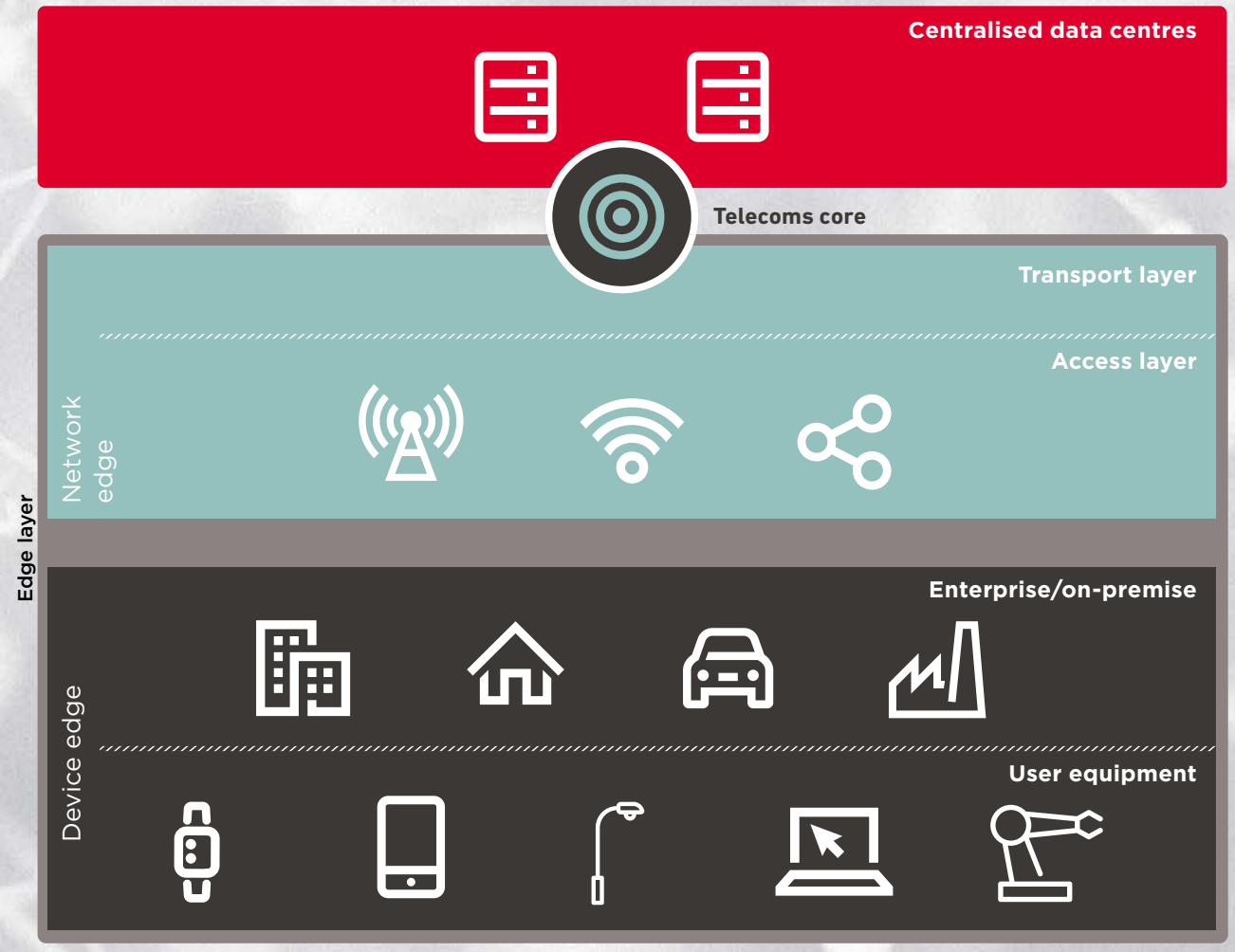
Where is the 'edge' for edge computing deployments in mobile networks?

Edge architectures drive cloud functionality – such as storage, computing, processing and networking – closer to the device generating or consuming the data than in a traditional, fully cloud-based model. In the context of a mobile network, 'closer' is a relative term that could span from marginally nearer (i.e. in the transport network) to sited with the customer – whether within a user device or at their premises. Figure 2 offers a simplified representation of the edge in mobile networks.

There is no one-size-fits-all answer to where the edge should be located. A number of factors will determine the location, including the specific requirements of the various edge use cases (latency, bandwidth, real-time analytics, volumes of data transferred, security), technology (edge configuration, distance from cloud and devices) and business aspects (actual demand, economics). Approaches to edge computing may also vary across markets, reflecting local factors such as spectrum licensing or data privacy regulations. The factors determining the location of the edge are analysed in depth in Chapter 3.

Figure 2

A simplified representation of the edge in mobile networks



Source: GSMA Intelligence

2.3 The emerging edge computing ecosystem around the world

Edge computing is still in its early stages. However, trials and small deployments are growing in the US, China, Europe and some developed markets across Asia-Pacific. Given the potential impact and transformative nature of edge computing, it comes as no surprise that many companies in the mobile and cloud ecosystems are exploring it in its early stages.

A growing range of telecoms operators around the world are either engaged in edge computing trials or in the process of launching initial edge commercial products and solutions (see Figure 3).[2] While current trials mostly use 4G or early 5G networks, the expectation in the wider mobile industry is to leverage the gradual rollout of 5G networks for future deployments on a larger scale.

Edge computing should theoretically fit with operators' deployments in 5G and software-driven technologies such as software-defined networking (SDN) and network functions virtualisation (NFV), which will run certain virtualised network functions in a distributed way, including at the edge of networks. In turn, edge technology potentially benefits from the network capabilities of a virtualised network in the 5G era to extract the full potential of distributed computing.

2 See the *Edge computing in China* section for a full overview of edge deployments by Chinese operators.

Figure 3

Edge computing initiatives in telecoms

US

AT&T

AT&T is commercialising its MEC platform for enterprises, including customisable solutions. Potential applications span multiple industries. In retail, AT&T is working with Badger Technologies (a supplier of retail automation solutions) to explore how MEC and 5G can help retailers process large amounts of data in local stores. This could facilitate the use of robots in stores, as well as allowing retailers to decide which sensitive data should remain on the premises.

The AT&T Foundry has a dedicated edge computing zone that works with partners from across the technology ecosystem to gather insights for the development of AT&T's infrastructure and help develop potential edge services and solutions for AT&T's customers.

Microsoft has a multiyear partnership with AT&T – combining the global scale of Microsoft's Azure cloud with AT&T's domestic 5G capabilities – that aims to expand edge deployments to more locations and accelerate the development of edge computing use cases, such as gaming.

Verizon

Verizon has developed its own edge computing platform, targeting commercial services by the end of 2019. During early tests in New York the platform recorded latency of sub-10 ms. The operator expects to deploy edge computing technology primarily in urban and industrial areas, using a mix of both its own and third-party data centres. Replicating this in other locations, however, will require edge assets to be deployed across the network, with the trade-off being that costs will increase.

Verizon is working closely with enterprise customers and local start-ups at innovation centres and incubation labs, where it is developing applications to utilise the reduction in latency. The operator is undertaking a range of trials. Using MEC equipment located in the network facility, a facial recognition application was able to analyse information right at the edge of the network where the application was being used (instead of traversing multiple hops to the nearest centralised data centre). As a result, the engineers were able to successfully identify the individual twice as fast as when they duplicated the experiment using the centralised data centre.

CenturyLink

CenturyLink (an enterprise-focused fixed line operator) is planning a "several hundred million dollar investment" in an edge computing network, starting with 100 initial locations across the US. The facilities will be designed to serve their local locations within 5 ms of latency.

EUROPE

BT

BT is looking to extend its cloud platform to around 100 locations across the UK, under an initiative referred to as 'Network Cloud'. This will allow it to reduce network latency and offer new services. The cloud platform could eventually be extended beyond metro nodes and into some of the central offices BT maintains across the UK. It currently has about 1,200 local exchanges that could serve as a first point of aggregation.

BT is reportedly targeting a latency reduction from 30 to 20 ms on average, in the first year of deployment of 5G by the firm's mobile subsidiary EE. The medium-term target is below 10 ms, which will enable a new set of 5G use cases including dynamic robotics and drone services. BT's new architecture would also allow the company to deliver services across multiple access technologies.

Deutsche Telekom

Deutsche Telekom claimed to launch the world's first public mobile edge deployment in Germany in early 2019, using technology developed by MobiledgeX (a company founded by Deutsche Telekom), which aggregates existing network operator resources to host application cloud containers. The operator has given MobiledgeX access to six sites in the country, where it is testing live applications. MobiledgeX is building the "middleware" for third-party applications to run on the operator's edge computing assets. Deutsche Telekom has also begun to launch trial services, including a cloud gaming service called MagentaGaming. The service will be rolled out commercially in 2020.

Telefónica

MEC is an important component of Telefónica's general network evolution strategy, as part of its migration to a fully converged, virtualised and software-defined network, referred to as the open access network (OPA) and Unica initiatives. As part of Unica, the company is completing the virtualisation of its data centres and now focusing on central offices. There is some discussion around how extensively edge capabilities will be deployed, which in the longer term is likely to reflect how the market develops.

Telefónica is already setting up live use case trials with customers, with cloud gaming launched in the second quarter of 2019 and hybrid storage services launched the previous quarter. The company recently launched extended reality (XR) content using its edge capabilities.

ASIA PACIFIC

Telstra

Telstra has partnered with Ericsson to explore edge computing use cases and network capabilities for the financial sector; it has been testing end-to-end banking solutions over 5G with the Commonwealth Bank of Australia. The trials are expected to help showcase what the bank branch of the future might look like and how 5G-powered edge computing can help reduce the network infrastructure currently required at individual bank branches.

Korea Telecom

KT has deployed edge computing at eight locations across major cities in South Korea. The company has indicated that the initial focus will be on providing services to its 5G devices in each locality. KT added that it plans to use MEC centres to support deployment of autonomous cars, smart factories and AR/VR services.

Rakuten

Rakuten has indicated that it will undertake a large-scale edge deployment as part of its virtualised network build, with a total of 4,000 edge services planned. While initially focused on the delivery of the company's own core mobile services, the deployment of edge computing resources should allow the operator to explore and develop third-party applications and services once its 5G network has launched commercially in 2020.

Major cloud companies are also looking to support the drive towards edge computing globally (Figure 4).[3] It may be somewhat ironic that the big cloud providers, which championed the move to centralised computing, are now also looking to support moves back to a more decentralised model. However, there is an important distinction in that the cloud players are not looking to replace cloud-based services. Rather, it is a reaction to some of the drivers outlined earlier in this section – in particular, the challenge of transferring and processing huge amounts of data from the customer location to the central cloud.

3 See the *Edge computing in China* section for a full overview of current deployments by cloud players in China.

Figure 4

Edge computing initiatives by major cloud companies

MAJOR CLOUD COMPANIES

Amazon (AWS)

Amazon launched its first commercial edge product in 2017 – AWS IoT Greengrass, which seamlessly extends AWS to edge devices so they can act locally on the data they generate, while still using the cloud for management, analytics and storage.

Amazon provides AWS Snowball Edge – a data migration and edge computing device suited for local storage and large-scale data transfer. Snowball Edge devices can be deployed on customer premises and offer on-board storage and computing power. Snowball Edge can undertake local processing and edge computing workloads in addition to transferring data between local environments and the AWS Cloud, where required. AWS claims the devices can also be deployed in rugged, temporary or mobile environments that have limited or no network connectivity.

Amazon also offers AWS Outposts, running AWS infrastructure on-premises. It is designed for connected environments and can be used to support workloads that need to remain on-premises due to low latency or local data processing needs. This allows businesses to utilise the same native AWS services they are used to from the public cloud.

Microsoft

Microsoft has defined the intelligent edge as a continually expanding set of connected systems and devices that gather and analyse data, close to end users, the data or both. It was one of the first to allow customers to replicate the cloud environment on a smaller scale in their own data centres with its Azure Stack. An alternative solution, for premises without a data centre, was to physically move the data, as with its 'data box' products that offer large amounts of storage. The boxes are then periodically shipped to Microsoft so that the data can be extracted and processed in the cloud. In contrast, the Azure data box edge is designed to transfer data over the internet as well as performing computing at the edge.

At Microsoft Build 2019, the company announced its Azure SQL Database Edge, designed to help address the requirements of data and analytics at the edge using the highly available and secure SQL engine. Developers will be able to adopt a consistent programming surface area to develop on a SQL database and run the same code on-premises, in the cloud or at the edge. Microsoft Azure SQL Database Edge also helps developers build AI apps that can run in edge devices operating even in fully disconnected edge scenarios.

Google

Google has launched its Cloud Anthos – an application platform that enables enterprises to modernise their existing applications, build new ones and run them anywhere, including on-premises, ensuring consistency between on-premise and cloud environments. Its open source nature means it can support hardware and applications from a range of different vendors.

As AI models trained in the cloud increasingly need to be run at the edge, Google has also launched its Edge TPU solution, designed to run AI at the edge. Edge TPU complements Cloud TPU and Google Cloud services to provide end-to-end infrastructure (cloud-to-edge, hardware plus software) for the deployment of customers' AI-based solutions. It delivers high performance in a small physical and power footprint, enabling deployment of high-accuracy AI at the edge.

Major telecoms network vendors such as Ericsson, Huawei, Nokia, ZTE and Cisco are active in the edge computing field, playing the dual roles of suppliers of some of the edge technology needed for trials and deployments, and partners for operators and cloud companies looking at edge deployments.[4] For operators specifically, these partnerships are part of a wider network transformation strategy, which aims to build intelligent, automated and efficient networks in the 5G era.

In addition to the larger vendors, a number of smaller companies are already looking to deploy edge networks and solutions. EdgeMicro is an edge computing company that is developing edge micro data centres in the US and, in the longer run, EMEA and Latin America. The initial focus is to develop a containerised six-rack micro data centre that can be deployed in the field. The company envisions a future in which thousands of network-neutral, small modular data centres provide multi-tenant co-location services at telecoms towers and on urban rooftops.

Infrastructure company Vapor IO has organised the Kinetic Edge Alliance (KEA) – an industry working group of hardware, software and networking companies dedicated to making edge computing easy and connecting stakeholders with end users. Vapor IO is creating a distributed network of edge co-location sites, housed in micro modular data centres, which can be deployed at key points on the network, including telecoms towers and antenna sites.

4 See the *Edge computing in China* section for a full overview of current deployments by telecoms network vendors in China.

2.4 Global challenges: from business models to physical locations

Although at an early stage of development, a growing number of trials and initiatives are focused on developing the potential of edge computing. The actual business models and practical uses cases are in many cases still unclear, however. Indeed, the whole definition of edge remains opaque – in particular, where to put computing resources and the magnitude of edge infrastructure needed.

There are certainly different roadmaps between many operators and the cloud players. For example, BT is currently focused on around 100 locations for the UK market, whereas Google has suggested services such as its cloud gaming platform Stadia could require several hundred locations per market. A senior executive at a large European operator suggested that its company's edge plans are unlikely to cover more than a few hundred locations, as latency requirements may mean it is not necessary to have a presence in every single local central office.

Operators themselves have yet to fully decide on their own business models, with provision of co-location facilities to third parties one option to support the needs of companies such as Google, Amazon and Microsoft. However, cloud players are already building out their own edge facilities (or using those of third-party providers), while a number of smaller players and tower companies are developing their own edge solutions, often in collaboration and encompassing not only the provision of physical space and hardware but also services. Competition between the different players in the edge ecosystem will likely increase as the traditional boundaries blur between infrastructure focused on network functions/capabilities and that more focused on computing and storage.

Beyond local concerns and regulations over data security and privacy, the key determinants of where exactly the edge is will be the level of latency required for a particular service or application, and the need for real-time or near real-time processing and analytics. Several operators have indicated that limited edge deployments in select major cities could allow them to deliver latency as low as 20 ms across their footprint. However, delivering latencies as low as 5 ms or below – theoretically feasible with 5G – for mission-critical services will clearly require far more extensive edge deployments. Justifying the significant incremental investment required then leads back to questions of specific use case and business model.

The deployment of edge infrastructure will clearly involve significant investment for those that choose to play in this space, which can be a challenge for operators to justify at a time when use cases and business models are still relatively opaque. There may be both financial and strategic synergies from linking edge and the moves to fully virtualised 5G networks. Both require a more distributed form of processing power, while realising the potential of ultra-low latency capabilities of 5G will require computing power close to the device. We are already seeing the initial stages of edge deployments, with the likelihood that edge will develop in a number of phases. Regional and metro data centres are already being built more extensively in many markets, with a gradual move towards more edge locations as demand and use cases develop.

Physical challenges will need to be addressed as computing moves towards the edge, particularly if it moves to more challenging locations such as cell towers rather than enterprise sites. These include issues around power, security, service assurance and the lack of available onsite staff with the right technical skills (an issue that may be a challenge in a local enterprise office as much as a cell tower). Ironically, these are some of the same issues that led companies to migrate their servers and software from owned, on-premise data centres to remote server farms. While a number of initiatives are under way to address these challenges, they could prove the biggest barriers to fully distributed, truly localised edge infrastructure. However, this could also be the area where telecoms operators – with extensive field staff and an existing range of secure physical sites – are able to demonstrate a clear competitive advantage.

3 Edge computing in China: laying the groundwork for global leadership

3.1 Edge computing momentum is building in the Chinese ecosystem

Though in its early stages in China, the pace of developments in edge computing is accelerating. Over the last two years there has been significant progress, positioning China ahead of other major countries and regions in terms of trials, initial deployments and ecosystem cooperation.

Edge computing trials and initiatives gain momentum

Various stakeholders are engaged in the current, early phase of edge computing in China. These include the three mobile operators, major telecoms network vendors (Ericsson, Huawei, Nokia and ZTE) and the big cloud players in China (Alibaba, Tencent and Baidu). A number of smaller ICT companies, cloud & edge specialists, and enterprises from industry verticals are also in the game, looking to explore opportunities for new services and solutions at the edge. The list is long and growing. The *About this report* section includes those who participated in our survey.

The Chinese operators are among the most active companies in the space. China Mobile's edge computing roadmap included 300 specific edge actions in 2019, including evaluating testing nodes, opening up application programming interfaces (APIs) and working with partners to promote edge commercial applications. China Unicom claims more than 60 MEC trials and commercial projects in 20 provinces since 2018. Figures from the Chinese Edge Computing Consortium (ECC)[5] confirm momentum, with more than 100 MEC pilot projects in 40 cities across various industries and use cases, including smart campus, smart manufacturing, AR/VR, cloud gaming, smart ports, smart mining and smart transportation.

Ecosystem cooperation is on the rise

There is no shortage of edge forums and industry working groups in China. These involve operators, network vendors, other ecosystem players, government bodies and global/local industry associations such as the European Telecommunications Standards Institute (ETSI), the ECC, the 3rd Generation Partnership Project (3GPP), the China Academy of Information and Communications Technology (CAICT), the China Communications Standards Association (CCSA), the 5G Deterministic Network Alliance (5G DNA) and the GSMA.

The ECC is playing a key role in promoting industry coordination, fostering innovation and boosting awareness and early application of edge computing. Established in 2016, the ECC has more than 260 members across virtually all major industries, and various working groups for technical standards, testing, security and market promotion. In September 2019, the ECC and the Network 5.0 Industry and Technology Innovation Alliance (N5A) signed a cooperation agreement to jointly establish an Edge Computing Network Infrastructure Joint Working Group (ECNI) to promote the development of edge computing.

Open source initiatives are also on the rise. In November 2017, China Mobile, China Telecom, China Unicom and other technology companies launched the Open Telecom IT Infrastructure (OTII) for telecommunications applications in the ODCC, aiming to form an open and unified server solution suitable for edge computing deployments in 5G networks.[6] OTII edge servers will be distributed in a large number of edge and access central offices, and have been already used in some field trials.

5 In 2016, six organisations joined together to establish the Edge Computing Consortium (ECC): Huawei Technologies Co., Ltd., Shenyang Institute of Automation of the Chinese Academy of Sciences, China Academy of Information and Communications Technology (CAICT), Intel Corporation, ARM Holdings and iSoftStone Information Technology (Group) Co., Ltd.

6 The Open Data Center Committee (ODCC), jointly established by Baidu, Tencent, Alibaba, China Telecom, China Mobile, the CAICT and Intel, aims to create an open data centre platform in China to promote the development of infrastructure standardisation for industries.

In October 2018, China Mobile established the Edge Computing Open Laboratory, aiming to provide an industry cooperation platform to promote the development of an edge computing ecosystem across industries. As of early 2019, the Open Lab had 34 partners and had carried out 15 testbed projects with partners in various fields: four in smart cities, six in smart manufacturing testbeds, four in live streaming and gaming, and one in vehicle interconnection. Akraino and StarlingX are two other major open source edge computing projects supported by an open community of operators, enterprises and developers trying out the software and participating in the community through documentation and use cases.

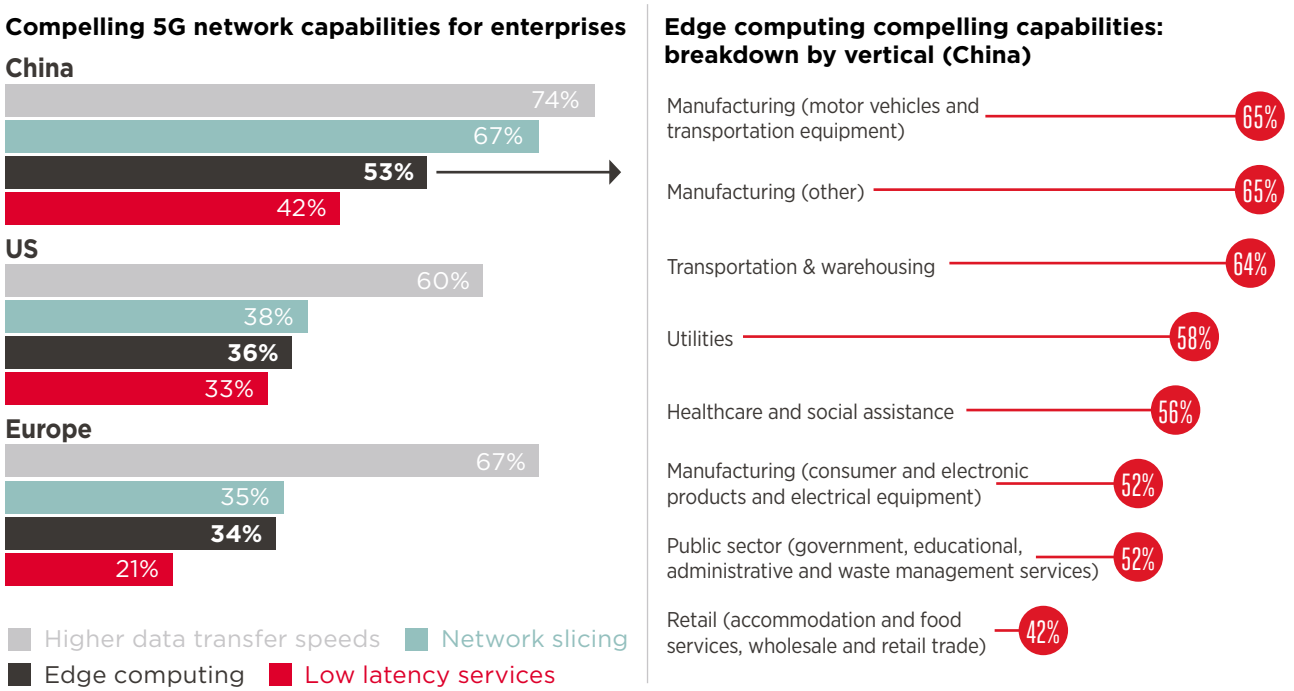
Awareness of edge computing grows among Chinese enterprises

The GSMA Intelligence global IoT Enterprise Survey reveals that 76% of Chinese enterprises plan to use 5G for their future IoT deployments.[7] While speed gains from 5G appear to be the most compelling 5G capability in most countries, Chinese enterprises show greater awareness (compared to other regions) of the other network capabilities that 5G promises to deliver, from network slicing to edge computing and lower latencies (see Figure 5). The larger the Chinese enterprise, the more attractive the IoT-specific capabilities of 5G.

Early partnerships and trials from the Chinese operators have contributed to raise such awareness, evidenced by widespread enterprise intent to use edge computing capabilities. Around half of Chinese enterprises find edge capabilities compelling for their future IoT deployments, compared to less than 40% for enterprises in the US and Europe. Manufacturing and transport lead the way, with companies in these sectors showing greater-than-average expectations to explore the benefits of edge computing technology for their businesses.

Figure 5

Compelling 5G capabilities for enterprise



Question: Which of the following 5G capabilities would make it compelling for your organisation to use 5G for future IoT deployments? Percentage of respondents; multiple answers allowed

Source: GSMA Intelligence IoT Enterprise Survey Q4 2018

7 IoT in business: Enterprise views on solution requirements, GSMA Intelligence, 2019

3.2 China's unique backdrop for edge computing

While edge computing trials are gaining momentum in the US and developed markets across Asia-Pacific and Europe, the following factors make the outlook in China particularly distinctive. These factors will play a key role in determining whether edge computing will ramp up over the next five years in China.

Significant progress with 5G – the access technology that will drive edge deployments and use cases

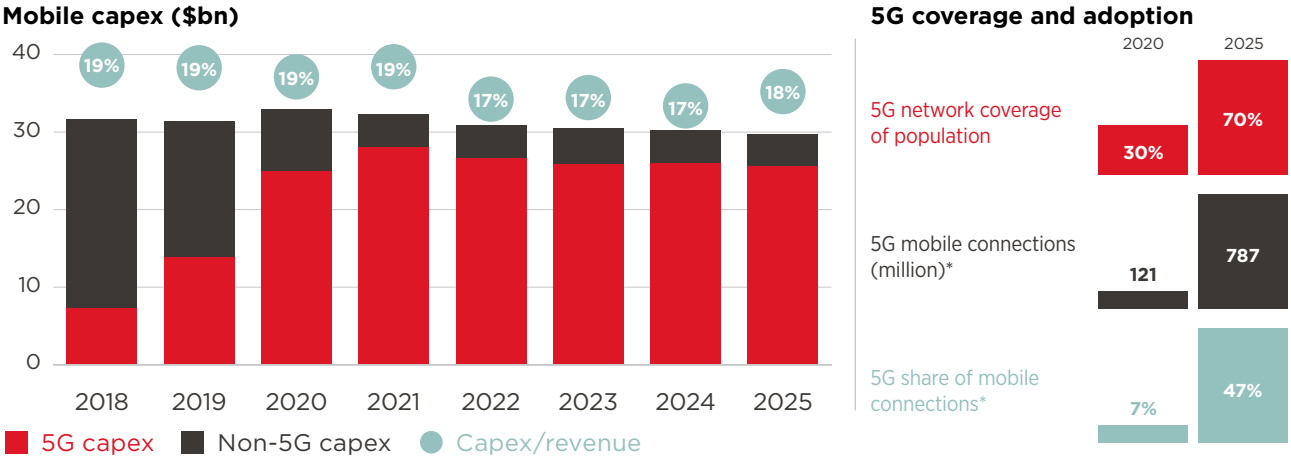
China has made 5G a national priority, with the 5G connectivity layer helping drive broader digital transformation of the economy. Having obtained nationwide 5G mid-band spectrum (2.6 GHz, 3.4–3.6 GHz and 4.8–4.9 GHz) in late 2018, and granted commercial 5G licences in June 2019, all three Chinese operators are moving fast with their 5G rollouts. The 2019 target was to build more than 130,000 5G base stations (50,000 China Mobile, 40,000 China Unicom, 40,000 China Telecom), covering more than 50 cities, with Beijing, Shanghai and Guangzhou getting contiguous coverage in their core urban areas. In 2020, operators will expand 5G coverage to all prefecture-level cities.

GSMA Intelligence forecasts that China will have the largest 5G consumer market in the world by 2025, with nearly 800 million 5G connections. This accounts for nearly half of the total number of mobile connections in China. To supply the networks required by 5G services, Chinese operators will invest up to $250 billion in mobile capex between 2018 and 2025, of which $180 billion will be on 5G networks. Nearly 20% of global 5G network investment will be in China.

The three Chinese operators are also demonstrating a clear commitment to rolling out standalone (SA) 5G networks, which will support a range of industry applications. This will make China the market leader for SA deployments and commercialisation, driving the global SA-compatible ecosystem for equipment and devices. 5G is key for edge computing; it will act not only as the lead access technology for edge deployments but also as a driver of momentum supplying opportunities for use cases. Building SA 5G networks offers a favourable environment for the deployment of edge computing in China as many of the edge use cases as discussed in Section 3.5 require ultra-low latency, real-time processing for real-time analytics, and high-volume data transfers.

Figure 6

China 5G outlook



*Excluding licensed cellular IoT and fixed wireless. 5G coverage and adoption figures are year-end.

Source: GSMA Intelligence

Government ambition to make China a leading country in new technologies and Industry 4.0

The Made in China 2025 strategic plan is a major force in driving forward digital evolution. Over the last few years, China has emerged as a leading place for testing and implementing new technologies, including early edge computing applications. Benefitting from the largest digital consumer base in the world (nearly 900 million mobile internet users at the end of 2019), competitive costs and enormous economies of scale, the Chinese ecosystem is ramping up its technology leadership and innovation, giving rise to a large number of start-ups and innovative companies in mobile and beyond. Like other nascent technologies, edge computing requires an ecosystem of innovation and partnerships.

Many national governments are aiming to position their countries at the forefront of technology innovation in the 2020s, but the scale of the Chinese industrial sector (41% of China's GDP comes from manufacturing, compared to 19% in the US), coupled with an established ecosystem of services and businesses centred on mobile, makes China a favourable environment for edge computing deployments in the 5G era.

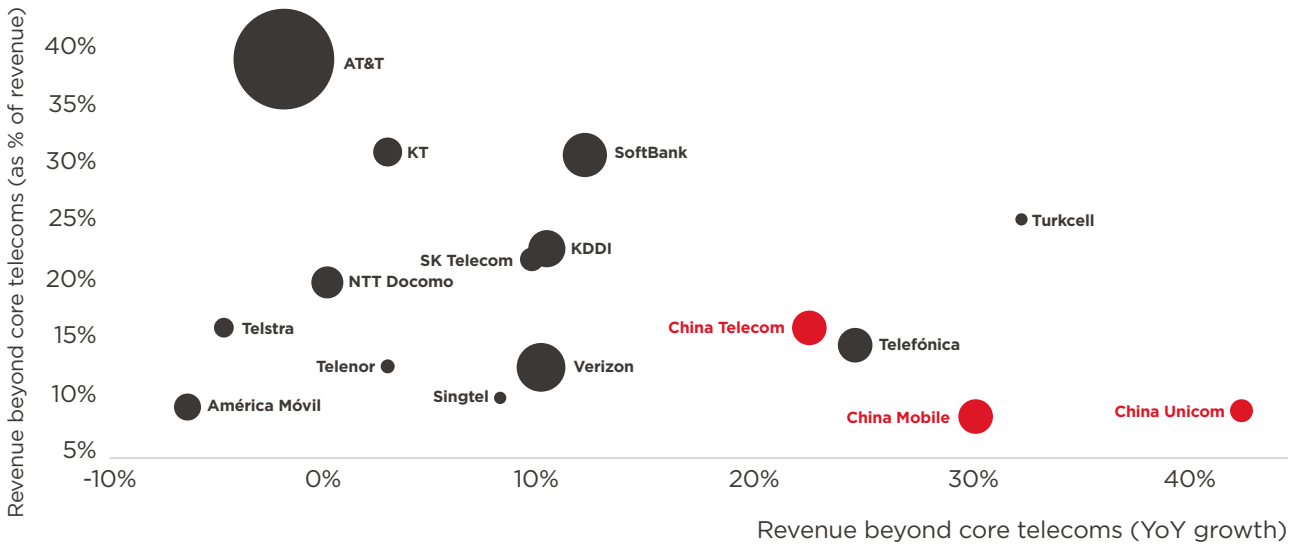
Operator intent to move beyond connectivity on a greater scale

For most major operator groups in the world, core mobile and fixed services account for 80–90% of revenue, with non-telecoms at 10–20%. A few exceptions exist, namely AT&T, KT and SoftBank (non-telecoms around 40% and 30% respectively) but these are the result of M&A rather than organic growth.

China leads on growth beyond core. Non-telecoms services – both consumer and enterprise – generated a total of RMB144 billion ($22 billion) in revenue for the three Chinese operators (in aggregate) in 2018, growing around 30% year-on-year in local currency. This includes pay TV, content and advertising, IoT, enterprise solutions and the broader universe of digital services including finance, payments and lifestyle. China Mobile, China Telecom and China Unicom are betting on the digital transformation of industries and enterprises to grow their future revenues beyond connectivity, positioning the integration of core networks, cloud and edge as a key technology enabler for companies looking to digitise their operations and services.

Figure 7

Revenue beyond core telecoms services, 2018



Source: company figures at group level and GSMA Intelligence reclassifications and estimates. Annual figures based on fiscal year reporting periods. For AT&T: last 12 months to June 2019 (to reflect 100% of WarnerMedia, fully consolidated since Q3 2018). For SoftBank, SoftBank Corp. plus Yahoo Japan. Bubble size reflects 2018 non-telecoms services revenue.

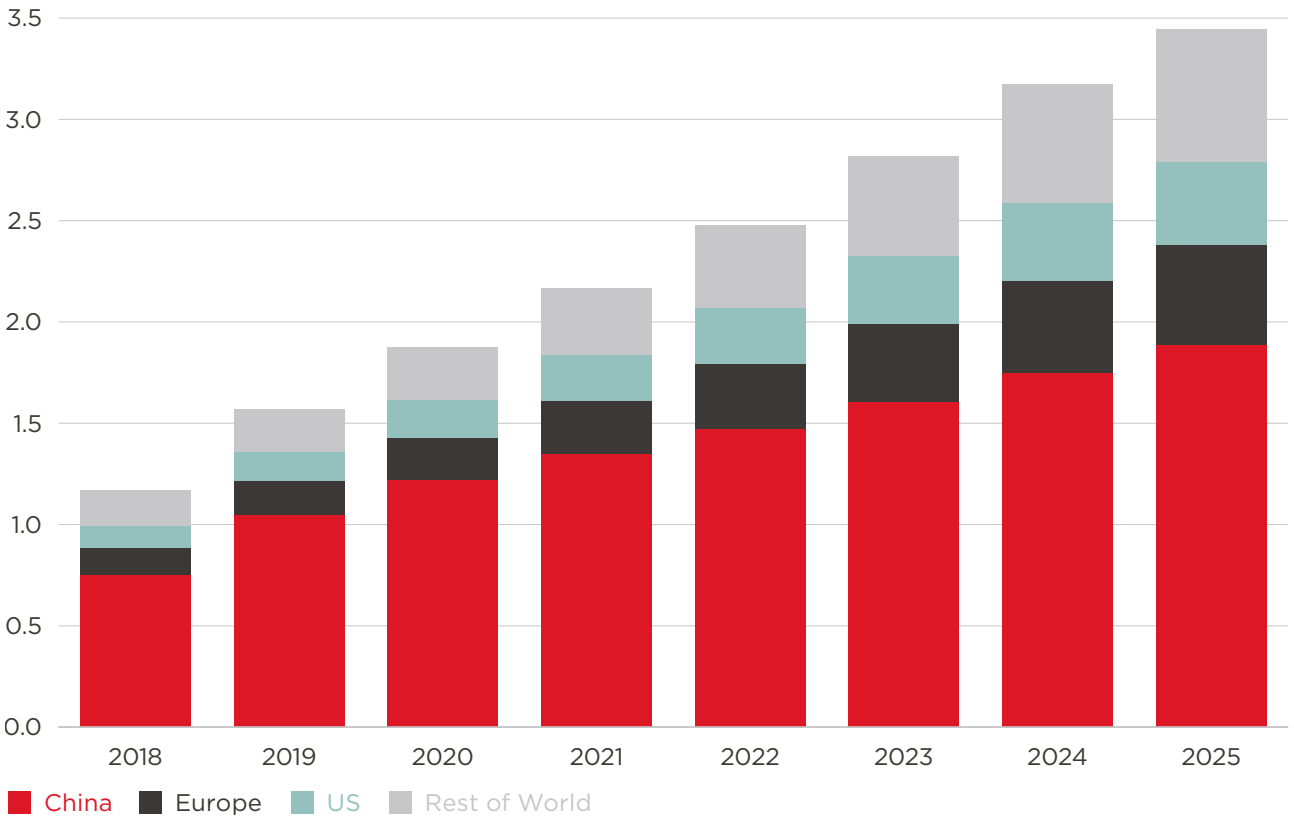
Global leadership in IoT – a promising and scalable market for edge computing solutions

China is by far the largest and most developed IoT market in the world. Around two thirds of global licensed cellular IoT connections reside in China (2019) – over 1 billion. Furthermore, three quarters of Chinese enterprises have deployed IoT – the highest proportion globally. China is also a major supplier of the technologies required to drive developments and growth in the global IoT market, including sensors, microchips and other components.

The three Chinese mobile operators generated a total of RMB11 billion ($1.7 billion) in IoT revenue in 2018, of which two thirds was by China Mobile. IoT revenue grew around 50% in local currency, largely driven by the boom in connections and the push on NB-IoT. While this accounts for a very small percentage of Chinese operators' total revenues (approximately 1% in 2018), enterprise IoT is an important driver in the move beyond core fixed and mobile services. China's leadership in both IoT and edge computing offers a favourable environment for deploying edge technology, particularly for IoT use cases that require large amounts of data to be stored, processed and analysed closer to the user, for faster analytics and response.

Figure 8

Licensed cellular IoT connections globally



Source: GSMA Intelligence

3.3 Key players driving developments in edge computing in China

Many Chinese companies are contributing to the momentum behind edge computing, by launching projects, forming partnerships and participating in industry forums and initiatives.

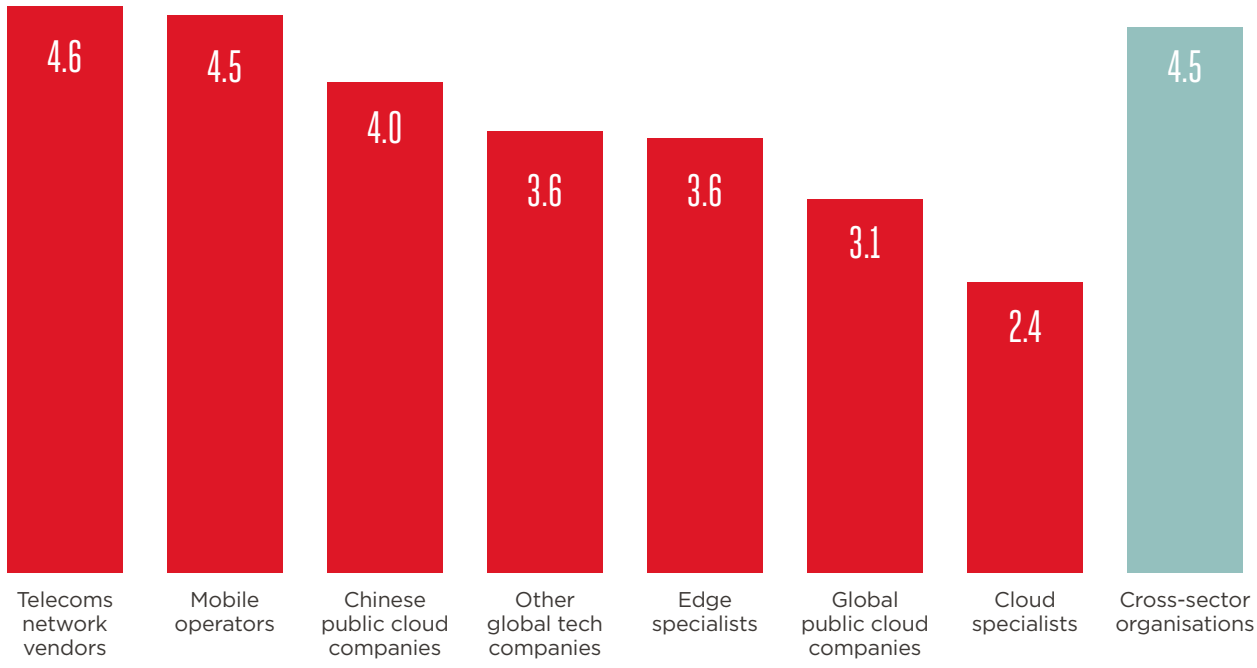
According to surveyed companies, telecoms network vendors (Huawei, ZTE, Nokia, Ericsson and smaller vendors) and the three Chinese mobile operators are making the biggest efforts in the early stages of edge computing (see Figure 9). This comes as little surprise considering the direct link between 5G and edge computing.

The top two Chinese cloud companies by cloud revenue (Alibaba and Tencent), as well as Baidu and other smaller cloud companies, are making significant moves, looking to expand their cloud capabilities and offerings at this nascent edge. Many have edge computing platforms commercially available. Alibaba has launched Edge Node Service (ENS), while Baidu and Tencent have OpenEdge and Smart Edge Connector respectively. Alibaba has the largest presence in the cloud market, but Baidu has an interesting proposition that sees edge as part of a wider strategy centred around AI, the so-called ABC (AI, big data, and cloud computing) development strategy. Autonomous driving, which involves both computing at the edge and extensive use of AI-powered technologies, is a key focus area for Baidu.

Cross-sector organisations are also playing a key role, driving industry work and promoting cooperation. This explains the high score (4.5), with most surveyed companies recognising the high value that these industry forums and working groups add to the nascent ecosystem.

Figure 9

Types of company driving technology developments in edge computing in China



Question: Who is currently driving technology developments in edge computing in China? Total score ranges from 1 to 5, where 1 is 'very minor effort' and 5 is 'very significant effort'

Source: GSMA Intelligence Edge Computing in China Survey 2019

CHINA MOBILE

China Mobile is undergoing a network transformation plan that aims to integrate technologies such as AI, IoT, big data, cloud and edge computing into 5G networks, in order to combine connectivity with digital services and provide customised service capabilities.

China Mobile's telecoms cloud architecture includes core cloud and edge cloud. These can cover a variety of data centres/equipment rooms, from centralised core nodes to distributed edge nodes. The edge cloud can be deployed at the city and district levels, and even extended to lower levels according to service requirements. China Mobile has already reserved hundreds of edge nodes to be used in combination with 5G networks to carry out trials of edge computing services across different use cases and industries.

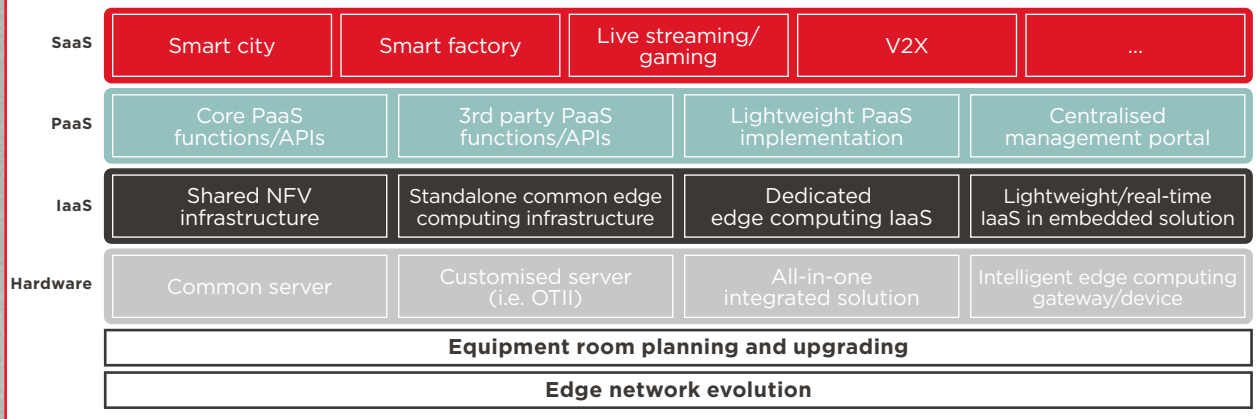
From a commercial perspective, China Mobile Internet of Things (a wholly-owned subsidiary of China Mobile) has launched OneNET – a centralised cloud platform that enables the aggregation of data from various IoT devices over a range of network environments and protocols. The stored data can be accessed by third-party applications and analytics services through a range of APIs and application templates. A number of value-added service capabilities allow the integration of different types of services in end-to-end solutions. These include OneNET Edge, currently used in industrial scenarios. OneNet Edge enables low-latency applications for enterprise customers at scale. IoT devices and applications can be monitored and managed in real-time locally, while real-time decision making can be made based on data wherever it is collected and stored.

In February 2019, at MWC Barcelona, China Mobile published its Edge Computing Technical White Paper, offering the operator's perspective on edge computing and clarifying its technology roadmap.[8] China Mobile's Pioneer 300 edge computing campaign included specific edge actions and targets for 2019: 1) evaluate 100 testing nodes on which edge computing equipment can be deployed; 2) open and expose 100 APIs for edge cloud computing capabilities; 3) introduce 100 cooperative partners on edge computing to promote the implementation of commercial applications.

Figure 10 shows China Mobile's perspective on edge computing configuration. The edge computing technology system involves multiple areas: services and applications (SaaS), PaaS capabilities, IaaS facilities, hardware devices, site planning and edge network evolution. The PaaS, IaaS and hardware platforms for edge computing need to be designed to be compatible with two application ecosystems: applications deployed in public clouds and edge-native applications. For various locations of the edge computing deployment, customised technology choices are expected in all these areas.

Figure 10

China Mobile's perspective of the technical system of edge computing



Source: China Mobile

8 China Mobile Edge Computing Technical White Paper. February 2019.

CHINA TELECOM

Cloud-network integration is a key strategic pillar for China Telecom in the 5G era. The operator is building a new generation cloud-network operating system that involves the deployment of a full cloud-based 5G core and multi-access edge computing (MEC).

From a commercial perspective, the operator has launched full cloud-based and all-fibre 5G cloud-network solutions for enterprise customers. China Telecom's cloud revenue is growing nearly 100% year-on-year; the cloud revenue generated in the first half of 2019 (RMB5,030 million, around $720 million) was higher than for the full year 2018 (RMB4,480 million, around $680 million).

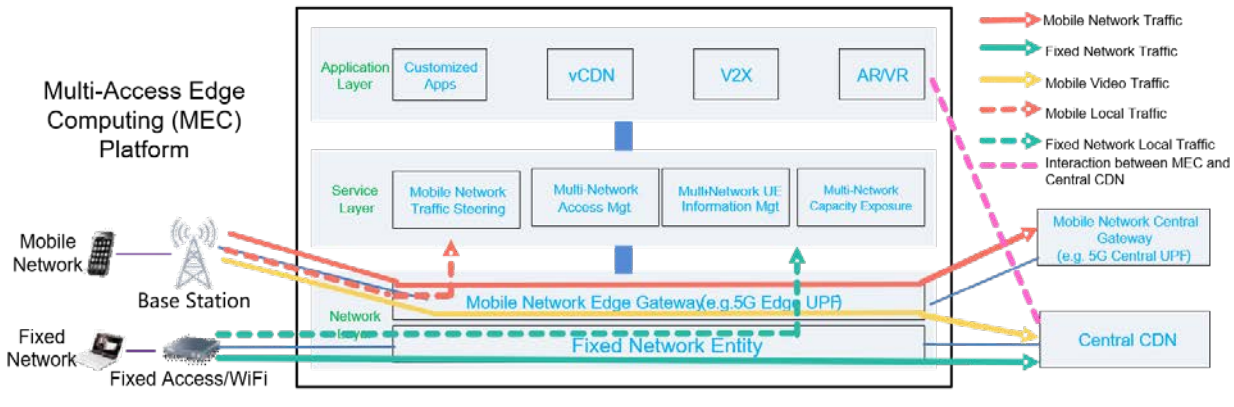
China Telecom is heavily involved in the promotion of edge computing in mobile networks across various areas, from participating in the forming of international standards, to R&D, and tests with partners including Huawei, ZTE and Tencent. Trials and small deployments span industries including oil & gas, ports and media & entertainment.

Over the last 12 months, China Telecom has invested in developing platforms for edge computing and network slicing. These platforms, fully integrated with cloud resources and 5G networks, help build dedicated networks for enterprise customers that have localised demands. 5G will be a key enabler. The operator is rapidly building its 5G network, with 40,000 5G base stations at the end of 2019. It aims to leverage its 5G network upgrade to standalone (SA) to offer 5G network capabilities such as SA-based edge computing and network slicing. 5G coupled with cloud-edge coordination will allow enterprises to benefit from superior network and computing capabilities. The operator has indicated various scenarios for edge computing adoption, including industrial internet, Internet of Vehicles, campus/enterprise parks, and VR live broadcast.

China Telecom has extensive operations in both mobile and fixed, with the two businesses almost equally contributing to total revenues. China Telecom aims to leverage both networks for edge computing. More specifically, to relieve the pressure on backhaul caused by network traffic and ensure the same user experience on different networks (mobile and fixed), China Telecom is constructing a unified MEC to achieve edge convergence of fixed and mobile networks by exploiting the advantages of existing fixed network resources (transmission and content delivery network – CDN). Figure 11 shows China Telecom's FMC-oriented MEC architecture.[9] The platform can flexibly route traffic to different networks according to service type or requirement, improving user experience and achieving intelligent distribution of content by sharing the edge CDN resources between multiple networks.

Figure 11

China Telecom's FMC-oriented MEC architecture



Source: China Telecom

9 China Telecom 5G Technology White Paper

CHINA UNICOM

As part of its wider strategy of building intensive, agile and open networks in the 5G era, China Unicom has launched an intelligent edge service platform – CUBE-Edge – built around a "6C" concept: close-to-user, cloudification, connection, coordination, computing and capability.[10]

Version 1.0 was released in 2018 and upgraded to 2.0 subsequently. As shown in Figure 12, the CUBE-Edge service platform involves a hardware resource layer, a virtualisation layer and a platform capability layer, and provides flexible platform capabilities and numerous APIs for developers to enable applications in industries.

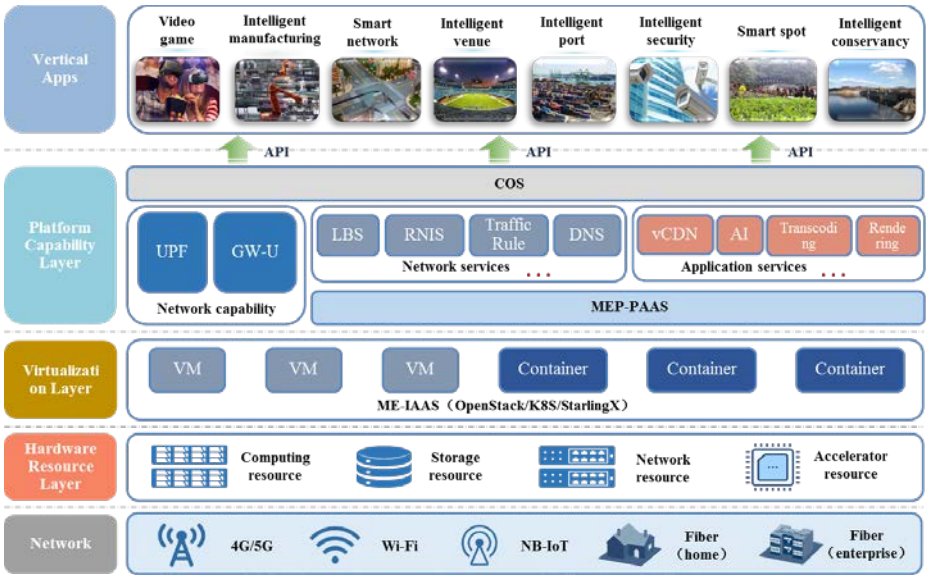
China Unicom is building its MEC edge cloud architecture on top of its DC-centric, all-cloud network, integrating edge and cloud. Management planes are deployed in a centralised region, while service planes are deployed closer to users and integrated with the communications cloud. The edge cloud is interconnected with public and private clouds for cloud-edge collaboration. Edge DCs at municipal level are used for wide coverage services, such as VCDN, AR, VR, video surveillance and cloud gaming. Edge DCs at the district level are suitable for applications such as connected vehicles and smart stadia as they meet requirements for large-scale data localisation and low latency.

Integration between cloud and edge is key. Cloud computing (public and private clouds) focuses on non-real-time and long-period big data analysis, whereas edge computing focuses on real-time and short-period data analysis, pushing most data to the network edge for faster processing, and reducing the waiting time and network bandwidth consumption.

China Unicom is involved in several edge-related projects and initiatives spanning sectors, from smart manufacturing to smart cities and ports, and has edge-related partnerships with various companies including Baidu, Tencent, ZTE and Intel. In 2018, China Unicom launched MEC edge cloud pilot projects in 15 Chinese provinces and cities: Beijing, Shanghai, Zhejiang, Fujian, Guangdong, Hubei, Chongqing, Shandong, Henan, Hebei, Jiangsu, Sichuan, Tianjin, Liaoning and Hunan. The latest update sees more than 60 MEC trials and commercial projects in 20 provinces since 2018, with a target to work with more industry partners in 31 provinces across the country.

Figure 12

China Unicom's MEC edge cloud platform architecture



Source: China Unicom

10 China Unicom CUBE-Edge 2.0 and industry practice white paper, 2019

TELECOMS NETWORK VENDORS

Huawei

Huawei offers various edge computing products and capabilities, such as MEC technology, Intelligent EdgeFabric (IEF) and edge-dedicated COTS. Edge computing sits in – and is increasingly integrated with – the wider portfolio of network offerings, covering RAN, core network, public cloud and IT infrastructure.

Huawei positions MEC as a key solution to enable edge computing in the 5G era. Huawei's MEC technology, based on the integration of connectivity and computing, provides an application-centric edge computing experience, guaranteed by dynamically adjusted network resources. It enables easy and flexible deployment and management of edge applications, and high-performance computing. With cloud-network-edge collaboration, each MEC node is interconnected with the control plane, so that centralised resource management and business orchestration can be achieved.

Huawei's 5G MEC supports a variety of edge business scenarios and is already being used in a range of commercial applications and pilots, including smart campus, smart factories, smart ports, smart agriculture and smart transportation. As 5G networks expand in coverage, 5G MEC solutions will help campus owners build a proprietary network more quickly and simply, and will accelerate the commercial pace of applications such as smart ports, smart mining, smart manufacturing and AR/VR.

As well as contributing to establish the Edge Computing Consortium (ECC) in 2016 and the 5G DNA in 2019, Huawei has embraced open source initiatives, including KubeEdge, an open platform for extending native application orchestration capabilities to hosts at the edge. Both cloud and edge are fully open source, and the edge can run even when disconnected from the cloud.

ZTE

In October 2019, ZTE introduced its fully convergent edge cloud platform, Common Edge. This includes a MEC capability exposure platform, a lightweight edge cloud, and a full range of edge-oriented servers. It supports and integrates mobile and fixed networks (4G, 5G and Wi-Fi), building a unified fixed and mobile convergence platform. The Common Edge solution has been used in various fields including smart grids, industrial manufacturing, Internet of Vehicles, media & entertainment, public safety and agriculture.

ZTE has also won The Greatest Commercial Potential for Edge Computing Concept Award at the Edge Computing Congress for its Slice Store for MEC solution. The Slice Store helps operators expose edge infrastructure and edge network capabilities to vertical industries and OTT providers. More broadly, ZTE has announced plans to invest more than 10% of its revenue in R&D, focusing on 5G chips and edge computing.

In China, ZTE has various partnerships and projects with operators across different fields, from manufacturing to live entertainment, gaming and immersive tourism. In manufacturing, in October 2019 the Zhejiang branch of China Telecom and ZTE used a 5G standalone site to trial 5G network slicing, edge computing and smart manufacturing to help Bluetron build a new 5G smart factory.

TELECOMS NETWORK VENDORS

Ericsson

Ericsson has established Edge Gravity, a corporate entity (fully owned by Ericsson) that aims to create edge computing solutions for an ecosystem of operators and edge technology vendors. Edge Gravity's Edge Cloud Platform connects service providers' last-mile networks to a dedicated global Ericsson network, empowering fast deployment of new services and applications that require low latencies and localised computing and storage. This ecosystem also enables experimentation with various technologies to determine optimal techniques for future edge computing services. Edge Gravity's ecosystem involves 85 operators around the world, including China Telecom and China Unicom.

Ericsson has also launched an edge solution built on its network functions virtualisation infrastructure (NFVI) – Edge NFVI – designed to optimise distributed workloads and edge use cases. Edge NFVI allows traffic to be moved through a distributed network with the required latency at low cost and with high throughput. The design has a unified management of cloud-native applications and virtual network functions running on a single platform.

In China, Ericsson is working with ecosystem partners to test and deploy early edge technology across various industries, including smart factories and transport. During MWC Shanghai 2019, Ericsson and China Mobile demonstrated remote surgery and an automated guided vehicle (AGV) prototype running on a standalone 5G network.

Nokia

Nokia launched its first Edge Cloud data centre solution in 2018. The Nokia AirFrame Open Edge server sits in the wider AirFrame data centre solution portfolio which enables operators to optimise network resources and intelligently distribute workload across the network, based on the type of data traffic as well as latency and throughput needs. Nokia AirFrame open edge server uses open architectures and is designed in an ultra-compact size for deployment even at base station sites.

Nokia has been working with the nascent Chinese edge computing ecosystem for several years, testing the capabilities of the new technology in various fields, including industrial automation, smart cities, IoT and consumer-focused use cases such as AR/VR. In the automotive space, Nokia, China Unicom, Tencent and Intel worked together in 2017 to build a network edge cloud system at Shanghai Mercedes-Benz Arena. In the gaming sector, during MWC 2019 in Barcelona, Nokia and China Mobile demonstrated cloud-based VR gaming on an AI-powered 5G network using O-RAN architecture and Nokia's edge cloud computing platform. This is part of a wider collaboration between Nokia and China Mobile who have been working on an open, intelligent radio network architecture to support the use of AI and edge cloud computing capabilities.

Nokia and China Unicom have also created a private LTE network for a BMW plant in Shenyang, where Nokia's virtualised MEC solution will leverage China Unicom's 4G network to provide low-latency support for smart manufacturing activities at the plant.

CHINESE CLOUD COMPANIES

Alibaba

Alibaba Cloud has launched its edge computing platform Edge Node Service (ENS) which aims to power consumer and enterprise use cases at the edge of Alibaba Cloud's Content Delivery Network (CDN). ENS relies on edge nodes deployed close to terminals and users to provide the computing distribution platform service. This enables customers to run their business modules on the edge and establish a distributed edge architecture through cloud-edge synergy. It offers low latency and low cost, and reduces the pressure on the centre.

Alibaba Cloud is working with partners for edge computing trials and implementation in China across a range of use cases and industries, including smart cities, logistics and autonomous vehicles. In September 2018, Alibaba and Intel announced the launch of a Joint Edge Computing Platform – an open architecture for IoT applications that integrates Intel's software, hardware and latest AI technologies with Alibaba Cloud IoT products, including Link Edge and AliOS Things.

In 2019, Alibaba Cloud announced that it had completed the deployment of more than 300 edge computing nodes in 30 China provinces, and is deploying edge chips, edge devices, and edge computing platforms and operating systems.

Tencent

In June 2019, during the KubeCon conference in Shanghai, Tencent Cloud presented its Smart Edge Connector (TSEC), a customisable edge computing solution that powers intelligent synergy of applications from edge to cloud. TSEC uses MEC technology, integrated with 5G networks, to provide low latency and high bandwidth for consumer and industrial use cases.

Given Tencent's position in gaming, a lot of emphasis is on cloud/edge gaming, AR/VR, ultra-high-definition video and live broadcasting. In August 2019, Tencent Cloud released its Tencent Cloud Gaming Solution at ChinaJoy, providing a one-stop tool for global games developers and platforms. Edge technology at the IaaS layer allows Tencent to further shorten the distance between players and services through the national edge computing data centres.

Tencent has been working with a number of Chinese companies to implement edge computing technology. During MWC Shanghai 2019, Tencent, ZTE and China Mobile demonstrated a 5G-powered, end-to-end slicing and MEC system for cloud games, using the 3GPP 5G SA standard. Tencent's WeChat team has been working with Intel to optimise their voice recognition workloads to be used inside cars and for in-car voice recognition systems.

Baidu

Baidu Cloud has embraced an "ABC" (AI, big data and cloud computing) development strategy to help enterprises execute their digitisation plans. Edge computing fits into this strategy as an extension of cloud resources and processing closer to end users.

In early 2019, Baidu released its open source edge computing platform – OpenEdge – which allows developers to build their own edge computing systems, extending cloud computing to their edge devices. OpenEdge is designed to gather and distribute data, perform AI inference and synchronise with the cloud. OpenEdge is a component of the wider Baidu Intelligent Edge platform (BIE), designed to run on the Baidu cloud.

Baidu and China Mobile have formed a strategic partnership to cooperate in new technologies such as AI, big data and 5G, and agreed to jointly explore opportunities in autonomous driving and IoT. Baidu is also working with Huawei and China Mobile on 5G trials.

A number of other companies – such as smaller network vendors, ICT companies, cloud & edge specialists, and research organisations – are also working on edge computing initiatives spanning manufacturing, automotive, media and other sectors.

OTHER COMPANIES PARTICIPATING IN THE SURVEY

99Cloud	99Cloud develops open stack platforms for enterprise SaaS applications, and provides a range of solutions including private cloud, virtual internet data centre (IDC) portal and enterprise app store.
BaishanCloud	BaishanCloud is a CDN provider that offers end-to-end cloud managed services, including caching servers, platforms for delivery of data and web content, and security.
China Academy of Information and Communications Technology (CAICT)	The CAICT is a scientific research institute under the MIIT. It supports the development of industries across various areas: plans, policies, standards, testing and certification.
DTmobile	DTmobile focuses on boosting the commercialisation of TD-SCDMA and associated TD-LTE technologies. It provides TD network solutions and integrated services to mobile operators in more than 20 provinces. DTmobile also works to promote 5G international standards and technologies.
Haier Smart Home	Haier is a multinational manufacturer of consumer electronics and home appliances that has recently transformed into an IoT partner for the smart home ecosystem.
HollySys	HollySys is an automation and IT solutions provider, focusing on process automation, factory automation, railway transport automation, and engineering.
Horizon Robotics	Horizon Robotics develops AI chips and solutions for smart mobility and IoT. It allows systems integrators and companies to develop AI-powered IoT solutions for smart cities, smart retail and intelligent robots.
iQIYI	iQIYI is an online video platform streaming original and licensed movies and other high-definition media content.
Neusoft	Neusoft is a provider of software technology and IT services. It provides industry and product engineering solutions, related software products and platforms, and IT services.
Shenyang Institute of Automation (SIA), Chinese Academy of Sciences	SIA is a research institute. It has 11 research departments across areas such as robotics, space automation, autonomous underwater vehicles, and digital factories.
SIASUN Robot & Automation	SIASUN is a high-tech robotic company belonging to the Chinese Academy of Sciences. It focuses on providing intelligent products and services in the robotics industry.
Sunny Intelligent Technology	Sunny Intelligent Technology focuses on the research and development of cutting-edge technologies for smart manufacturing, centred on the concept of intelligent digital factories. The company configures products and solutions tailored to the needs of different industries and enterprises.
Wangsu Science and Technology	Wangsu Science and Technology researches key technologies including big data and cloud computing. It also provides CDNs, customised IDCs, cloud security, as well as cloud and edge computing solutions.

3.4 Technology perspective: critical questions for deploying edge computing in mobile networks

From a technology perspective, the Chinese ecosystem is learning from the first wave of trials and small deployments. It will take time to address some of the critical questions around the most appropriate edge deployment architecture, including the location of the edge and the magnitude of edge technology needed to serve use cases across industries. There is also a need to integrate cloud, edge and telecoms networks as seamlessly as possible, as well as integrating edge technology with enterprise applications that run on it. However, the groundwork needs to be done now, with the nascent Chinese edge ecosystem showing clear intent to move things forward.

For China Mobile, China Telecom and China Unicom, deploying edge technology in mobile networks sits in the context of wider network transformation strategy, following naturally from previous developments such as the softwarisation and virtualisation of the network. Over the last few years, all three operators have invested in speeding up cloud-enabled network transformation, adding software-defined networking (SDN) and network functions virtualisation (NFV) capabilities. In the 5G era, core network virtualisation will accelerate, allowing operators to support faster service provisioning and enhance a range of network operations.

To some degree cloud and edge may be rivals, competing for operator network investment budget and capex allocation. In practice, the two technologies are complementary. Developing a cloud/edge infrastructure that combines the capabilities of both cloud and edge will help power a new service delivery model in the 5G era, optimally distributing computing and intelligence capabilities between various layers of the network. The ultimate goal is to cost-effectively provide an end-to-end 5G network that delivers the reliability, latency and bandwidth expectations of customers, allowing services to be easily accessed by application developers and content providers.

Which access technologies will be most used for edge computing use cases in China?

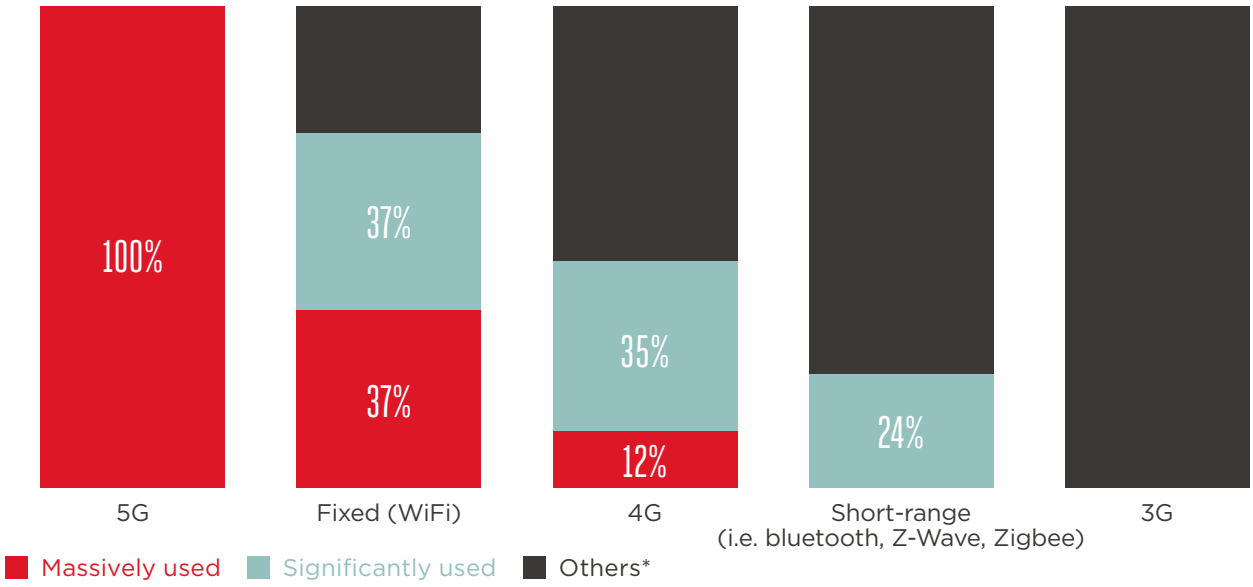
In the survey, 5G was highlighted as the most relevant edge computing access network (see Figure 13). All respondents said that 5G will be massively used for edge use cases – a much higher percentage compared to other network access technologies. A previous GSMA Intelligence edge computing global survey (in 2018) also highlighted 5G as the lead technology for edge use cases, but with smaller differences compared to 4G and fixed networks. This reflects faster rollout of 5G networks in China but also the country's ambition to leverage 5G as an enabler of digital transformation of industries and enterprises.

Early edge technology is being explored in a 4G context, but there is widespread agreement in the Chinese ecosystem that the gradual rollout of 5G networks will play a key role in driving future edge deployments and applications. 4G and 5G networks will likely coexist and remain complementary for many years in China. While 5G is built, 4G will continue to support edge trials and implementations, and can be used for edge use cases that don't require ultra-low latency or real-time (or near real-time) data processing.

While 5G is the most relevant access technology, there is a role also for the distributed edge beyond cellular. More than 70% of the surveyed companies believe fixed networks will also be used (massively or significantly) for edge use cases. Due to the variety of access technologies and applicable scenarios, fixed networks, short-range access technologies (Zigbee, LoRa), Time-Sensitive Networking (TSN) and other Ethernet technologies (PROFINET IRT and EtherCAT) could be an important alternative or supplement to 5G access. Access technologies may also not be exclusive. For a specific edge computing node, services with different access technologies could share the same IT resource.

Figure 13

Edge computing access technologies in China



Question: In the long term (2025), which access technologies do you believe will be most used to supply connectivity for edge computing use cases in China? Percentage of respondents. * Sum of 'moderately used', 'marginally used' and 'very limited use or not used at all'

Source: GSMA Intelligence Edge Computing in China Survey 2019

Where to locate the edge?

There is no one-size-fits-all answer to the best location of the edge for mobile networks. The fact that individual network vendors – as well as individual operators – have different views on the best location highlights the diversity of scenarios. A number of factors play a role, including the specific requirements of the edge use cases (latency, bandwidth, real-time analytics, volumes of data transferred, security) as well as technology (edge configuration, distance from cloud and devices) and business aspects (actual demand, economics). Figure 14 shows the options that need to be considered, depending on the use case.

Many surveyed companies indicated that the edge should be located on-premises for some use cases, such as edge applications for smart factories, smart ports, smart grids and smart campuses. This comes as little surprise (and is also unique to China) considering industrial applications requiring localised services are important scenarios for edge computing in China. This may also reflect the fact that many of the early edge computing deployments are bespoke implementations for private enterprises. Smart factories, smart campuses and other large environments also involve a huge number of devices connected to the network that need to work under close and coordinated control. Edge computing will be required when enterprises want to scale the number of devices, necessitating edge-powered platforms that can deal with a huge amount of data in real time and enhanced analytics.

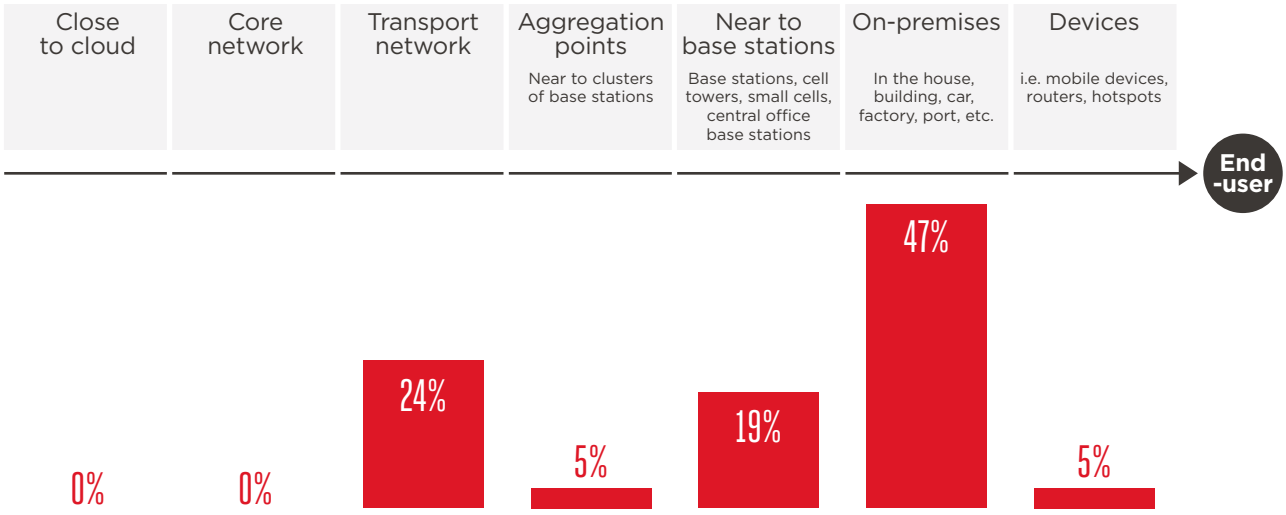
Deploying edge technology on devices is not viable in most cases as heavy application processing can strain devices, particularly lower end devices, also impacting battery life. Some pre-processing can be done on devices but the data will then need to be sent to the nearest edge computing centre on-premises, or in the transport network, for further processing.

Deploying edge infrastructure at the district or city level can be a more cost-effective solution to cover a wider range of use cases, including smart cities, autonomous vehicles, cloud/edge immersive gaming, and other services accessed and consumed on mobile. In such scenarios, edge infrastructure would be deployed near to base stations (in some locations, the base stations are located in a smart campus together with MEC), or in aggregation points (close to clusters of base stations). Deploying edge on-premise or near to base stations or aggregation points aligns with the MEC deployment model. The rapid rollout of 5G by the Chinese operators, combined with network slicing, would then provide the capabilities required by those edge use cases, including large bandwidth, high speed, low latency, network reliability and security.

For many use cases, edge technology may therefore not be as close to the end user as for those requiring ultra-low latency for critical applications or real-time processing and analytics. Even deploying edge infrastructure and edge technology on-premises for bespoke, private implementations should not be considered a given: several factors need to be considered, including the cost/benefit of deployment.

Figure 14

Location of the edge for mobile networks in China

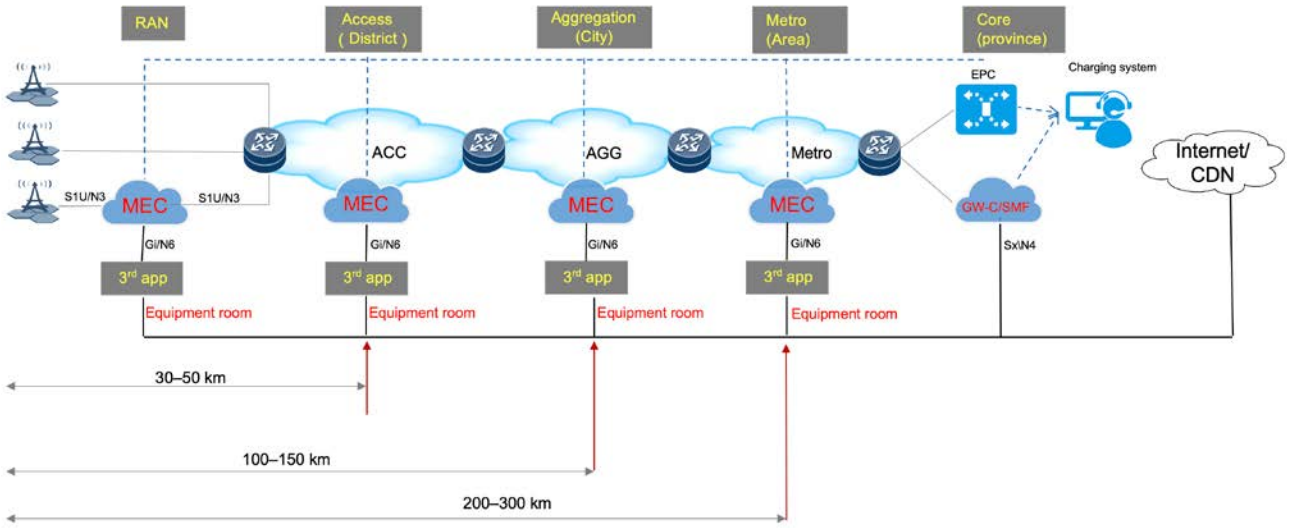


Question: Where do you think is the best place for the edge to be located? This question refers only to edge computing in mobile networks. Percentage of respondents.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Figure 15

MEC deployment scenarios and hierarchical levels in the context of mobile networks in China



Source: ECC

Which benefits are most important to drive edge computing deployments and adoption in China?

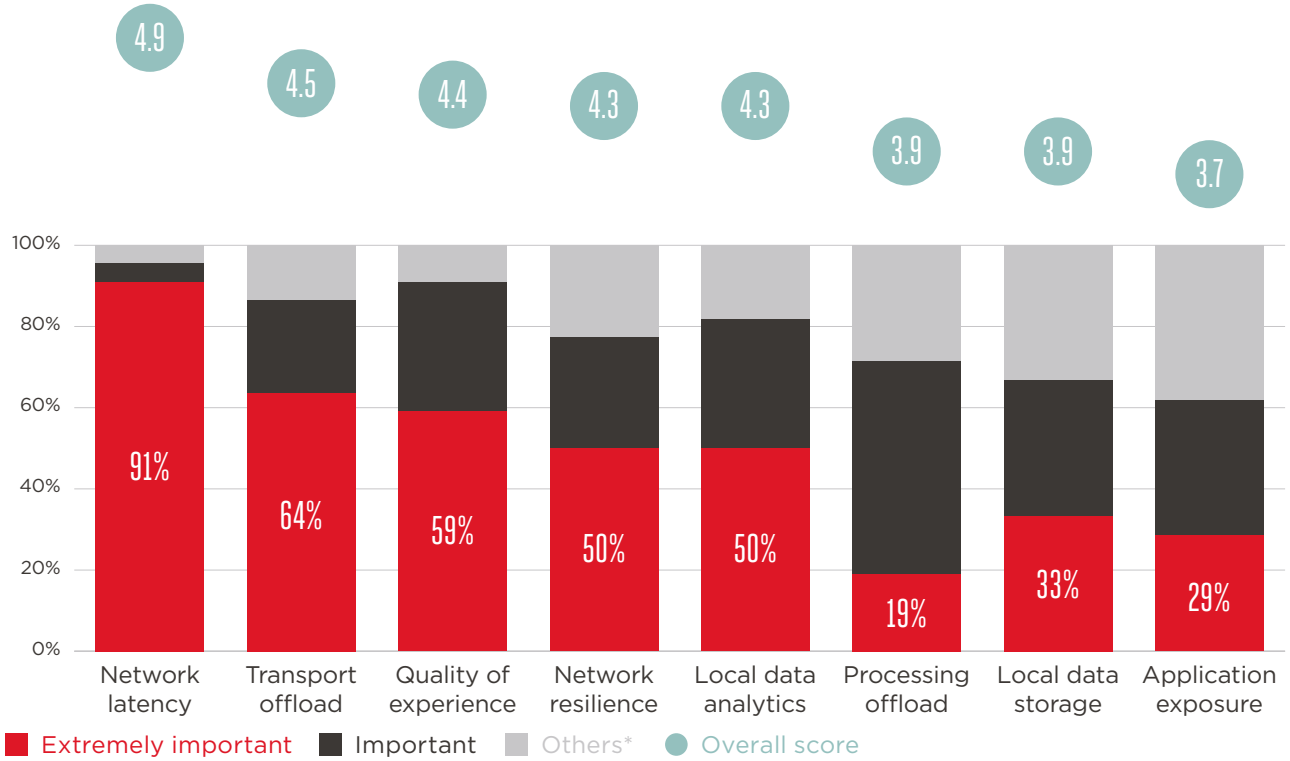
Ultra-low latency is the top benefit. More than 90% of surveyed companies said that network latency is extremely important in the context of edge technology in mobile networks (see Figure 16). This fits with the overwhelming expectation that 5G will be by far the most relevant edge access technology in China. Whereas LTE latency can average 25 ms, 5G specs call for response down to 1 ms, or even sub-1 ms.

Quality of experience – which is a function of low latency, network resilience and processing offload – plays well into consumer entertainment use cases such as immersive gaming powered by AR/VR, and enterprise demands, particularly in industrial environments and healthcare. Transport offload is also a key benefit. Considering 5G bandwidth promises, the backhaul implications could be massive. Delivering services from the edge leads to a reduction in backhaul traffic, by routing traffic to the internet directly from the edge (as opposed to the core) of the network.

Application exposure ranks low, but this may change over time as edge technology and 5G scale. This functionality drives the ability to make applications accessible to a broad set of users within both public and private networks. Operator core networks traditionally have not delivered the same open access as public cloud resources. To some extent, 5G is targeting this, promising to provide access to services for a diverse set of third-party users. Edge computing could enable this, particularly where tied to enterprise deployments. MEC technology allows the opening of the network, including running external APIs near the user. In the media and entertainment sector specifically, in scenarios where the content is not owned by the serving operator (e.g. AR content from a social network), there have to be interconnection points at edge servers so that third parties can host or cache their content. This is the rationale for exposing APIs for edge computing.

Figure 16

Benefits important to driving edge computing deployments and adoption in China



Question: Rank the following edge benefits based on how important they are to drive deployments and adoption of edge computing in mobile networks in China. Percentage of respondents and overall score. The overall score ranges from 1 (very limited importance) to 5 (extremely important). *Others is the sum of 'moderately important', 'marginally important' and 'very limited importance'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Who will deploy/manage the edge hardware, workloads and applications in China?

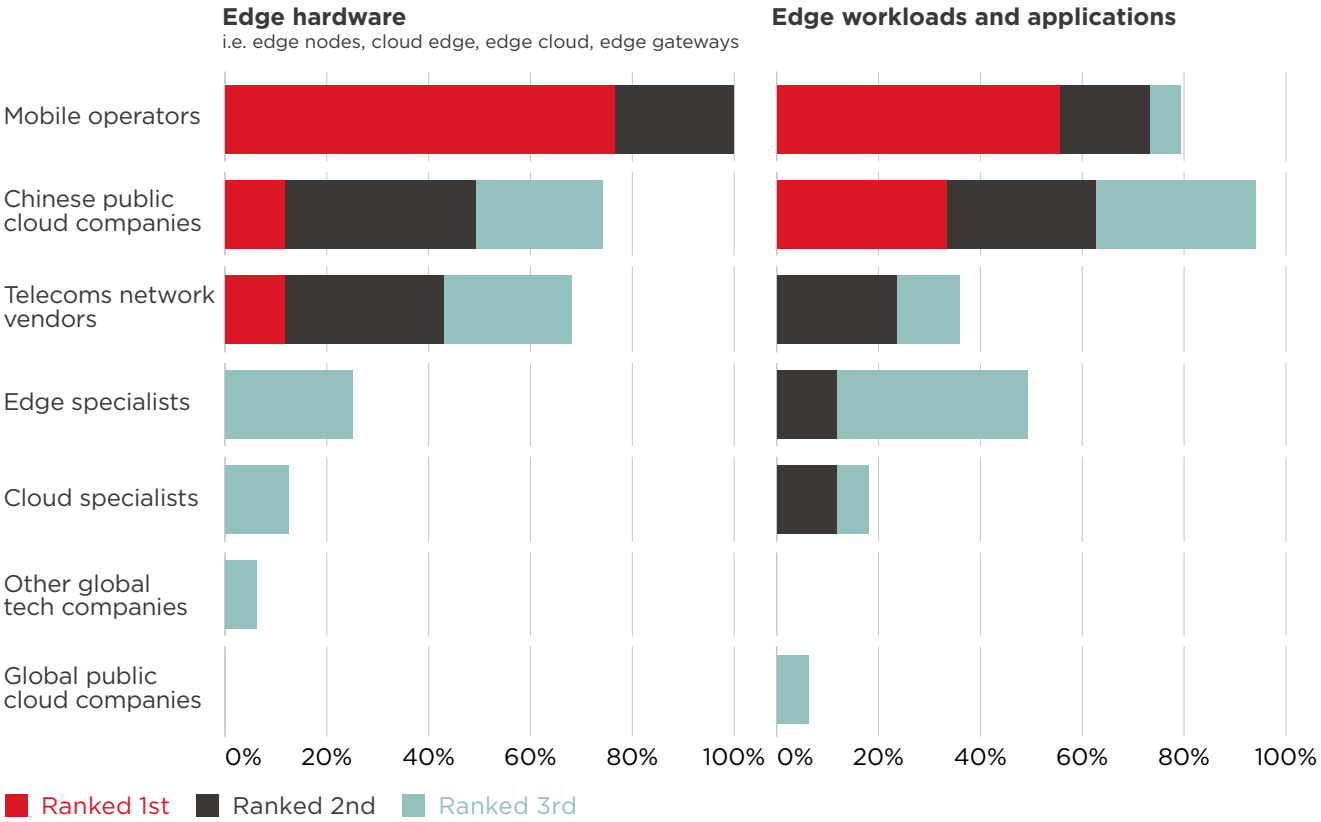
Edge hardware includes edge nodes, cloud edge, edge cloud and edge gateways that will enable edge services and applications. Since nodes could reside in multiple locations, multiple players could deploy them. It is also likely that individual companies will need to work with other stakeholders to site their nodes. However, there is widespread agreement in the Chinese edge computing ecosystem that the three Chinese operators will deploy and manage the largest portion of edge hardware, with cloud companies and telecoms network vendors also involved at scale (see Figure 17).

According to surveyed companies, owning large mobile infrastructure and network resources, coupled with established network operation teams, puts the Chinese operators in a favourable position to lead the deployment and management of edge hardware. Operators' intent to accelerate the rollout of standalone 5G networks in 2020 is also seen as a strength. In practice, there are many other technology and business factors that will determine the extent to which operators – or other edge stakeholders – will deploy and manage edge hardware at scale, and its location. Operators also need a supportive ecosystem to do this, with network vendors the closest partners.

There is a more balanced picture when it comes to deploying and managing edge workloads and applications, with both the Chinese operators and public cloud companies seen as the top candidates. For operators, fulfilling this role would be a natural extension of deploying edge nodes, allowing them to provide end-to-end solutions. Chinese cloud providers (Alibaba and Tencent) are already the de facto cloud service providers for enterprises. They have the advantage of owning extensive cloud assets, a history of doing so from the central cloud and a large number of enterprise users.

Figure 17

Deploying and managing edge technologies in the context of mobile networks



Questions: 1) Who will deploy/manage the largest amount of edge hardware (such as edge nodes, on-premise edge, cloud edge, edge cloud, edge gateways) that will enable edge services in China? 2) Who will deploy/manage the largest number of edge workloads and applications in China? These questions refer only to edge computing in mobile networks. Percentage of respondents

Source: GSMA Intelligence Edge Computing in China Survey 2019

How many edge nodes will ultimately be deployed in China?

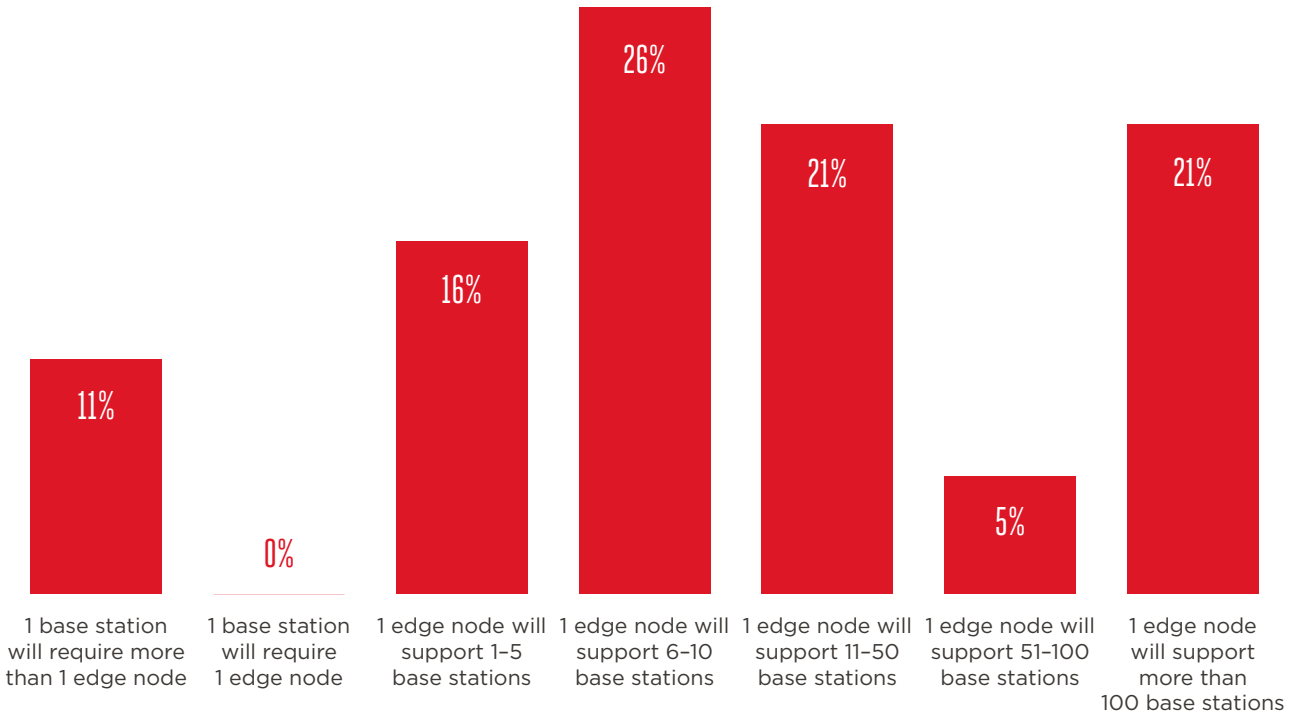
The number of edge nodes that will be deployed – which is also a function of the location of the edge analysed earlier – is a key factor in determining total ecosystem investment in edge computing. There is no clear view yet in China (as in other major countries). This comes as little surprise considering the technology is still in its early stages, and that the amount of edge hardware needed will ultimately be driven by developments in edge use cases.

Even on a five-year horizon, uncertainty remains, with most survey responses distributed across four options (see Figure 18). The fact that nearly half of companies expect one edge node to support between 6 and 50 base stations suggests that in the long term many edge nodes will be deployed near to base stations or at aggregation points (clusters of base stations). Physical space at many cell/aggregation/city core sites is limited and energy to power the additional equipment may not be easily available. There will also be a higher risk of theft in some locations for MEC equipment, so security costs may rise. From a cost perspective, an edge site supporting more base stations would significantly reduce the total cost of deploying edge technology, but if the distributed edge cloud reaches into the enterprise, the number of edge nodes will likely outnumber the number of base stations.

A possible scenario – which reflects considerations around cost of deployment, use cases and business circumstances – is that one edge node supports a limited number of base stations (i.e. less than 10) for use cases in smart campuses or similar 'closed' environments, while one edge node supports more than 50, possibly 100, base stations for public use case scenarios.

Figure 18

Base stations and edge nodes in China



Questions: In the long term (2025), how many base stations will an individual edge node support? Percentage of respondents.

Source: GSMA Intelligence Edge Computing in China Survey 2019

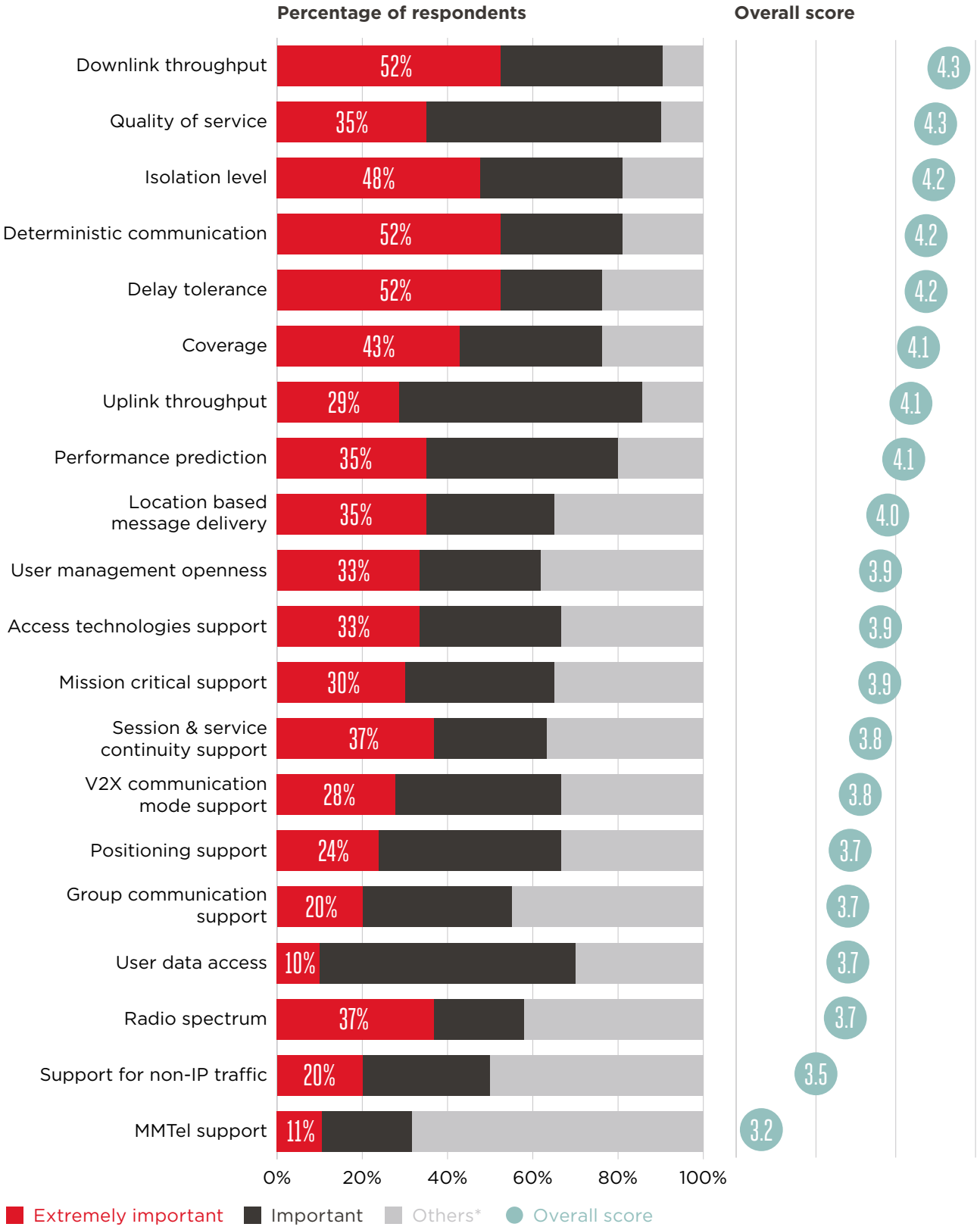
Which mobile network capabilities are most important for edge computing use cases in China?

Most mobile network capabilities shown in Figure 19 are important for a large number of edge computing use cases. That explains the high scores across most capabilities, ranging from 3.2 to 4.3 (on a scale of 1 to 5). However, surveyed companies highlighted the following capabilities – as well as quality of service, which applies more generally – as the most important for edge computing use cases.

- **Downlink throughput** (score of 4.3) ranked more highly than all other capabilities. The ability to have a high, guaranteed data rate in downlink, supported by the mobile network, is extremely important, especially for truly autonomous vehicles (level 4 and 5 autonomy) and their surrounding driving infrastructure, remote driving (tele-operated), and media & entertainment applications (on-location TV production and broadcasting, and immersive gaming and e-sports powered by AR/VR).
- **Deterministic communication** (score of 4.2) is increasingly important for use cases that have stringent latency and reliability requirements such as autonomous driving, industrial and vehicular automation, remote surgery and mission-critical applications. These use cases – belonging to a wider category of ultra-reliable and low-latency communications (URLLC) – create a need for upper-layer functionality to occur in much more deterministic and precise timing intervals, to deliver a defined range of latency, packet loss and jitter.
- **Delay sensitivity** (score of 4.2) is extremely important for cloud/edge gaming and e-sports, remote surgery, high-precision manufacturing and autonomous driving (truly autonomous vehicles and remote driving). However, there are services that have delay tolerance (for example, some of the connected vehicle features that are not linked to autonomous driving decisions), meaning real-time or near-real-time data transmission and processing are not particularly critical. Delay tolerance allows service delivery flexibility. For instance, the service could be delivered once the mobile network system has sufficient resources, during off-peak hours, or even at regular intervals such as at a specific time of the day or week.
- **Isolation level** (score of 4.2) is a key expectation in 5G networks, especially when linked to network slicing. For services running on individual network slices over a common, public network infrastructure, isolation could be a key network requirement. In this scenario, each virtual network slice should operate in isolation from other network slices. Some of the edge computing use cases may also have specific security and privacy requirements, such as applications where confidential data (personal or enterprise) may be stored or transmitted. In these situations, an isolated network slice can minimise the risk of data leaking outside the network, ensuring efficient transport of protected (encrypted and authenticated) data. Isolation is important particularly for industrial use cases, with energy and oil & gas notable examples.

Figure 19

Mobile network capabilities important for edge computing use cases in China



Question: Please rank the following mobile network capabilities based on how important they are for edge computing use cases in China. Percentage of respondents and overall score. The overall score ranges from 1 (very low importance) to 5 (extremely important).
* Others is the sum of 'moderately important', 'marginally important' and 'very low importance'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

3.5 Edge computing adoption in China: key use cases and timelines for ramp-up

The Chinese ecosystem is testing early edge technology across a range of use cases and industries. However, deploying edge computing at a greater scale will depend on the real need for computing capabilities at the edge.

5G and edge computing use case scenarios appear to be overlapping and mutually supportive. In practice, key edge computing use cases will largely rely on 5G, whereas many 5G use cases will develop independently from edge computing as they may not need capabilities at the edge. There is still uncertainty about edge use cases at scale, but our survey helped shed light on expectations within the Chinese ecosystem.

Use cases with the greatest need for edge computing in China

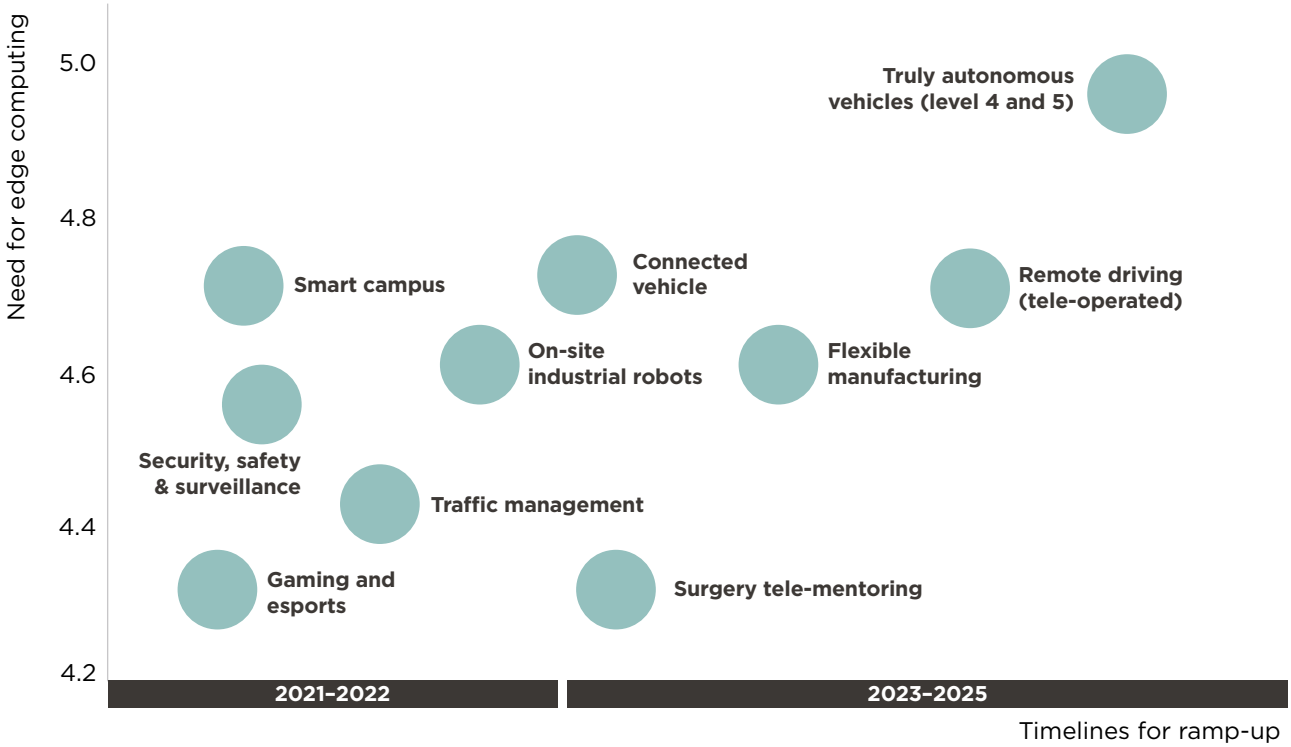
Edge computing is most suitable for use cases that require at least one (possibly all) of the following: ultra-low latency (usually less than 10 milliseconds of round-trip time); real-time processing for real-time computing, rendering and analytics; high-volume data transfers; and deterministic networking. Beyond technical requirements, security and data protection are also key factors in the drive towards edge computing.

As edge computing reduces the physical distance of communications nodes, latency can be reduced significantly while allowing real-time rendering and analytics to take place, and the bandwidth will be highly improved. Having the core functionality at the edge also allows a more efficient transfer of massive volumes of data, reducing network opex. However, use cases that are not very delay-sensitive, where aggregated analytics are more important than real-time analytics, or where high-quality data is preferred over a high volume of data would be more cost effectively addressed using the traditional fully cloud-based approach.

We asked Chinese companies to share their views on nearly 50 potential use cases for edge computing across more than 10 industries. Figure 20 shows the 10 use cases that – according to the Chinese ecosystem – have the greatest need for edge computing, as well as the expected timelines for ramp-up. Many of the top 10 use cases belong to the automotive and manufacturing sectors, with smart campus, gaming and e-sports, surgery tele-mentoring, and applications for smart cities also on the list. Figure 22 shows the results for all the use cases analysed.

Figure 20

Top 10 edge computing use cases in China



Questions: Which of the following use cases will have the greatest need for edge computing in China? When will edge computing deployments reach scale in China? Score ranges from 1 to 5 where 1 is 'very low need or no need at all' and 5 is 'very high need'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Truly autonomous vehicles have the greatest need for edge computing, but ramp-up will take time

Self-driving vehicles scored more highly than all other edge computing use cases, at 4.9 (on a range of 1–5). A level 4 or 5 autonomous car will rely on on-board computers to continuously process huge amounts of data and make autonomous driving decisions, including sub-second decisions. Given that cloud-based solutions do not allow for real-time processing in critical situations, augmenting on-board computers through edge computing and C-V2X technologies will provide the capabilities required to enable interaction with the wider ecosystem (see Figure 21).

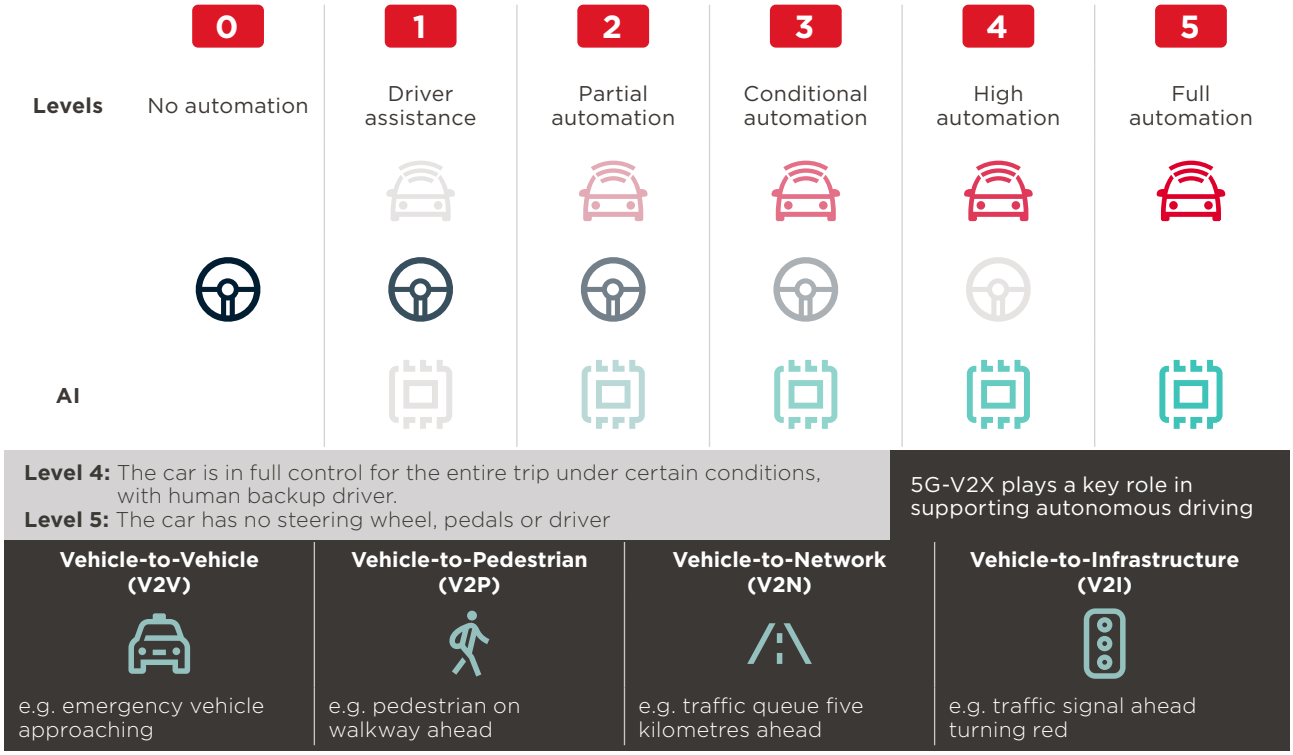
China is one of the first countries to deploy C-V2X, with more than 20 C-V2X projects already initiated. While 4G networks are enabling early C-V2X pilots and launches, 5G will enhance C-V2X and support larger-scale deployments. However, there are still open questions around the location of the edge. The vehicle itself could be a small edge node, but this is probably an expensive, difficult-to-scale solution.

As autonomous vehicles will be allowed only in predefined, pre-tested areas, most discussions are looking at edge nodes located in these regulated areas – for example, district-level edge computing centres connected to 5G.

Autonomous vehicles are the top use case for edge computing but ramp-up will likely occur in 2023–2025. Bringing level 4 and 5 autonomous vehicles (robotaxis, autonomous buses, and automated cargo trucks) to commercial deployment at scale presents a number of challenges that need to be addressed, including legislation and public perception. China also has a complex traffic environment which could slow adoption. Beyond autonomous driving, edge computing is being explored in the context of connected vehicles for features such as content caching for in-car entertainment (including in-vehicle AR/VR services) and real-time traffic monitoring and analytics as part of smart city deployments.

Figure 21

Autonomous driving – levels of vehicle autonomy and the role of 5G-V2X



Source: GSMA Intelligence, SAE and NHTSA

Digitisation and automation of manufacturing offer a range of use cases for edge computing

Two of the top 10 edge computing use cases in China come from the manufacturing sector: on-site industrial robots and flexible manufacturing.[11] These are part of a wider trend of digital-based reconstruction of Chinese factories, aiming to improve production efficiency, boost accuracy in quality detection, and reduce factory operations and management costs. China's economy is highly reliant on the industrial sector (accounting for 41% of GDP), making productivity increases essential.

The shift to automate processes in high-tech manufacturing (Industry 4.0) depends on low-latency connectivity to satisfy precision thresholds and real-time analytics. 5G theoretical standards are for sub-1 ms roundtrip, which is attractive when combined with the option of a network slice offering guaranteed QoS to factory owners. Achieving that latency will require edge computing infrastructure where servers sit in close proximity to (or ideally inside) factories. Also, factories use a diverse range of devices (cameras, robots, machines and sensors) to perform operations. Most of these need to work in coordination with each other. In an edge scenario, the data gathered by a factory device is transmitted to the edge platform through the mobile network, and the edge platform interoperates with the factory management system.

The ultimate goal would be an autonomously controlled factory. Changying Precision Technology Company, a Chinese mobile phone factory, has provided an early template for such a design; it has shifted 90% of its production line to automated robots.

Gaming and e-sports will be among the first edge use cases to ramp up in 2021–2022

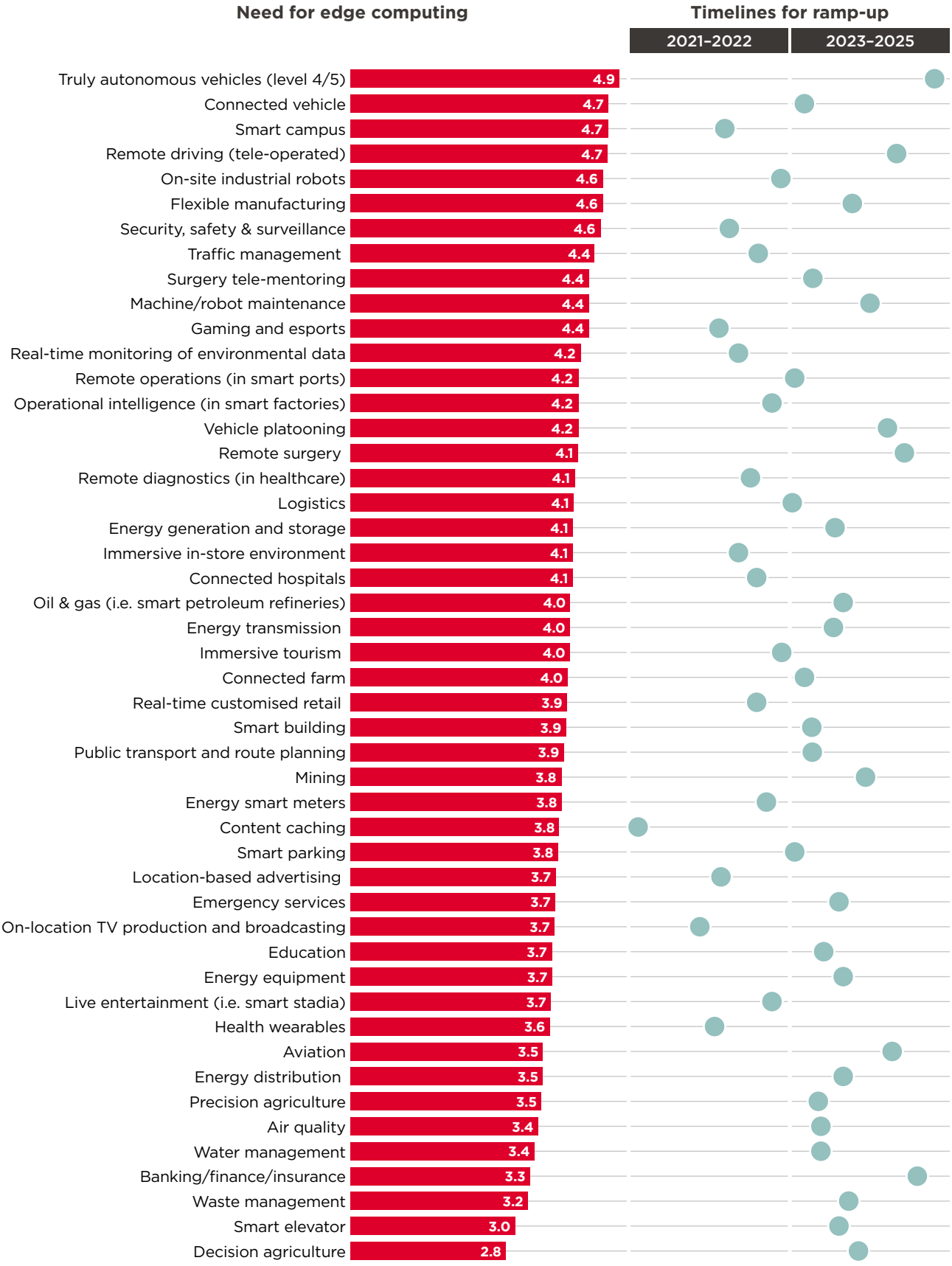
According to surveyed companies, the top two benefits for consumers associated with edge computing are enhanced gaming experience via AR/VR and more powerful and enriched e-sports. As gaming and e-sports become more immersive, interactive and data-intensive, the need for edge computing comes from three factors: ultra-low latency to annul delays, real-time processing to power real-time content, and the ability to deal with large volumes of data that need to be processed closer to the user.

Given the real-time nature of immersive gaming, the latencies required for a solid user experience align with 5G and workloads at the edge. Cloud functionality may be distant for some of the more immersive applications, and locating all the computing capabilities in the device would not be practicable from a real-estate and design perspective. Also, if most of the computational task is offloaded to the edge, the VR/AR headset does not have to be as high quality. Given the content involved, storing content at the edge also drives backhaul efficiencies.

11 On-site industrial robots include autonomous or semi-autonomous robots that execute routine processes with high accuracy (manufacturing, warehouse, inventory tracking). Flexible manufacturing involves a range of features such as virtual control of machines and robots, remote real-time or near-real-time manufacturing, easy configuration control network, real-time orchestration and remote control.

Figure 22

Potential use cases for edge computing in China



Questions: Which of the following use cases will have the greatest need for edge computing in China? When will edge computing deployments reach scale in China? Score ranges from 1 to 5 where 1 is 'very low need or no need at all' and 5 is 'very high need'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Media & entertainment

EXAMPLES OF EDGE COMPUTING SOLUTIONS INVOLVING MOBILE OPERATORS AND MOBILE NETWORKS

Smart tourism

China Mobile

In September 2019, China Mobile, CAS-VISION and Huawei unveiled a commercial 5G MEC + cultural tourism project, to deliver a new tourism model built around the integration of technology and culture.

The project – named Wonderland of Mountains and Rivers – uses 5G networks and Huawei's Kunpeng (an ARM-based server CPU) computing platform. Kunpeng interacts in real-time with sensors to perform a combination of lighting effects and virtual scenes in real time. Mobile replaces fixed to transfer data in real time, accelerate time to action, and ensure the security and reliability of data.

Cloud/edge gaming and sporting events

China Unicom

China Unicom has deployed a cloud gaming solution in Shanghai and Guangdong that involves installing the MEC edge service platform at the edge of a mobile network, closer to user terminals, with distributed servers connected to the 5G MEC edge cloud platform.

A terminal (smartphone or gaming device) accesses the local application content on the MEC edge service platform through the gNodeB or 5G NR. Some of the intensive features such as video transcoding, graphics computing and rendering of cloud gaming are performed locally. There is no need to transmit service flows through the core network and process them over the cloud. Key benefits are reduced latencies and improved video experience. It also eliminates the need to download and update large game installation packages.

China Mobile

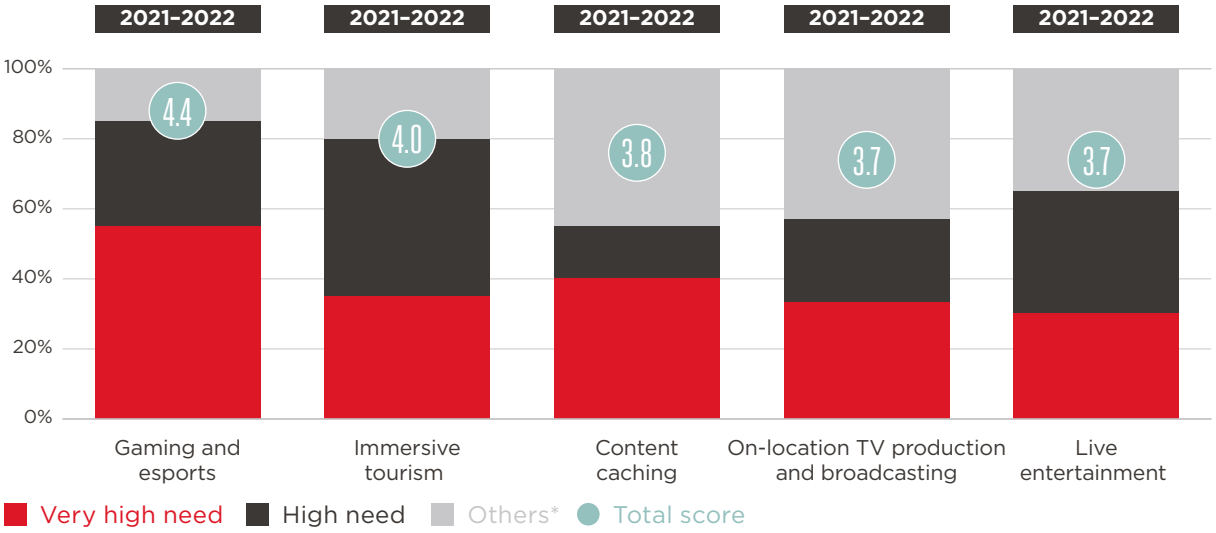
In August 2019, ZTE and the Shanxi branch of China Mobile broadcast the 2nd National Youth Games of China with integrated 5G Live TV solutions, powered by MEC. This reduces the live end-to-end latency to less than 1 second, so that the off-site audience can experience the games in real time. This is an example of how future live streaming of sporting events will benefit from the combination of 5G, MEC and 8K/VR/AR video technologies.

In 2017, China Mobile Beijing and Huawei also announced the launch of a pilot project for a smart stadium at Beijing South Railway Station, based on MEC. This allows China Mobile to integrate specific video content sources into the edge gateway of the smart stadium.

Media & entertainment

SURVEY RESULTS

Media & entertainment



Timelines for ramp-up

Questions: Which of the following use cases will have the greatest need for edge computing in China? When will edge computing deployments reach scale in China? Percentage of respondents and total score. Total score ranges from 1 to 5 where 1 is 'very low need or no need at all' and 5 is 'very high need'. *Others is the sum of 'moderate need', 'low need' and 'very low need or no need at all'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Manufacturing and ports

EXAMPLES OF EDGE COMPUTING SOLUTIONS INVOLVING MOBILE OPERATORS AND MOBILE NETWORKS

Smart manufacturing

China Telecom

In October 2019, the Zhejiang branch of China Telecom together with ZTE launched a 5G slicing manufacturing solution for Bluetron. A 5G standalone site was used to trial 5G network slicing, edge computing and smart manufacturing solutions to help Bluetron build a new 5G smart factory. The use of slicing and edge technologies (such as industrial cameras and edge computing gateways deployed on the production line) helps reduce the latency, jitter and packet loss rate of video data transmission. It also guarantees the bandwidth and quality of video transmission, and improves the accuracy and real-time performance of video analysis results.

China Mobile

In June 2019, Ericsson and China Mobile demonstrated an Automated Guided Vehicle (AGV) prototype on a standalone 5G network. The prototype shows how AGV helps automate product testing using a 5G network. The AGV application systems are deployed on edge cloud. The forwarding plane for edge computing is used to divert traffic locally. AGV applications can leverage the powerful computing capability of edge clouds to make in-depth analyses of test data, improve efficiency and integrate data from other manufacturing systems.

China Mobile

The GSMA, China Mobile, Huawei, MStar and Haier have completed a proof of concept encompassing the deployment of edge computing, 5G and machine vision into a manufacturing environment.[12]

Huawei and China Mobile implemented a 5G-connected MEC architecture inside the Haier factory to enable high-volume image processing with minimal latency to ensure no delays to the production line. The edge server is used to host the machine vision application from Mstar and all data processing is conducted within the production facility.

The Huawei MEC Platform (MEP) works to dynamically allocate and adjust available resources so that the machine vision application is able to operate at maximum efficiency the whole time and the data processing workload on the server can be efficiently managed. Additionally, MEP sends data analytics reports to end users for tracking. 5G enables efficient MEC deployments as the user plane and control plane functions can be separated. In this use case, 5G network functions could be moved closer to the production line, resulting in reduced latency and improved reliability of data packet delivery.

A number of benefits have been recorded through the duration of the proof of concept, including improved implementation times, reduced space and resources required (compared to legacy solutions), and improved product quality monitoring.

Smart ports

China Unicom

China Unicom is working to build smart and automated ports in various locations, including the Jiangyin port in Fuzhou, the Qingdao port, and the Tianjin port. This involves using MEC and mobile networks to deploy fully connected, low-latency and high-bandwidth networks.

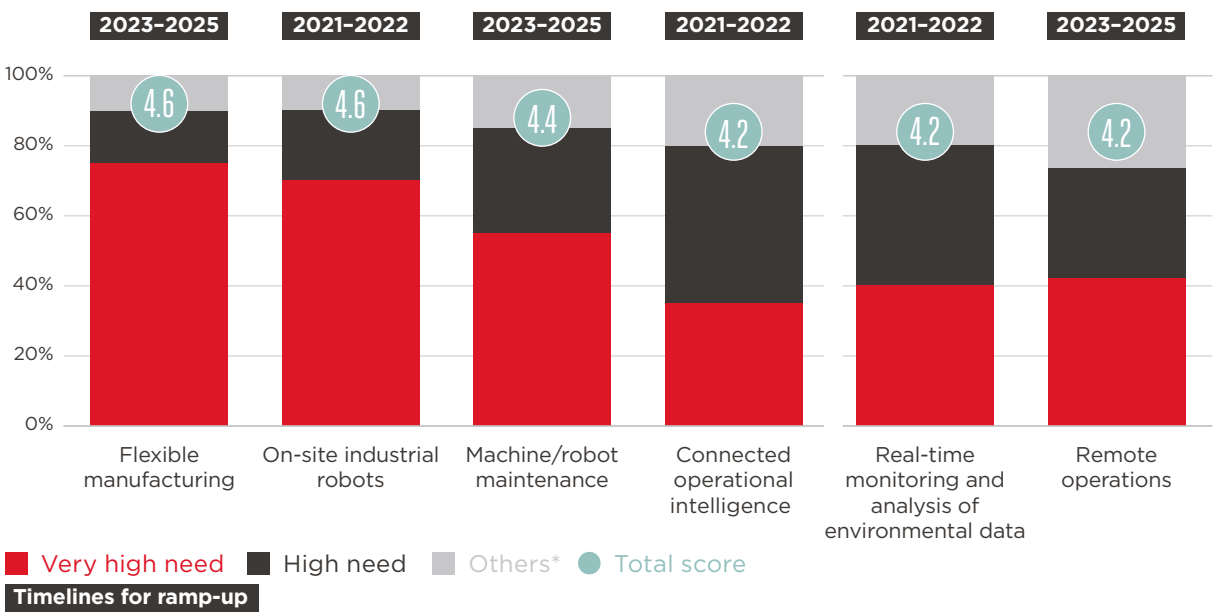
The MEC platform is directly deployed in ports, greatly reducing the network transmission latency. This solution also provides HD video surveillance for bridges, containers and transportation vehicles through automatic video analysis, automatic container scheduling, security protection and other applications.

In the production environment, cranes are remotely operated to deliver containers, provide smart services for ports, realising industrial control with millisecond-level latency. MEC is fully integrated with various port transportation elements, and works with port applications to improve the operations efficiency of the wharfs as well as the user experience and data security of ports.

12 "Haier: Optimising Manufacturing performance through 5G, Edge Computing and Machine Vision", GSMA, February 2020

Manufacturing and ports

SURVEY RESULTS



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Source: GSMA Intelligence Edge Computing in China Survey 2019

Automotive

EXAMPLES OF EDGE COMPUTING SOLUTIONS INVOLVING MOBILE OPERATORS AND MOBILE NETWORKS

Autonomous driving

China Unicom

In 2018, China Unicom and Geely Automobile signed a partnership in the Zhejiang province to integrate China Unicom's MEC and 4G/5G networks with Geely's driving private cloud platform through private lines. The aim is to power autonomous driving features and a range of vehicle analytics.

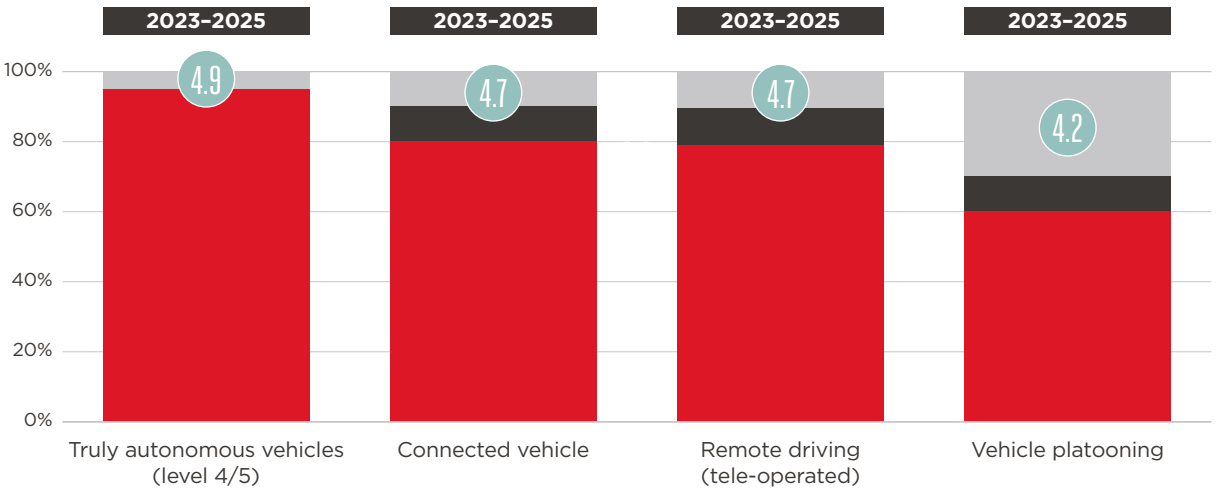
The solution provides real-time and high-speed upload of vehicle surveillance videos and driving behaviour, helping vehicle manufacturers accurately analyse and understand the running status of important components of vehicles and driver behaviour. The solution also pushes dynamic HD maps and navigation information in real time and at high speed, enabling accurate driving assistance to be provided to drivers.

China Telecom

In March 2018, ZTE, together with China Telecom and Baidu, completed China's first road test for autonomous driving based on a 5G network environment in Xiong'an.

SURVEY RESULTS

Automotive



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Source: GSMA Intelligence Edge Computing in China Survey 2019

Other industries

EXAMPLES OF EDGE COMPUTING SOLUTIONS INVOLVING MOBILE OPERATORS AND MOBILE NETWORKS

Oil & gas

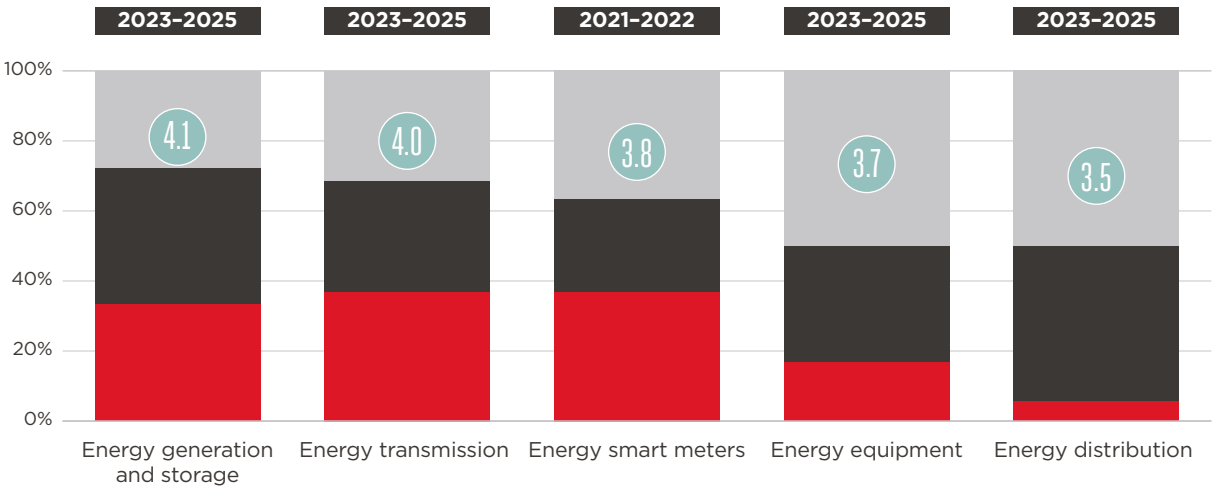
China Telecom

China Telecom is working with Zhenhai Refining and Chemical Company (ZRCC) – a subsidiary of China Petroleum & Chemical Corporation, one of the largest integrated energy and chemical companies in China – to build a MEC network as part of a wider project of creating a smart petroleum refinery in Ningbo.

China Telecom's MEC network will be based on Huawei's cloud/edge technology. The technology uses a cloud-native architecture and positions the network functions and third-party applications at the network edge so applications and content are processed closer to the user. China Telecom plans to use Huawei's technology for services such as video surveillance, mobile office, and on-site data collection and transmission. When the MEC network is complete, a registered user with ZRCC will be able to access both the private enterprise network and the public network. The first phase of the project adopted 4G and MEC to build a virtual private network. The second phase considers the integration of 4G and 5G, with 4G the main carrier at the initial stage and 5G a supplement for hotspots.

SURVEY RESULTS

Energy



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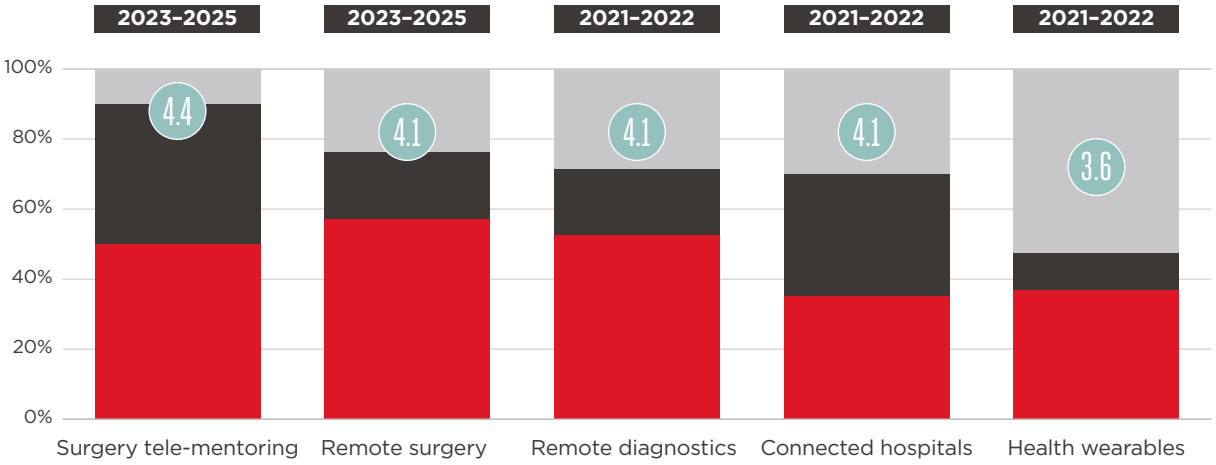
Source: GSMA Intelligence Edge Computing in China Survey 2019

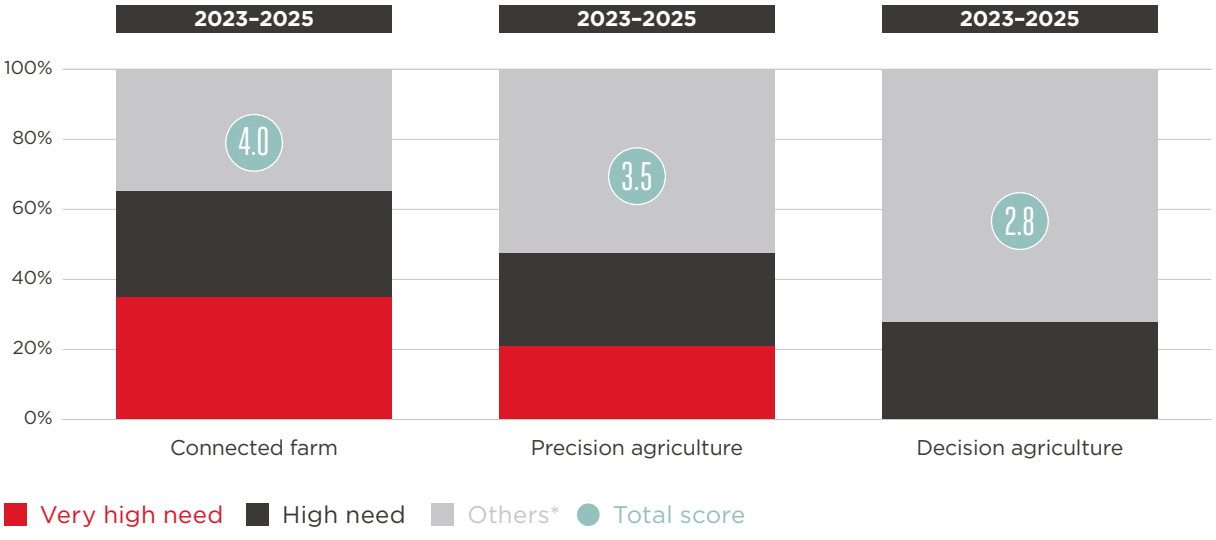
Other industries

SURVEY RESULTS

Healthcare



Agriculture



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Source: GSMA Intelligence Edge Computing in China Survey 2019

3.6 Opportunities and challenges for the Chinese edge computing ecosystem

Judging from the pace of trials and initial deployments, it is clear that many Chinese companies are looking to explore opportunities in the early stages of edge computing. However, different categories of company are coming at edge computing from different angles in terms of opportunities and challenges.

Opportunities and challenges by company type

Major cloud companies: Alibaba, Tencent and Baidu

For major cloud providers, edge technology fits well as an extension of their cloud capabilities and offerings, to serve a range of use cases that require storage, computing and networking closer to the device generating or consuming the data. Alibaba Cloud has already completed the deployment of more than 300 edge computing nodes in 30 provinces in China, and all three cloud players have edge computing platforms commercially available (Alibaba's ENS, Baidu's OpenEdge and Tencent's Smart Edge Connector). Major cloud companies come at edge computing with experience in working with Chinese enterprises of all industries, and extensive cloud resources to build on. However, an edge computing ecosystem increasingly built on 5G poses new challenges to cloud companies, taking them into a new world of distributed computing that involves mobile connectivity and devices on a larger scale.

From a technology perspective, edge/cloud orchestration is one of the new challenges. Cloud companies will need to engage in a decentralised ecosystem that powers distributed storage/processing and more localised access to data. A high level of coordination between the cloud and edge is required to extend cloud processing across different edge sites, challenging cloud companies' ability to provide a seamless experience to end users.

This cloud/edge coordination is extremely important for applications that rely on real-time data processing and decisions, such as remote surgery, high-precision manufacturing and autonomous driving. Cloud companies therefore need to work closely with edge infrastructure providers and operators to build integrated cloud/edge/network interfaces and ensure consistent levels of quality of service to enterprises. Co-locating their equipment or hosting their applications in operator cloud/edge/network infrastructure may be an option in certain scenarios.

Major telecoms network vendors: Ericsson, Huawei, Nokia and ZTE

For the leading telecoms network vendors in China, edge computing introduces new opportunities to strengthen market positions in the 5G ecosystem, adding an extra layer of technology to future network architectures. As the integration of new technologies such as edge computing and AI into core and access networks grows in scale and complexity, vendors will increasingly be seen as a much needed partner for Chinese operators looking to incorporate edge computing into their network transformation roadmaps on a larger scale.

Ericsson, Huawei, Nokia and ZTE are working closely with the Chinese operators, cloud companies, application developers and other partners to promote the deployment of edge computing across vertical industries. The challenge for vendors is to design not only truly seamless end-to-end network transformation solutions that can operate in all cloud and edge scenarios, but also to develop a new B2B2B approach (vendor–operator–enterprise) on a larger scale, to help bridge the ICT and vertical industry worlds.

Operators: China Mobile, China Unicom and China Telecom

Chinese operators are at the centre of discussions around edge computing because of their connectivity and platform resources, and strong commitment to roll out the access technology that will drive most edge use cases (5G). To a large extent, the move of part of the computing power from the cloud to the edge could be seen as an operator-centric technology shift. If the ecosystem expectation materialises that the three Chinese operators will deploy and manage the largest amount of edge hardware, and a significant share of edge workloads, there will be opportunities for operators to take a growing role in the edge value chain. Edge computing also fits well with a wider, ongoing strategy of cloudification of the network, allowing Chinese operators to strengthen their presence in the cloud market. China Mobile, for example, aims to become a first-tier cloud service provider in China in three years.

Finding the right business model for edge computing is one of the top challenges for the Chinese operators. This is discussed in the next section, alongside considerations for edge rollouts and revenue models.

Other edge players: smaller network vendors, cloud & edge specialists, start-ups and developers

For many other Chinese companies currently involved in the edge value chain, edge computing may open up new opportunities to work with small to medium-sized enterprises at provincial or city levels and with the Chinese operators, by supplying the edge technology (hardware, software) required by specific use cases, or even new service models. Those fully focused on computing (whether cloud, edge or both) can be more agile and innovative, but offering end-to-end solutions may be challenging. Their business success will also largely depend on the pace and magnitude of edge computing developments over the next five years.

Edge computing opens up new opportunities and challenges for developers. The opportunity is in developing not only new edge applications that run on standard edge APIs (i.e. MEC APIs) but also customised applications to cooperate with devices and cloud. Compared to a traditional programming model designed to run on centralised architectures, edge computing requires a shift towards new tooling and programming languages that can operate over multiple systems. The work of developers in an edge computing world will likely be more complex than in a traditional fully-cloud based world, as they need to deal with new edge parameters, device types and network requirements.

New revenue versus operational efficiencies

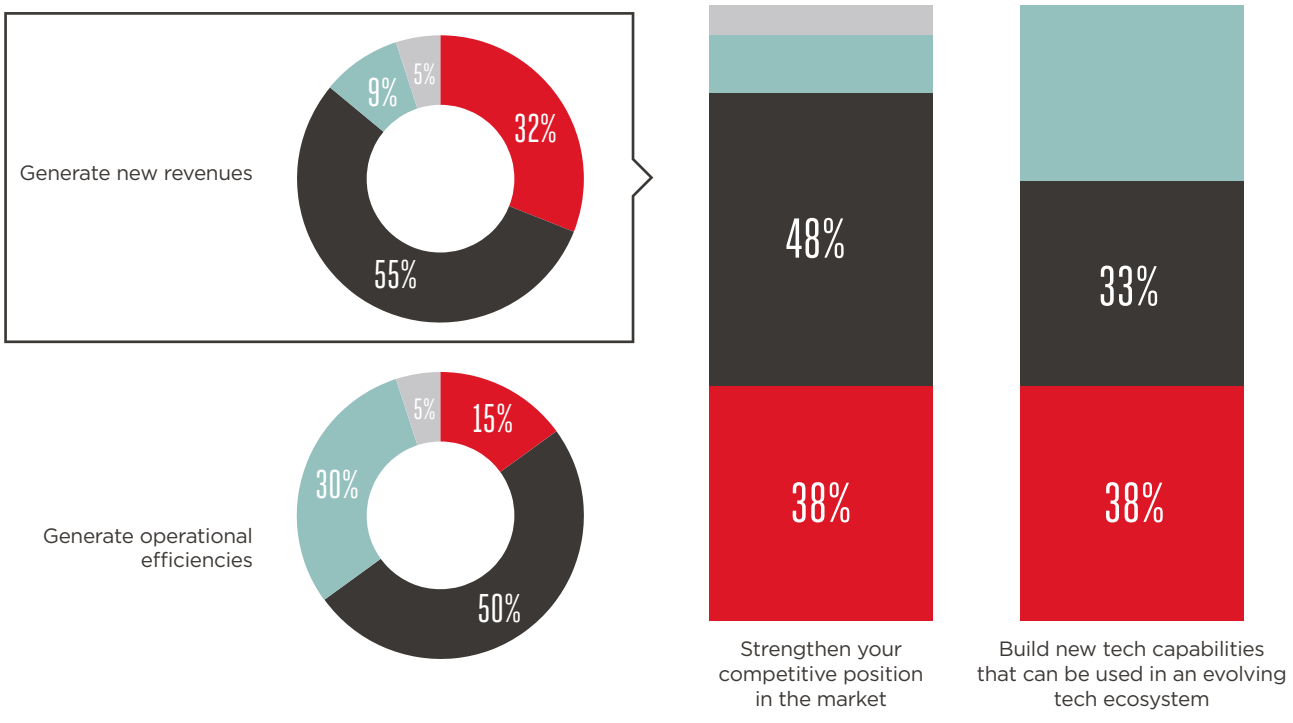
New revenue dominates edge thinking in China, with nearly 90% of surveyed companies seeing edge computing as an opportunity to generate incremental revenue in the 5G era (Figure 23). For most, the expectation is to generate new revenues by supplying the edge technology (hardware, software and platforms) required by edge use cases, and/or providing end-users with edge services and applications. Beyond the direct contribution of edge computing to new revenues, there are indirect benefits for the traditional core businesses, whether cloud or telecoms. Providing an expanded portfolio of services helps strengthen competitive position in the market, by building new technology capabilities that can be used in an evolving tech ecosystem.

Edge computing as a tool for generating operational efficiencies appears to be less of an opportunity, but only on a relative basis. This comes as little surprise – all the new technologies are often justified by hopes of revenue generation. However, two thirds of surveyed companies expect to generate edge computing value from operational efficiencies also.

For the Chinese operators, network capex and network opex are the largest individual sources of cash out, accounting for around 45% of total revenue (in aggregate for the three operators). Of this, around 20% is capex and around 25% opex. As such, deploying edge to help optimise network operations and deliver services in a cost-effective way is as important as undertaking new initiatives targeting incremental revenue. One obvious rationale is to increase network cost efficiency. As traffic loads increase in the IoT and 5G eras, the more processing that can be handled at the edge, the more money can be saved on transport to central cloud servers. In practice, it is not binary – incremental value will come from both new revenues and operational efficiencies.

Figure 23

Edge computing opportunities in China: new revenues versus operational efficiencies



Question: What are the main opportunities for your company associated with edge computing in mobile networks in China?
Percentage of respondents .

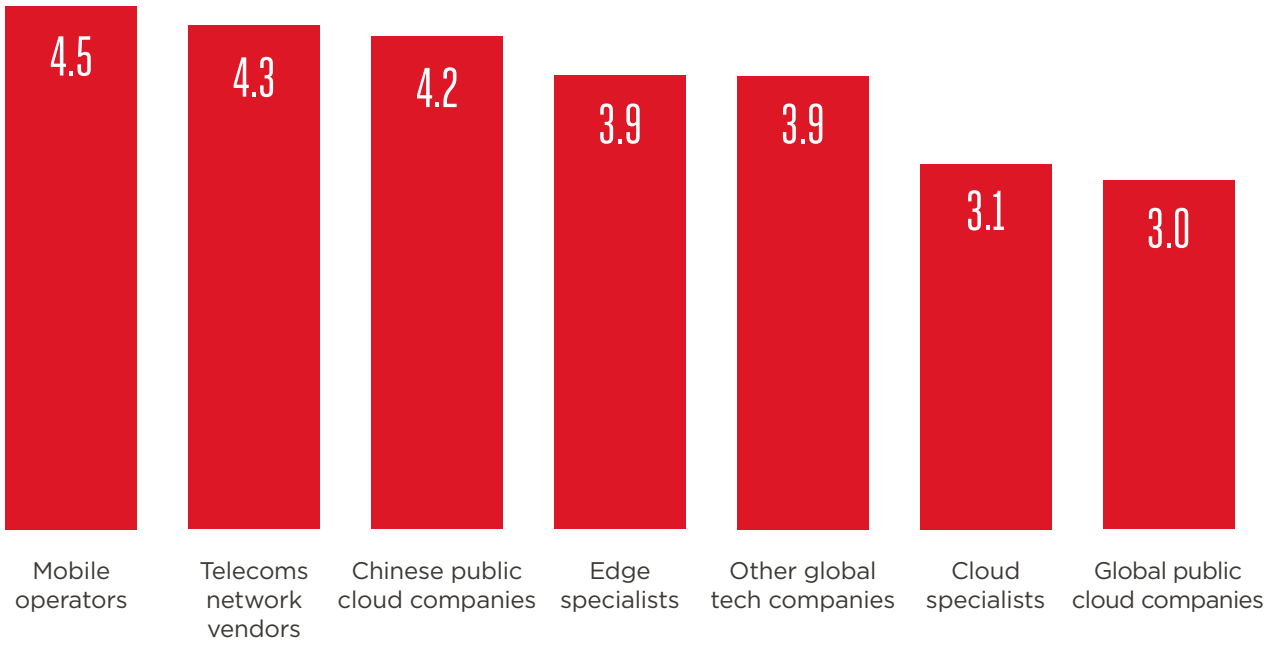
Source: GSMA Intelligence Edge Computing in China Survey 2019

Generating revenue from edge computing in China: who will gain and when?

There is widespread agreement in the Chinese ecosystem that many players will be able to get a share of the nascent edge computing revenue, with operators, network vendors and public cloud companies at the forefront. However, there is also agreement that generating edge revenue at scale will take time.

Figure 24

Revenue opportunity associated with edge computing in China



Question: In the long-term, who will generate the most revenue from edge computing in China? Overall score, ranging from 1 (very low value) to 5 (very high value).

Source: GSMA Intelligence Edge Computing in China Survey 2019

It is difficult to size the long-term revenue opportunity associated with edge computing in China. The technology is still in its early stages and there are a range of open questions around use cases and business models. There are also two major edge revenue components to consider – one associated with the initial deployment of edge computing infrastructure (largely a one-off component plus maintenance) and one from edge-related services such as analytics, security and storage, delivered through edge platforms (a recurring source of revenue).

High-level analysis based on the size of the Chinese cloud computing market[13] and a number of views and data points shared by surveyed companies suggest that edge computing may generate between RMB7 and RMB13 billion ($1 and $2 billion) in annual revenue for the Chinese edge computing ecosystem by 2025, accounting for less than 5% of cloud computing revenue. In the long term, a best case scenario suggested by one of the surveyed companies would see edge computing generating up to 30% of cloud computing annual revenue. Assuming that this scenario materialises 15–20 years from now, we can infer that edge revenue would reach RMB40–50 billion ($6–7 billion) at the beginning of the 2030s.

There is also a question as to whether edge computing is incremental or a substitute to cloud. Given that edge computing is designed to serve new use cases at the edge, it will most likely be a complement at least in the first five years, with substitution limited to a few areas. Cloud computing (public and private clouds) focuses on non-real-time and long-period big data analysis,

13 According to a white paper released by the CAICT, cloud computing revenue in China will grow from RMB96 billion ($14 billion) to RMB290 billion ($42 billion) between 2018 and 2022. Public cloud will be the main driver of growth, reaching RMB173 billion ($25 billion) by 2022, a four-fold increase. Private cloud will grow at a slower pace, reaching RMB117 billion ($17 billion) by 2022, a two-fold increase.

whereas edge computing focuses on real-time and short-period data analysis.

It is also difficult to predict what percentage of such potential edge revenue (RMB40–50 billion or $6–7 billion at the beginning of the 2030s) Chinese operators will be able to take. In the cloud market, the Chinese operators in aggregate are likely to have around a 10% share of revenue (with China Telecom leading). As the edge computing ecosystem will be mostly centred on 5G, operators may take a significantly higher than 10% share of the nascent edge revenue.

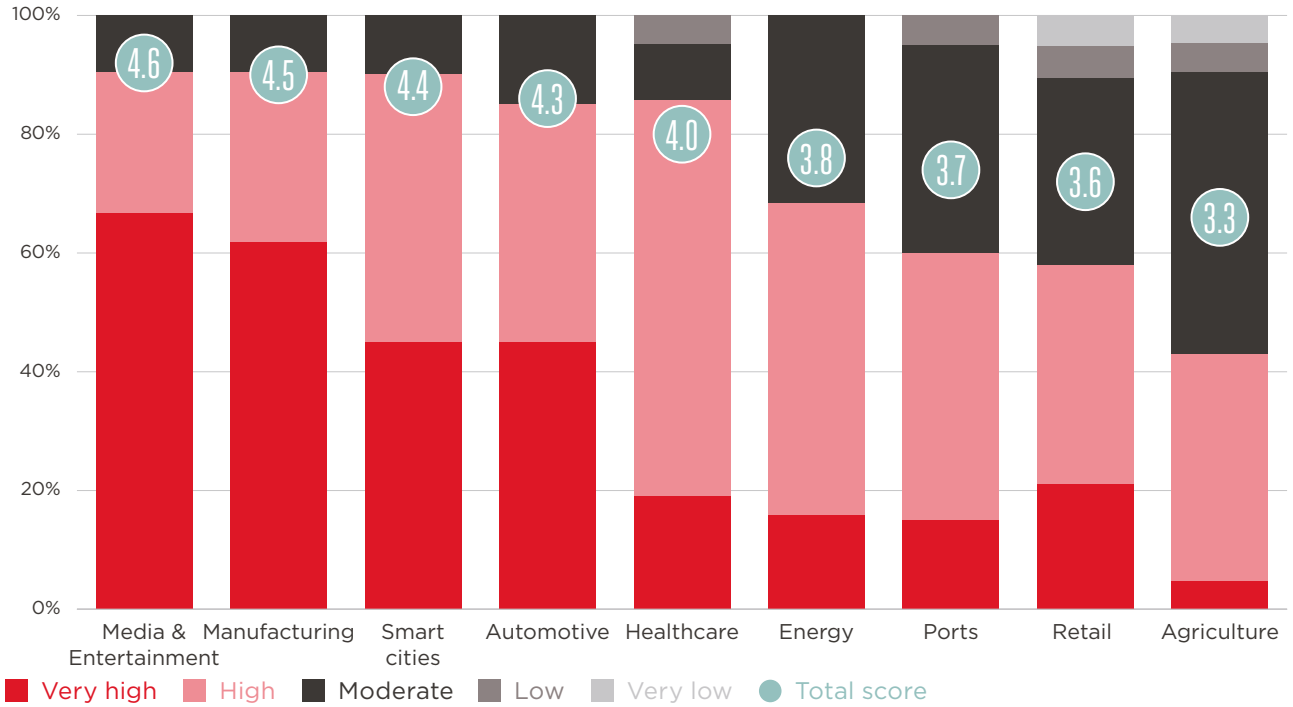
Sizing the edge computing revenue opportunity by sector

The Chinese ecosystem sees media & entertainment and manufacturing as the top two sectors, with smart cities and automotive following closely behind (Figure 25). This likely reflects a range of industry-specific or macroeconomic factors that will be either fundamental drivers of edge computing deployments (i.e. 5G network coverage and adoption, and growth in industrial IoT) or indicators of the wider momentum in digital transformation of industries.

The government's ambition to make China a leading country in new technologies and Industry 4.0 also plays a crucial role: manufacturing and automotive are some of the targeted key sectors in the 'Made in China 2025' strategic plan. The presence of consortia promoting cross-sector cooperation is another driver. Notable examples include the ECC, the 5G Automotive Association (5GAA) and the Alliance of Industrial Internet (AII).

Figure 25

Revenue opportunity associated with edge computing in China



Question: Which of the following sectors provide the largest revenue opportunity associated with edge computing in China? Percentage of respondents and total score. Total score ranges from 1 to 5 where 1 is 'very low revenue opportunity' and 5 is 'very high revenue opportunity'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Key barriers to realising the edge computing opportunity in China

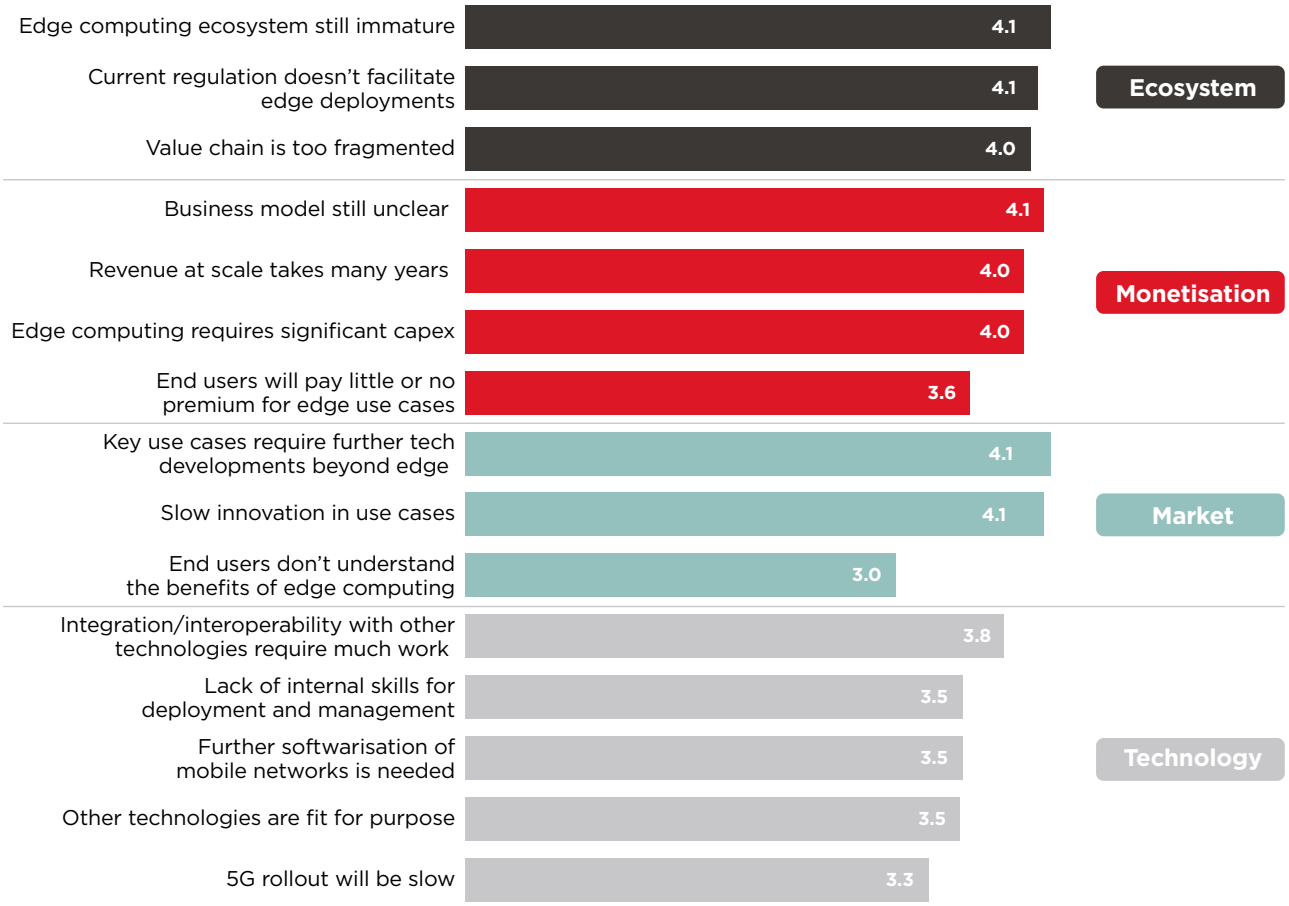
As with other emerging technologies, it is natural for the Chinese ecosystem to see the immaturity of the edge computing ecosystem as one of the top barriers (see Figure 26). Edge computing technology is still in its early stages, edge stakeholders are learning from the first wave of trials, and many use cases are still work in progress. The value chain is also fragmented, with different categories of stakeholder coming at edge with different strategies and roadmaps. Bridging ICT and vertical industries takes time, especially for highly regulated sectors such as energy and healthcare.

Uncertainty around monetisation and business models is another key barrier. Edge computing adds an extra source of network investment in the 5G era, with revenues likely to ramp up in five years or beyond.

Market adoption of edge-powered applications will also depend on technology developments in some of the key use cases such as autonomous driving and immersive reality. Slow movement from level 3 to level 4 of vehicle autonomy or a lack of commercially available content specifically designed for AR/VR are notable examples of factors that could slow edge deployments. From a technology perspective, there are a range of barriers and open questions, but overall these barriers had lower scores compared to those related to monetisation and ecosystem/market developments. This denotes a general confidence – at the ecosystem level – in being able to leverage existing technical and human skills to drive integration with other technologies, but it is also the result of a wider Chinese ecosystem push on 5G networks as a driver and enabler of edge.

Figure 26

Barriers to scaling edge computing in mobile networks in China



Question: To what degree are the following factors barriers to scaling edge computing in mobile networks in China? Total score ranges from 1 to 5 where 1 is 'very low barrier" and 5 is 'very high barrier'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

3.7 The edge computing business model for the Chinese operators

Much of the edge computing opportunity for China Mobile, China Telecom and China Unicom lies in the wider trend of digitisation of services, enterprises and industries.

To a large extent, this can be seen as a natural subset of the wider 5G opportunity in the enterprise market, with 5G playing a dual role of enabler and driver of edge computing use cases. From a practical perspective, this entails Chinese operators deploying not only high-speed/low-latency 5G networks but also some of the edge technology needed to serve edge use cases in the 5G era. Some opportunities may require siting edge hardware within an enterprise for bespoke implementations (for smart factories, smart campuses and smart ports); others may require delivering enterprise-specific services and applications from an edge node located in more central areas (for immersive gaming, smart cities and autonomous driving).

From a revenue perspective, the enterprise market is not new to Chinese operators. However, enterprise has mostly been about providing fixed and mobile connectivity so far, augmented by a range of managed services and ICT solutions. For China Mobile – which claims to have nearly 40% revenue share in the Chinese corporate market (2018 figures) – enterprise revenue accounts for 12% of total service revenues, but most of it is generated by voice and data traffic. Recent trends in the Chinese market show that enterprise connectivity revenue is growing slowly and those new services generate an amount of revenue that is still too small to make an impact on overall operator financials.

As we look to the 2020s, a new enterprise growth story is needed for Chinese operators. 5G provides an opportunity to target the digital transformation of industries and enterprises on a larger scale, pushing the boundaries beyond connectivity. This involves supplying premium infrastructure, such as edge computing and network slicing, and new services beyond connectivity. This introduces new challenges. Firstly, enterprise services beyond connectivity are a relatively new market for the Chinese operators, so getting the capabilities (5G standalone networks, network slicing, edge computing, spectrum) in place to fully service enterprises will take time. Some of the more promising edge computing use cases, such as autonomous driving and smart manufacturing, also require greater technology maturity beyond the connectivity/platform layer.

Secondly, edge computing brings the two major infrastructure-based industries of the ICT world – cloud computing and telecoms – into competition for Chinese enterprises seeking to digitise an increasing proportion of their operations and services. Providing customised network functionality is key to serving various verticals, but Alibaba, Tencent, Baidu and other cloud players are targeting the same opportunity. The three Chinese operators have a smaller presence in the cloud market than Alibaba and Tencent, so extracting new use cases from the integration of cloud, edge and core telecoms networks (mobile and fixed) offers more promise. Network slicing adds further possibilities, by reserving defined slices of network capacity for a particular enterprise customer (e.g. a smart factory or smart port). There are already examples of such initiatives in China. Opening up the 5G network itself to third-party developers is another opportunity, with the aim of catalysing an ecosystem of 5G service development at the edge of the network.

Edge computing rollout will occur in phases

Edge deployments by the Chinese operators are likely to come in three phases, reflecting the gradual rollout of 5G networks, the speed of developments in the digitisation of industries and enterprises, and the maturity of edge use cases.

Wave 1 (2018–2020): trials and bespoke small-scale deployments

The large number of edge computing trials conducted by China Mobile, China Telecom and China Unicom during 2018–2019 offers a significant base to build on. Edge trials will continue to grow in 2020 across various industries, with some turning into small deployments. In this wave, edge deployments are mostly private, bespoke implementations, specifically designed to serve enterprise requirements such as in smart ports, smart campuses or smart factories, with edge technology largely sited on-premises. Edge trials and demonstrations for public use cases such as live entertainment (smart stadia) are also happening in this phase, though at a limited scale.

Market education is key in this wave, to bring enterprises on board. This includes not only explaining the benefits of edge computing in a technical language that is accessible to Chinese enterprises, but also showing evidence of how edge deployments are benefiting similar companies, centred on the specific painpoints that the technology addresses. The usefulness of edge computing is not a given; it needs to be proven for each use case scenario. From a network perspective, Chinese operators need to establish 5G as the lead access technology for edge use cases, presenting its benefits compared to alternative technologies such as fixed networks (Wi-Fi 6).

Wave 2 (2021–2023): ramp-up

During this wave, 5G networks are more widely available (more than 60% coverage of population by the end of 2023), and the private edge deployments conducted in the first phase start to generate benefits on a larger scale. In addition to bespoke edge computing implementations on-premises, public use cases such as autonomous driving, sporting events and gaming are increasingly explored, with edge infrastructure deployed at the district or city level, near to base stations or aggregations of base stations. The costs of operating a large number of micro data centres mean the cost of running applications is higher in the ramp-up phase when there are fewer tenants to spread computing loads across.

Wave 3 (2024 and beyond): mainstream

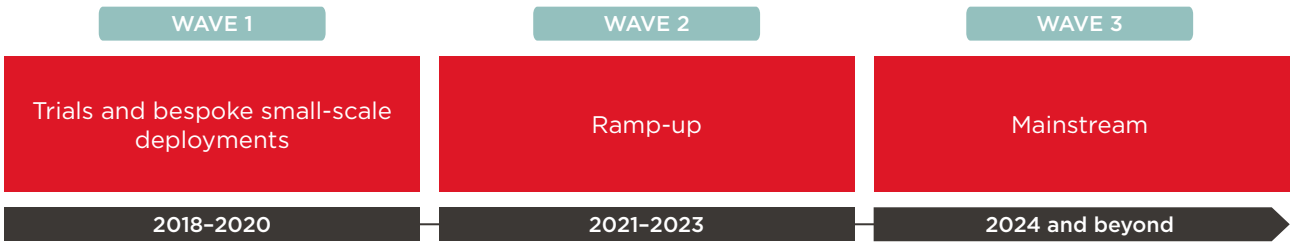
By the end of 2025, 5G will be available to 70% of the Chinese population. The maturity of 5G, lower cost of 5G and more established collaboration between the mobile industry and enterprises drive edge deployments on a larger scale. A higher number of 5G base stations means edge computing can be deployed more extensively, and the technology can increasingly be used for public edge use cases.

Further technology developments in autonomous driving (a bigger move from level 3 to level 4 vehicle autonomy) and smart manufacturing (AI-powered scenarios) create a more favourable environment and need for edge deployments. For example, in a scenario where autonomous vehicles emerge as a new mobility-as-a-service model (robotaxis in predefined driving areas), the opportunity to deploy and use edge computing grows significantly.

In this wave, the economics of edge computing improve as a result of the larger scale; upgrades are made to increase efficiency (such as nano-processing); and market acceptance grows. Although the Chinese operators have larger network resources than cloud vendors, a significant increase in the number of edge sites deployed adds the challenge of ensuring cost-effective rollout (i.e. autonomous maintenance, energy costs) while guaranteeing dynamic development of use cases and availability of applications to end-users.

Figure 27

Three waves of edge computing deployments by Chinese operators



Source: GSMA Intelligence

Revenue models for edge computing are still work in progress

There is very little – if any – disclosure about operator edge pricing and revenue-sharing models in the early edge computing era. Here we examine three possible scenarios for Chinese operators, through an incremental path:

Connectivity only – In a scenario where an operator is not involved in the deployment of edge computing infrastructure (i.e. cloud/edge companies and/or telecoms network vendors build the infrastructure for a specific edge use case), there are still opportunities for operators to supply the connectivity required by the edge use case, and possibly some of the devices needed. This is a low revenue scenario for the Chinese operators, which allows them to take a relatively low share of the overall edge computing revenue opportunity. Connectivity can be charged per device, by data usage or a combination of both. In all scenarios, connectivity revenues are the baseline as most other Chinese edge stakeholders do not have the capacity (or desire) to operate at the connectivity level of the edge value chain.

Edge deployment, connectivity and services – In this scenario, a Chinese operator deploys and manages the edge infrastructure required by a specific use case (on its own or in partnership with other companies such as a cloud provider and/or telecoms network vendor) and supplies the connectivity, devices and IT services (storage, maintenance) needed. Here the revenue model would include a one-off fee related to the edge deployment – likely determined through a 'cost plus mark-up' approach – plus a service fee. As the upfront cost of edge computing may be high, pricing will likely be higher than cloud computing. There is also an option to offer edge hosting/co-location to other companies, which some operators are doing in other regions.

Full stack: edge deployment, connectivity, services and platform – Moving up the value chain, Chinese operators could adopt a full-stack model. This is a full service proposition where connectivity is provisioned alongside supporting devices and, importantly, the platform layer. Owning the lead platform means Chinese operators can offer edge IaaS and edge PaaS solutions to third parties. Connectivity may be charged for or could be provided as part of a larger service bundle where the Chinese operator becomes an integrated partner in overseeing the edge-related operations of its clients.

A higher-value approach may involve providing connectivity free and instead charging for access to the edge platform for data management and analytics through a service wrap fee. The end-to-end model would involve operators handling all data transmission and analytics. For example, in the automotive market, operators can work with a third party (such as an automaker or a vehicle information service provider) to develop an Internet of Vehicles platform built around edge computing and take a share of some of the services delivered by the platform (such as data analytics, security, telematics), depending on B2B agreements. This is where the highest edge computing value exists, but also where competition is highest, with a number of Chinese cloud companies and ICT players targeting the same opportunity.

3.8 Edge computing for the Internet of Things: adding a new layer to digitisation

China has the most developed IoT ecosystem in the world, leading by number of connections and scale of enterprise deployments. By 2025, China will be home to 1.9 billion licensed cellular IoT connections. As Chinese enterprises continue to make progress with their IoT deployments, edge computing adds new capabilities to take the digitisation of services and applications to the next level. Specifically, edge computing will play a role in unlocking or enhancing all the IoT use cases that require local computing and data storage, and high volumes of data to be collected and processed for automated, real-time or near-real-time analytics and decisions. While different categories of company can fulfil the role of key partners for enterprises looking to implement edge technologies, operators were the most cited potential partner in the survey.

The boundaries between IoT and non-IoT edge use cases are not entirely clear. Our survey confirmed that: most companies did not make a clear distinction between edge computing trials and use cases in general and those specifically designed for IoT scenarios. This comes as little surprise as many of the use cases analysed in Section 3.5 involve at least one – if not several – elements of IoT, whether an IoT device, application or platform. However, in terms of edge requirements and design, there are important distinctions in the move to edge computing between IoT and other use cases.

IoT needs to support a large number of devices, many of which do not have their own dedicated computing and storage resources but may be generating a large volume of data that needs to be processed and stored. The relationship between IoT devices and the edge is therefore different to that of other connected devices such as smartphones or AR/VR devices, where at least a minimum part of the data processing can be completed on the device (and the computing power on these devices continues to increase and evolve). This has implications from an edge computing design perspective as the edge must perform a wider range of activities. For example, edge resources may need to be dedicated to IoT application in certain use cases, providing unique resources that are not required in non-IoT edge deployments. Additionally, many IoT use cases are mission critical so edge deployments need to be designed to support these essential applications.

Edge computing deployments in IoT have already started in China; momentum across industries will grow in 2020

Many of the surveyed companies are already involved in edge computing deployments for IoT in various forms, from testing the technology across a number of applications and use cases, to deploying it on bespoke, private projects. Smart factories, smart ports and smart cities lead the way (see Figure 28). There are also a growing number of platforms specifically designed for IoT that offer edge computing features, such as China Mobile IoT Company's OneNET, ZTE's ThingxCloud, Huawei's OceanConnect, and the Joint Edge Computing Platform launched by Alibaba and Intel.

Those who have not yet deployed edge computing for IoT expect to do so in 2020, or during 2021–2022. In the early days of edge computing in IoT, trials and small deployments have mostly relied on the combination of 4G networks and MEC – but the expectation is to leverage the nascent 5G for larger scale deployments.

Figure 28

Edge computing for IoT use cases in China

	Smart factories	Smart ports	Smart cities
Edge enabling opportunities highlighted by surveyed companies (examples)	• Improve real-time remote maintenance of robots, machines and smart factory devices • Enable real-time functioning of AGVs, based on information from radio waves, cameras, magnets or lasers for navigation • Enable AI-based inspection of production equipment via sensors and robots	• Enable real time, localised video analytics for port management • Enhance HD video surveillance systems to monitor port infrastructure and mobile assets • Aggregate data collected within the port to improve port management and operations	• Enable real-time person re-identification via intelligent camera networks • Enable AI-based analysis of video and historical data to enhance early accident detection, detect blind spots and deter accidents • Enable C-V2X features for autonomous driving
Location of edge	Mostly on-premises	Mostly on-premises	Various locations, from city-level edge centres to devices (cameras)
Expected benefits highlighted by surveyed companies (examples)	• Optimise production efficiency • Reduce unexpected downtime • Cost savings related to operating and maintenance expenses	• Optimise port processes through data and automation • Address the bottlenecks between ports and the rest of the logistics chain	• Enable facial recognition without breach of privacy • Improve road safety metrics in cities • Improve civil emergency responses

Source: GSMA Intelligence Edge Computing in China Survey 2019

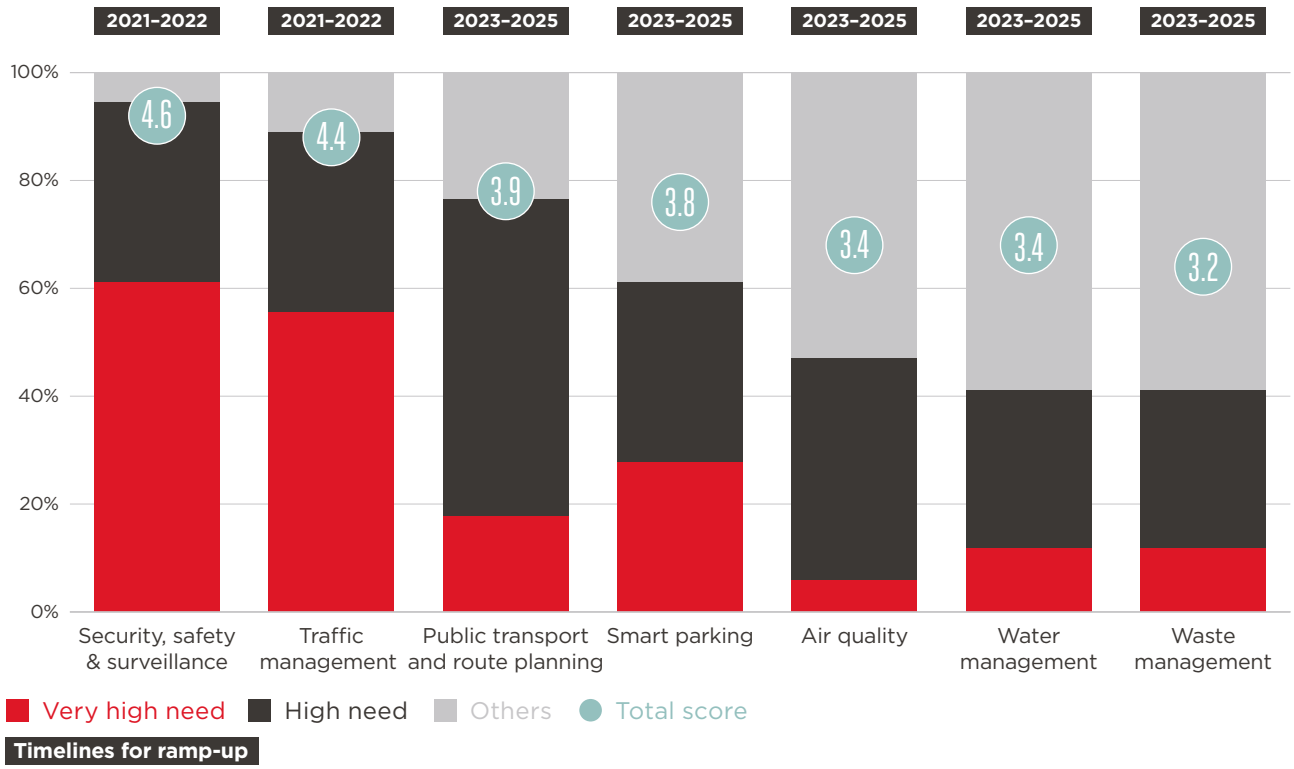
Smart cities offer a promising market for edge computing deployments in China.[14] The top two use cases related to smart cities (Figure 29) are also in the top 10 edge computing use cases across the board. A number of smart city initiatives have arisen in response to China's 13th Five Year Plan. For example, in 2017, Shenzhen Gas, China Telecom, Huawei and Goldcard jointly trialled NB-IoT gas meters, while China Mobile has conducted successful pilots of a smart parking solution in Yunnan and Guizhou. ZTE's Shanghai World Expo Smart City project uses the vendor's multi-layered IoT platform architecture to provide solutions such as smart street lighting and air quality monitoring. In addition, the GSMA is working with the mobile industry to establish an IoT big data ecosystem to make harmonised datasets from multiple sources available to developers and third parties through common APIs. Contributions from the Chinese operators mean that datasets on air quality and weather in China are now available.

On the specific use case of security, safety and surveillance (score 4.6), Horizon Robotics has also illustrated the possibility of facial recognition without breach of personal privacy. This solution embeds AI onto a chip, integrated into an HD camera capable of achieving accuracy and efficiency of facial recognition for public safety use cases. By using edge computing to enable person re-identification (facial recognition via use of anonymised datasets), Horizon Robotics allows its customers to overcome any privacy concerns and legislative restrictions.

Traffic management will also benefit from edge computing capabilities (score 4.4). DTmobile has cooperated with Xiamen Public Transport Group to build a Xiamen BRT 5G intelligent network system for V2X coordination. The integration of MEC and C-V2X allows improvement of vehicle safety and transportation management, promoting smart transportation in Xiamen.

Figure 29

Smart city use cases for edge computing in China



Questions: Which of the following use cases will have the greatest need for edge computing in China? When will edge computing deployments reach scale in China? Percentage of respondents and total score. Total score ranges from 1 to 5 where 1 is 'very low need or no need at all' and 5 is 'very high need'. *Others is the sum of 'moderate need', 'low need' and 'very low need or no need at all'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

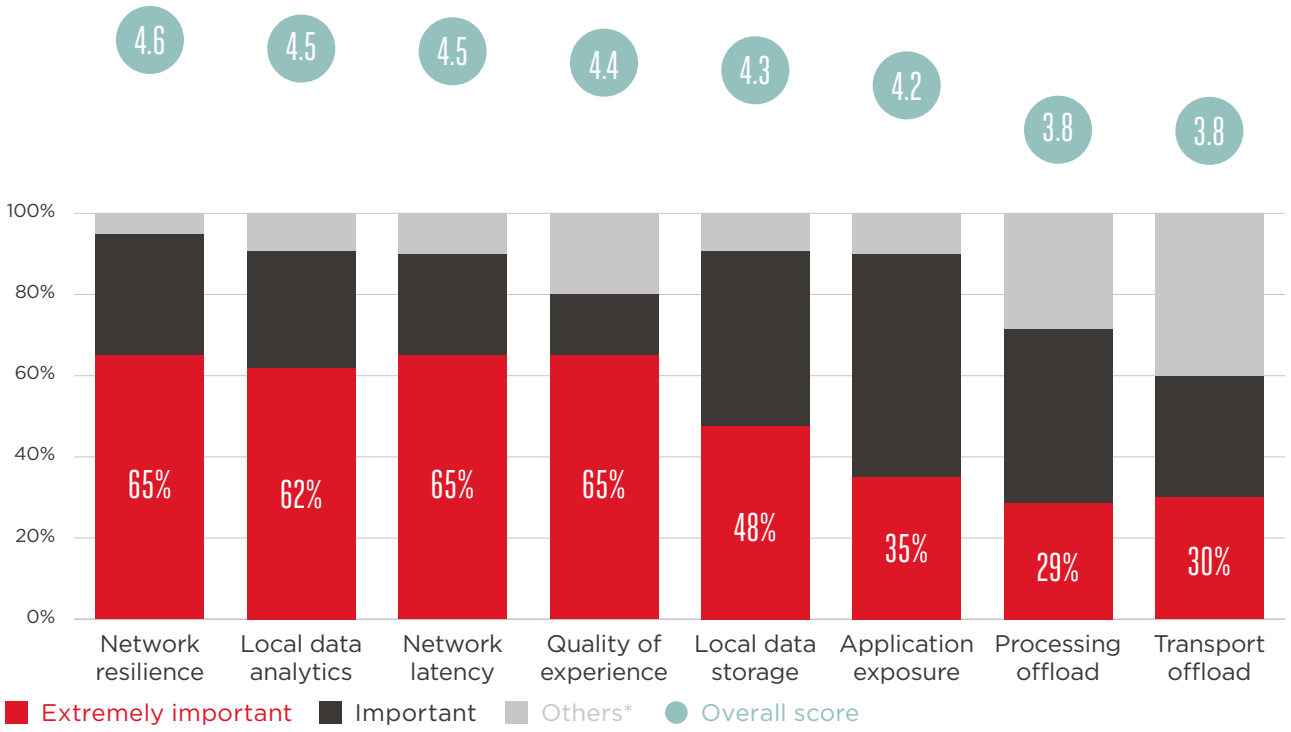
14 For smart factories and smart ports, see section 3.5.

Most important benefits to drive edge computing deployments and adoption in IoT in China

Network resilience – a key factor when dealing with the huge number of IoT devices connected to the same network – is the most important benefit according to surveyed companies (Figure 30). The most significant difference between benefits that will drive edge use cases in IoT and benefits that will drive edge use cases in general (IoT and non-IoT) lies in local data analytics and local data storage, which had higher scores in the IoT context. This comes as little surprise given that many IoT applications in smart factories, smart ports and smart cities heavily rely on access to large volumes of data and large amounts of processing power to deliver real-time insights and decisions. Having data stored and processed near the IoT devices – as opposed to central clouds – enhances or unlocks new IoT applications.

Figure 30

Benefits important to drive edge computing deployments and adoption in IoT in China



Question: Rank the following edge benefits based on how important they are to drive deployments and adoption of edge computing in mobile networks in China. Percentage of respondents and overall score. The overall score ranges from 1 (very limited importance) to 5 (extremely important). *Others is the sum of 'moderately important', 'marginally important' and 'very limited importance'.

Source: GSMA Intelligence Edge Computing in China Survey 2019

Several factors will help drive future deployments of edge computing in IoT in China

There is widespread agreement in the Chinese ecosystem that edge computing will play a significant role in the future of IoT. However, several companies highlighted a number of challenges or key ingredients for continued success.

Cloud/edge integration. Enterprises may require hybrid deployments as opposed to the two extremes of either a fully cloud-based solution, powered by public cloud resources, or a fully edge-based solution, powered by private and public edge resources. This adds technical complexity to all suppliers of edge technology, especially in the early stages, as cloud and edge resources need to be integrated. As these enterprises continue their digitisation strategies, they would need to see a smooth technical roadmap that expands beyond cloud and increasingly includes those edge computing capabilities needed to capture specific benefits at the edge.

Functional and secure data as the accelerant. Many respondents indicated that most IoT platforms would need to evolve from their current configurations to enable edge computing capabilities if they had to allow enterprises to use relevant data in a more timely and secure way. China Mobile's OneNET Edge is a positive step in this direction, making it easy to accurately ingest different datasets created by different devices, manufacturers and formats, to run real-time, AI-enhanced analytics on a large scale. Also, as AI expands the possibilities of dealing with larger amounts of data and generating analytics, it is important to ensure that edge-powered IoT use cases address data security and privacy requirements from the start.

Interoperability as the 'Holy Grail'. As enterprises increasingly rely on edge computing to further enhance their IoT solutions, they will have a new dimension to integrate with their internal IT systems. To accelerate deployments and time to market for new services, most surveyed companies are involved in discussions around standardisation of different edge interfaces, protocols and access technologies for IoT applications. Future IoT platforms will need to be compatible with all kinds of devices and support multi-protocol access, deterministic network access, remote deployment and updates, and even offline operation.

4 Policy and regulation: creating a favourable environment for edge deployments in China

Our edge computing survey highlighted several common challenges around the current policy framework in China, with the general topic of regulation also scoring as one of the top barriers to scaling edge computing deployments. However, it is important to note that this was not a unanimous perspective, as a number of respondents indicated that there were in fact few policy obstacles to edge deployments at present. Key challenges include the following:

- National and local government regulations that are applied to edge data centres draw almost exclusively on regulations designed to ensure the rational and energy-efficient deployment of centralised cloud data centres. As such, they are often not applicable to edge configurations that are by definition much smaller in scale and larger in number, with different energy consumption requirements.
- The lack of clear standards around the various elements of edge computing deployments can be a hindrance to scale adoption. Although there are a number of domestic and international bodies, industry associations and ecosystem players involved in the development of edge computing standards, the reality is that the market is still highly fragmented, making coordination laborious.
- There is a particular challenge when dealing with specific industry verticals, many of which have their own policies covering the use, processing and transmission of user and industry data. These barriers can encourage verticals such as the energy sector or police to develop their own solutions running on private networks, rather than more open solutions running on public networks.

Regarding this last point, the national Cybersecurity Law should ensure alignment of policies and regulations around data security and privacy. However, there will still be a need for operators, other ecosystem players and industry verticals to work together to ensure solutions meet any business-specific SLAs or other operational requirements.

The Chinese ecosystem also highlighted a number of policy and regulatory measures that should help address the challenges identified:

- Policymakers should promote the development of edge computing in terms of standard setting and regulatory policy formulation. This includes addressing the challenges of energy efficiency while also offering lower energy tariffs to help drive edge deployments.
- Policymakers should work closely with industry associations and alliances to develop standard edge computing techniques, interfaces and applications.

It is clear from the above that agreeing standards and developing a comprehensive, end-to-end view of the edge ecosystem will be crucial to develop scalable, future-proof technologies that have a positive long-term outlook. Despite the scale of the Chinese market, it would also be advisable to collaborate with international efforts around standards to help drive the scale and adoption of edge solutions. A common challenge for the development of edge capabilities in many markets around the world is the need for more focused regulations that recognise the unique nature and challenges of edge deployments. Edge computing sites are typically subject to regulations and security requirements applicable to large data centres, so they must comply with the same standards and regulation even where these may not be appropriate and indeed may hinder the uptake of edge facilities.

5 What next? Work to be done to drive edge computing developments and scale in China

Recent progress on edge computing, coupled with a clear intent of the Chinese ecosystem to be at the forefront of the new technology, represents a solid base to build on. However, much work needs to be done – by individual companies and the Chinese ecosystem as a whole – to realise the long-term potential of edge computing.

Surveyed companies highlighted a number of actions that, combined with the key barriers analysed earlier and GSMA Intelligence's own views, lead to seven key actions that should help drive edge developments and adoption in China over the next five years.

Many of these actions involve most edge computing stakeholders. Some are specific to individual categories of companies. These actions can be divided into three main categories: technology developments, market acceptance, and policy and regulation.

	What needs to be done	More specific actions
	Technology developments	
1	**Clarify the most suitable deployment model for edge computing, and drive edge standardisation.** While China on its own has significant scale to develop its local rules and deployments, collaboration at a global level is key, particularly for industries that are global.	**Local/global organisations and companies in the edge computing value chain** Work together to establish a unified approach on network and device specifications, edge technical interfaces, interoperability, cloud/edge coordination, security requirements for data storage, access and analytics, and standard APIs.
2	**Integrate edge computing into wider 5G network investment roadmaps, so that edge is no longer seen as a single application platform, but as an important part of future 5G network architecture.** In such a scenario, the combination of MEC and 5G would be more natural.	**Operators** Consider assigning a specific budget for edge deployments, linked to progress on trials, implementation and use cases, as well as business model considerations. Expand rollout of 5G standalone networks in key areas of edge computing demand. **Telecoms network vendors** Position edge computing as a key layer in network transformation offerings, deployed in conjunction with other technologies (SDN, NFV, 5G, AI, slicing).
3	**Address the issue of high energy costs related to cloud/edge computing and, more broadly, 5G networks.**	**Companies in the edge computing value chain** Consider the opportunities of sharing some of the edge infrastructure or jointly developing it – if viable from a business model perspective – to limit large-scale construction of edge resources. High deployment, maintenance and energy costs may limit edge computing adoption. **Chinese government** Adopt favourable policies for 5G and edge computing electricity consumption.

Market acceptance

4 **Take industry collaboration to the next level, expanding edge computing discussions with vertical industries.**

Involving more companies from across vertical sectors is key as edge computing adoption will also depend on other technology developments in key use cases (e.g. autonomous driving and immersive reality).

Companies in the edge computing value chain

Organise new forums and workshops to drive discussions not only between suppliers of edge technology but also between suppliers and end-user enterprises. These forums and workshops should increasingly include discussions about edge opportunities and business model scenarios.

5 **Leverage enterprise awareness of edge computing to promote new edge computing trials and deployments.**

Chinese enterprises have higher awareness of the edge capabilities compared to enterprises in the US and Europe. This is a solid base to build on.

Companies in the edge computing value chain

Provide tangible evidence of how edge deployments are benefiting enterprises in the first wave of trials, centred on the specific painpoints that the technology addresses. The usefulness of edge computing is not a given; it needs to be proven for each use case scenario.

Operators

Establish 5G as the lead access technology for edge computing use cases, showing its benefits compared to alternative technologies such as fixed networks (Wi-Fi 6).

6 **Increase focus on some of the potential edge computing use cases that have gathered less attention (on a relative basis) so far, such as media & entertainment and smart cities.**

Media players

Engage with edge stakeholders to explore opportunities for media services and applications at the edge, the investment needed, business model and timelines for deployment.

City governments (for smart cities)

Drive more discussions on the potential use of edge computing for smart city applications, and include early edge deployments in multi-year transformation agendas.

Policy and regulation

7 **Support the development of edge computing through clear and more focused regulations that recognise the unique nature and challenges of edge deployments.**

Policymakers and regulators

Work closely with industry associations to drive not only standardisation of edge technologies (see action 1) but also discussions on how the current regulation of public cloud should evolve to enable edge computing scenarios.

Creating a favourable ecosystem environment that supports technology developments and fosters innovation will ultimately determine the pace and magnitude of edge computing deployments in China and worldwide. In 2020 and beyond, the GSMA will continue to bring together all stakeholders in the global mobile industry to support industry cooperation and further progress with edge computing on several fronts: standards and specifications, technology developments centred on nascent 5G, spectrum, and policy and regulation. It will also continue to monitor – through industry discussions and research – edge computing developments globally, including trials, deployments, use cases, ecosystem initiatives, and other relevant factors that will help scale edge computing in the consumer and industrial segments.

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