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Perspective

Operator edge-native clouds can provide a unified compute fabric for multiple networks and use cases

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RESEARCH

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1. Executive summary

1.1 Demand is growing for edge-native clouds

Digital transformation is driving enterprise applications and processes to the cloud, and particularly to public clouds. Cloud infrastructure needs to become more distributed and ubiquitous to meet future enterprise needs as demand for cloud-based compute and storage grows. The first generation of distributed clouds is being rolled out in metro data centers to provide enterprises with a greater choice of compute locations, both within and between countries. Such clouds are serving the needs of enterprises that want to process certain types of data locally for regulatory compliance reasons and/or that do not want to incur the cost of backhauling large amounts of data to centralized clouds.

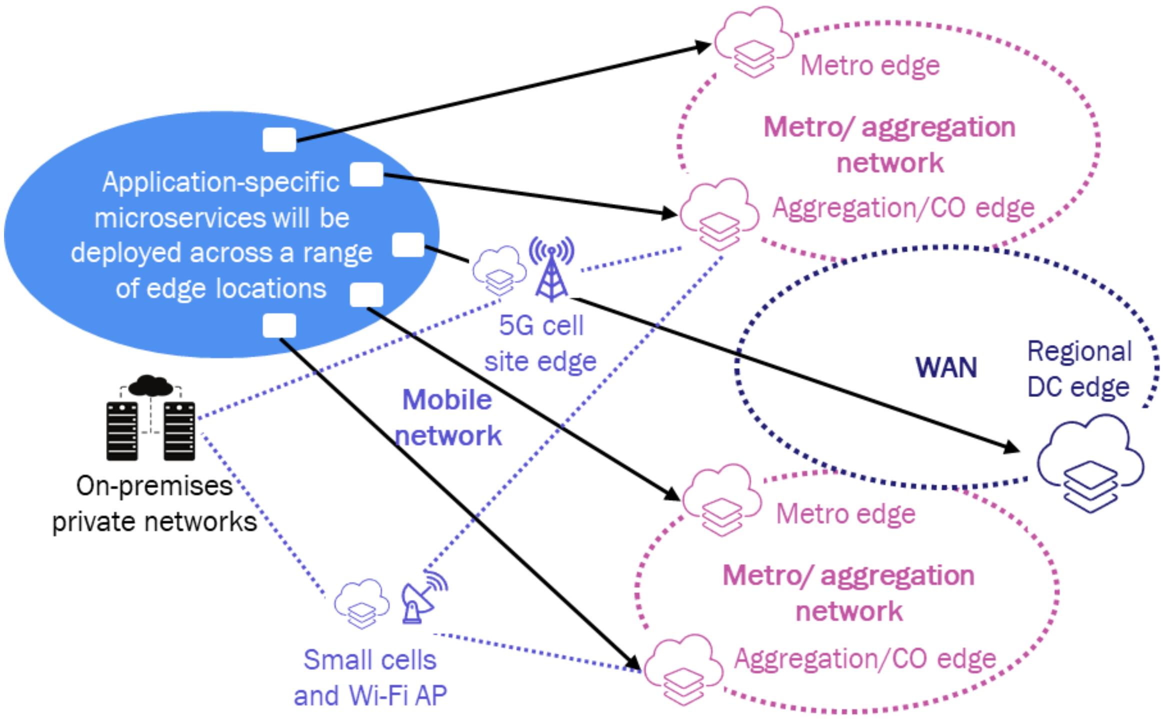
Beyond this first wave of ‘edge clouds’, a highly distributed, edge-native compute fabric will be needed in every conceivable location, not just in a few thousand distributed cloud data centers worldwide. This edge compute fabric is expected to serve the processing needs of a new class of data- and event-driven applications (termed edge-native services) that will support novel user experiences and an unprecedented ability to optimize business processes. Such applications include AI/ML, computer vision and autonomous mobility services, as well as those that support collaboration across multiple contexts and devices, such as multi-player, AR gaming. User/device location matters to these edge-native services, and the demand for location-specific, edge-native cloud compute, storage and connectivity will increase as they become more prevalent.

1.2 Operator cloud-native networks hold the key to edge-native connectivity and an edge cloud fabric

Edge-native services will be built using microservices-based architecture so that their containerized components can be distributed across many different types of clouds. As operator networks increasingly become cloud-native themselves, they will be able to participate directly in microservices-based ‘application pipelines’ that control the flow and processing of application data both locally and simultaneously across a fabric of edge clouds. As a peer facilitator of application pipelines, the network can use its understanding of both the locations of user(s)/device(s) needing access to applications and the properties and resource profiles of different edge-native cloud locations to match end users/devices to applications in appropriate edge-native cloud locations. The network will play a key role in connecting end users/devices, applications and edge-native clouds reliably, securely and with consistent latency.

The affinity between cloud-native networks and edge clouds means that telecoms operators have the opportunity to enable the nascent edge-native cloud value chain. Leading operators are already building, or are planning to build, a distributed fabric of edge clouds across their geographic network footprints to support cloud-based transformations of their access and transport networks. A common theme for the transformation of each network domain is the need for a highly distributed cloud fabric as the execution platform for the virtualized and cloud-native network functions (VNFs and CNFs, respectively) that will comprise the control and user plane of the software-based network of the future (though operators are currently addressing each transformation separately). The same edge cloud platform will also run the network’s increasingly autonomous operational and management functions. This is providing operators with the opportunity to create a distributed cloud fabric that can unify multiple network domains and which they can then make available to third-party application pipelines. Operators can play a key role in orchestrating third-party applications and CNF microservices across this fabric (Figure 1.1).

Figure 1.1: Operator-owned distributed cloud fabric with policy-based placement of edge-native services



Source: Analysys Mason, 2021

Operators can further sweeten the business case for building a unified edge cloud fabric to support their cloud-native networks by hosting shared platform services in that fabric that both they and the emerging category of applications need. The services include developer toolkits, data, AI and analytics environments, IoT management platforms and security capabilities. The most advanced operators that have plans to become digital service providers may also develop their own differentiated and innovative applications in conjunction with partners in different industry verticals. These applications can take advantage of operators' edge-native footprints and network properties, such as low latency.

1.3 There are several steps to edge-native success

This paper lays out the arguments for the operator implementation of an edge-native cloud fabric. These center on the benefits that operators can gain, both from deploying a fabric themselves and then from federating it with other operator and cloud service provider edge-native clouds in order to broker enterprise applications and data flows and their own network functions across a distributed, heterogeneous cloud environment.

The paper summarizes the critical success factors involved in deploying an edge-native cloud. Operators will need the following.

- **A modern software mindset.** Software will be at the heart of operators' networks, business processes and new revenue-generating services in the future. Operators need to understand and acquire the culture, skills and tools popularized by public cloud providers to manage the edge-native cloud infrastructure that will support this software at scale.
- **A state-of-the-art edge-native cloud fabric.** This should be able to support operators' network transformations and the emerging class of edge-native applications that have very similar cloud requirements to cloud-native network functions (CNFs).

- **Edge-native orchestration and automation.** This will be used to schedule microservices across a highly distributed cloud fabric according to location, security and other policy-driven requirements. It will also be used to cost-effectively manage the lifecycle of all edge cloud components, from bare metal to applications/network functions themselves.
- **Access to a developer community.** Operators will need to have access to a developed community that is working on the next generation of edge-native services that will enable interactive multi-modal, multi-device experiences that can delight users with their novelty, or which offer an exponential leap in the ability to optimize a business process. Such applications will be key to operators' ability to monetize the edge cloud fabric that they are building to support their networks.
- **Collaboration.** Operators will progress faster up the edge-cloud value chain, and will add further value to their edge locations and edge-native network clouds, if they co-operate with their peers. In doing so, operators can potentially create a new operator-led marketplace for emerging edge-native use cases that can make the most of operators' unique ability to converge cloud and networking, their cloud agnosticity and their combined footprints.

2. Why the world needs highly distributed edge-native compute locations

2.1 The need for cloud computing is evolving

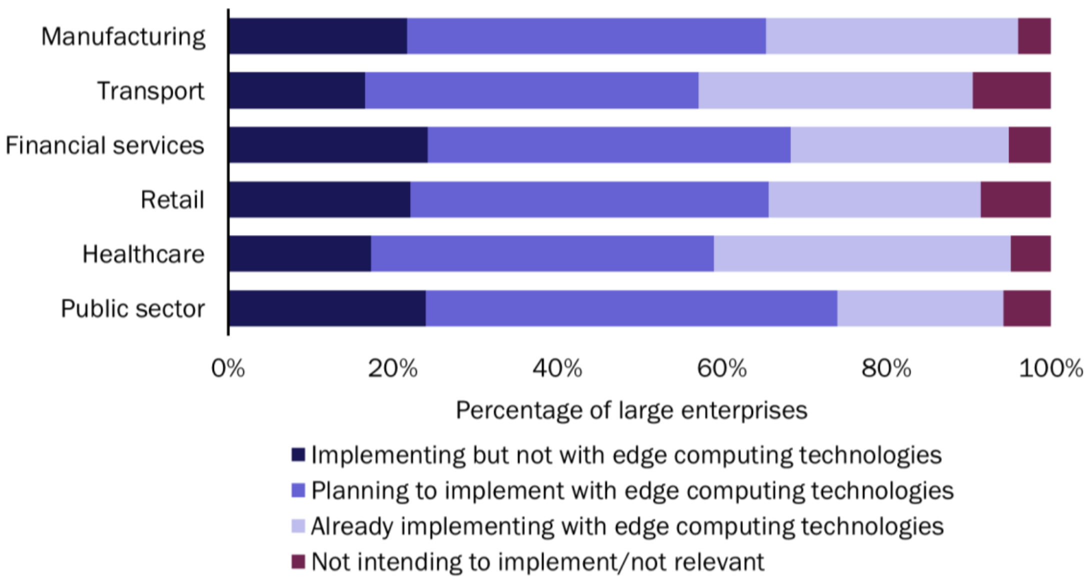
Digital transformation is driving enterprise applications and processes to the cloud, and particularly to public clouds. The cloud is an easily accessible, industrialized environment for running software workloads using an 'as-a-service' delivery model that is convenient to consume. To date, public cloud infrastructure has been placed in locations where land and energy are cheap, often in sparsely populated areas. Public cloud providers are increasingly being explicitly banned from expanding near cities because the huge data centers that they need to support their infrastructure compete with residents for power and land resources.

As the demand for cloud-based compute and storage grows, cloud infrastructure needs to become more distributed and ubiquitous to meet future enterprise needs. Analysys Mason's research has identified a strong demand for a first generation of local, 'edge' clouds that are situated close to end users. Enterprises want to process certain types of data locally, and certainly within the same country, for security and regulatory compliance reasons. They do not want to incur the cost of backhauling large amounts of data to centralized clouds, and as they introduce more automation into local sites (for example, into retail stores, quick service restaurants, intelligent buildings, warehouses, factories, mines and ports), they want the software systems that support such automation to be delivered as containerized applications that can run on local clouds, rather than on dedicated servers. Edge clouds enable enterprises to run semi-autonomous, latency-sensitive operations locally, to integrate applications into site-based processes more easily and to use server resources more efficiently at individual branches or sites.

The first generation of distributed clouds is being rolled out in metro data centers to provide enterprises with a greater choice of compute locations within and between countries. For example, public cloud providers are co-locating their cloud infrastructure in metro data centers owned by telecoms operators so that they can distribute their presence to more locations worldwide, mainly in response to enterprise concerns around data compliance and backhaul costs.

However, beyond this first wave of 'edge clouds', enterprises will require a more distributed, edge-native compute fabric that is available in every conceivable location, not just in a few thousand distributed cloud data centers worldwide, in order to support new software applications and software architecture. A new class of data- and event-driven edge-native services will depend on the existence of a seamless fabric of edge-native clouds that can process their data very close to where it is needed, for example, to support the near-real-time optimization of processes or to enhance the realism of a new experience that is delivered in the digital world. These edge-native services include AI/ML, computer vision, autonomous mobility and applications that support collaboration across multiple contexts and devices, such as multi-player, AR gaming (Figure 2.1). Such edge-native services are being developed using a very different architectural approach to that used for today's web applications that run in the public cloud, and they have in common the need to be deployed to specific edge cloud locations to execute with the right level of security, latency and compliance.

Figure 2.1: Median level of large enterprise interest in using edge computing to implement use cases related to AI/ML, computer vision, blockchain, mobility and compliance, by sector, July 2020, n=200



Source: Analysys Mason, 2021

2.2 The next generation of edge-native cloud will be everywhere

The new class of edge-native services will serve an increasingly hyperconnected web of devices that is producing and consuming more and more data. AI/ML applications will turn this wealth of data into intelligence far more quickly than humans could, and will replace manual steps that introduce friction into processes and experiences. At the end of this decade, industry visionaries expect an 'AI of Things' to have emerged, whereby everything in our lives will be able to exchange data with everything else, thereby enabling 'magical' and unprecedented levels of automation. The net effect of more data, and the application of AI/ML to it, will be the better optimization of business processes and user experiences, with all the benefits that optimization brings, such as cost reduction, improved customer loyalty, better supply chain resilience and greater sustainability.

Optimization and customer experience requirements will drive an increase in the amount of data processing, as well as the training of machine learning models and the wide distribution of ML inference algorithms. Such activities will, in turn, increase the demand for location-specific cloud compute, storage and connectivity. Edge-native services and their data flows will therefore need a ubiquitous edge cloud fabric to be available to them, as Figure 2.2 illustrates. Such services will be built using microservices-based architecture so that their containerized components can be distributed across many different clouds. These components will use highly reliable messaging and event streaming technologies to connect and co-operate with each other in response to external events, such as a change in user/device location or the detection of a local anomaly. Developers can take advantage of this combination of edge-native software architecture and edge-native cloud fabric to create personalized, multi-modal and multi-device applications, such as multi-player AR/VR gaming and fleets of autonomous drones from different companies that can 'see' and avoid one another.

Figure 2.2: Illustration of the new applications and data flows that will drive the need for local, intelligent processing

Source: Analysys Mason, 2021

3. What is the edge-native opportunity for operators?

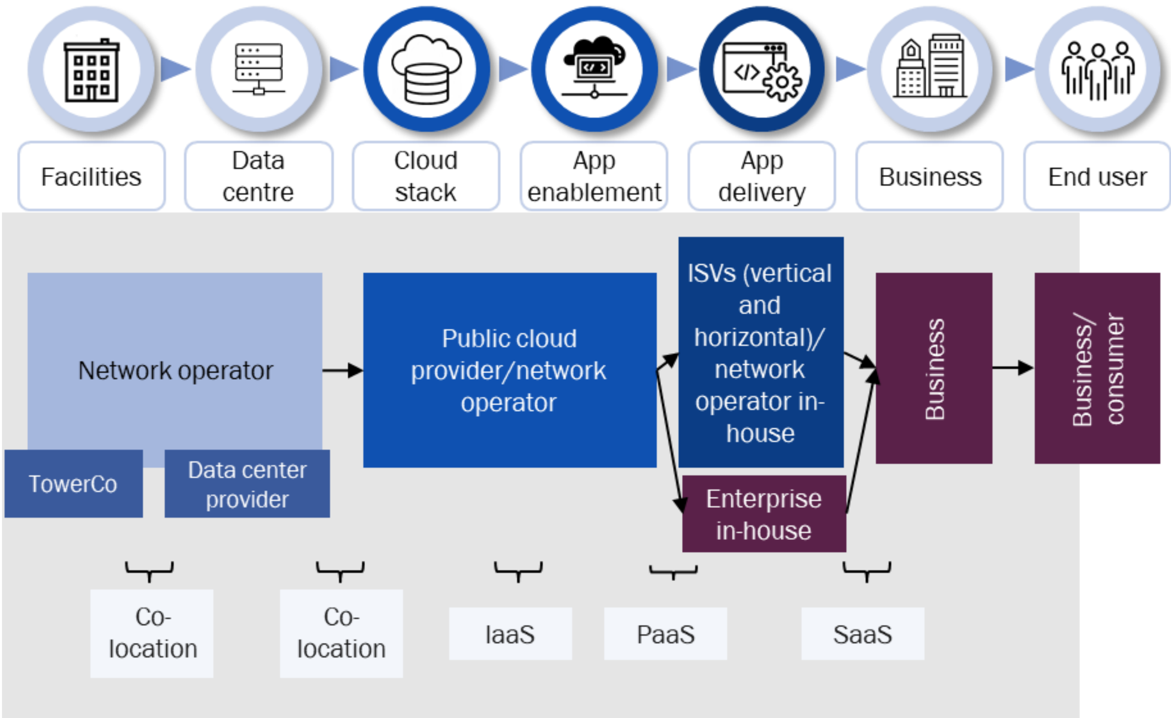
3.1 Operators have an opportunity to converge edge-native clouds and the network, thereby elevating their position in the enterprise value chain

The network is critical in an edge-native world as the connector of collaborating edge-native service components, data flows and clouds. The network itself needs to be an inherent part of a microservices-based 'application pipeline' that controls the flow of application data locally and simultaneously across edge-native clouds. The network is the peer facilitator of the pipeline: it determines which microservices locations should be connected to complete an application-driven process. This will be based on the network's understanding of the locations of user(s)/device(s) participating in the process, the properties and resource profiles of different edge-native cloud locations and the knowledge of how to both match end users/devices to the right edge-native cloud locations in order to provide access to applications, and connect end users/devices and edge-native clouds reliably, securely and with consistent latency. As we will see, the network can also expose the edge-native compute locations that it needs for its own operation to support enterprise application pipelines.

The affinity between networks and edge clouds means that telecoms operators can play an important role in the edge-native cloud value chain. This role can extend beyond that of a co-location facilities provider. Operators today are focusing on opening up their metro data centers as sites for public-cloud-provider-owned cloud infrastructure. As such, they are enabling public cloud providers to bring their cloud locations closer to enterprise customers and their applications.

However, operators can themselves become providers of cloud infrastructure because they will be placing edge-native clouds across geographic locations in order to effect end-to-end, cloud-based transformations of their access and transport networks (see Section 3.2 below). Operators can then expose such edge-native clouds to support third-party application pipelines in an infrastructure-as-a-service model (IaaS), as Figure 3.1 shows. Operators could use software-defined connectivity to federate their edge-native clouds with other operator and cloud provider edge-native cloud locations, thereby providing a more extensive edge IaaS solution that can support use cases that need a high degree of mobility across geographies.

Figure 3.1: Operators' potential roles in the edge-native value chain



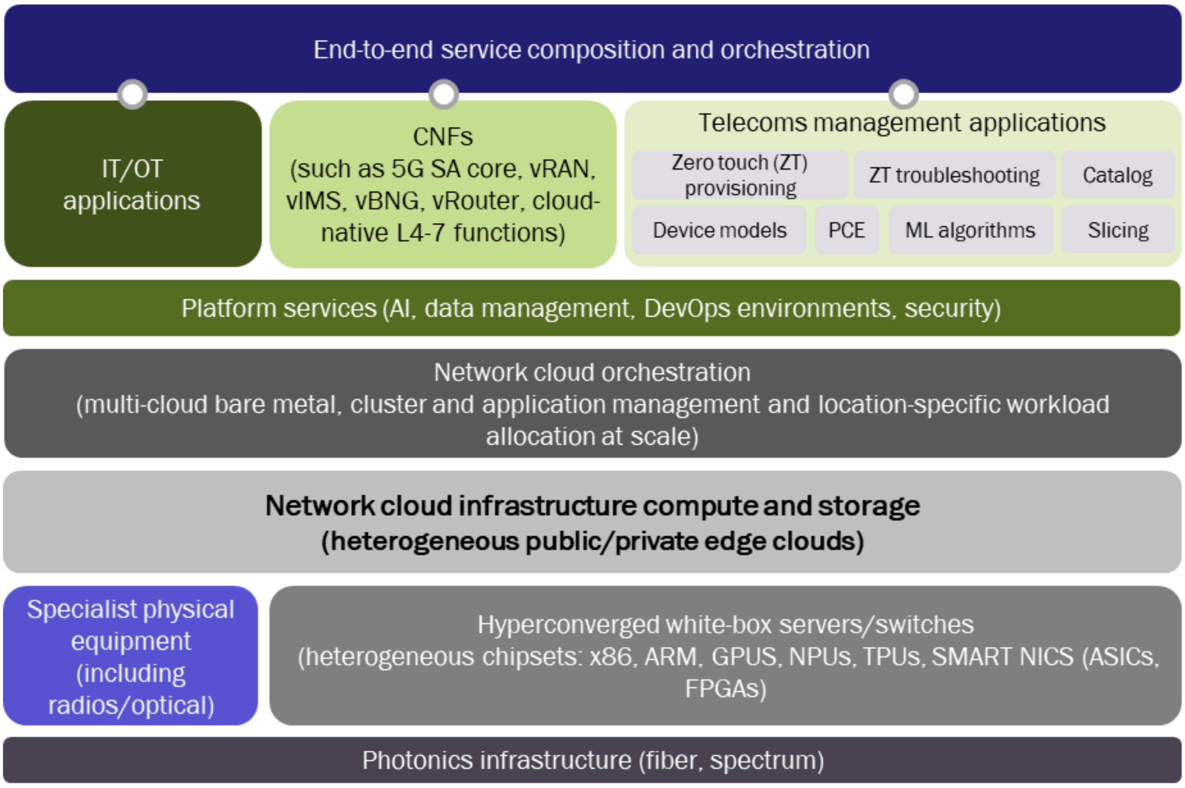
Source: Analysys Mason, 2021

Operators that host shared platform services (such as developer toolkits, data, AI and analytics environments, IoT management platforms and security capabilities) in their edge locations or across a federated footprint of edges can gain additional revenue through a platform-as-a-service business (PaaS) model. Operators will need many of these platform services in order to run and manage their own networks, so exposing them to third parties is a further edge monetization opportunity. The most advanced operators that have plans to become digital service providers may also develop their own differentiated platforms and applications that businesses can consume directly, and upon which enterprises can build their own solutions for end customers.

3.2 Edge provides the opportunity for operators to unify multiple network transformations

Operators are carrying out multiple, discrete transformations of their mobile access, fixed access and transport networks and associated operational systems. A common theme across all these transformations is the need for a highly distributed cloud fabric as the execution platform for the VNFs and CNFs that will comprise the control and user planes of the software-based network of the future. The same platform will also run the network's increasingly autonomous operational and management functions. This distributed cloud fabric may well have blurred the boundaries between today's distinct and siloed network domains in 10 years' time. Figure 3.2 depicts the future network architecture that leading operators are already planning for. It is important to note that operators do not have to own all the cloud stacks and distributed locations that contribute to their network cloud. In fact, for maximum flexibility, they should be able to host network and management components across infrastructure from multiple cloud providers, as well as in their own private edge cloud locations.

Figure 3.2: Overview of the cloud-converged network of the future



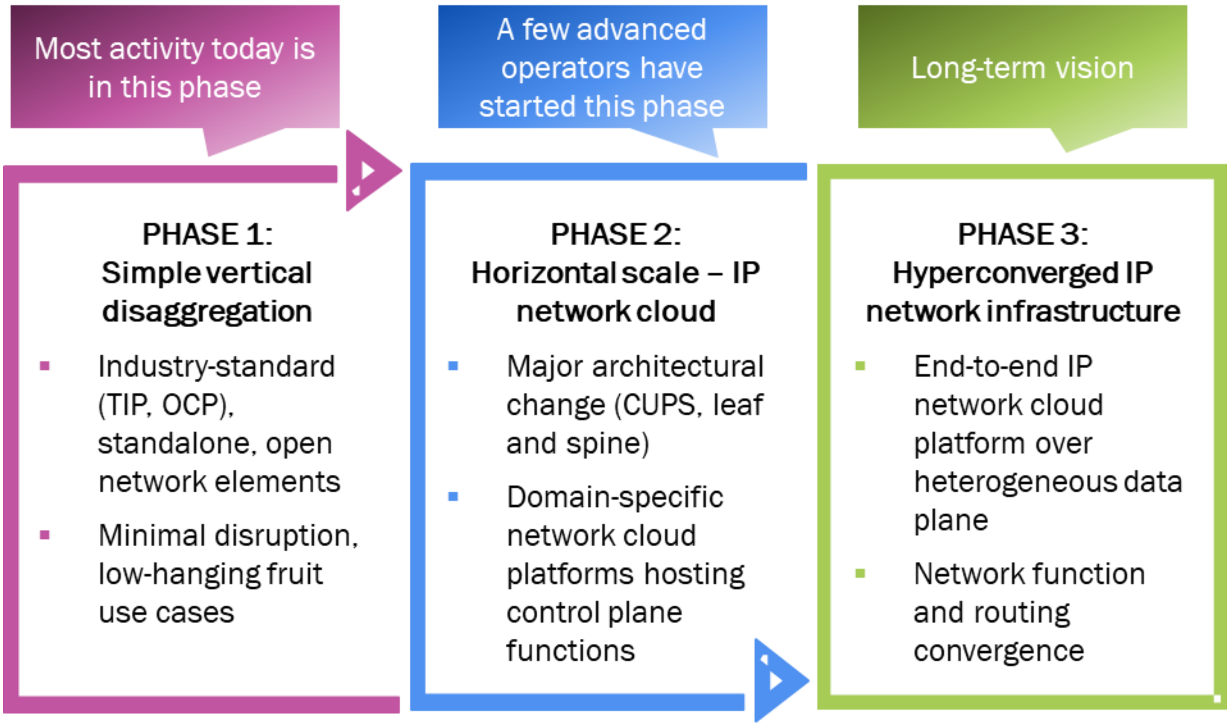
Source: Analysys Mason, 2021

The **5G (mobile access) network** is furthest along the path to fulfilling the vision of the software-based network of the future because it was designed from the outset to be implemented as a cloud-native, software-based network. 5G is therefore the first network generation to need a distributed fabric of edge clouds across an operator's footprint to support the virtualization and disaggregation of the RAN and mobile core. Operators potentially need to deploy thousands of edge clouds to support their macro 5G networks, and possibly many thousands more to support B2B customers that want to deploy private 5G networks on enterprise premises in the future, using either a dedicated or hybrid model.

At least some of these mobile edge locations will also support the virtualization of the **fixed access network**, and leading operators have access network convergence on their agendas. The same edge clouds can also support other types of access networks, from virtualized Wi-Fi 6 to virtualized LoRaWAN gateways for IoT networks.

The **transport network** is at the beginning of a long disaggregation journey (as described in Figure 3.3), which will eventually result in the implementation of a cloud-native control plane that can run across edge clouds rather than in individual routing devices. The latter will transform into specialized user plane devices that may be co-located with, or even host, edge clouds. Today, the most visible signs of this transformation are coming from new-entrant inter-cloud connectivity providers. Such companies are starting to showcase the power of a cloud-native approach to IP routing. They are building software-defined overlay networks that connect applications running in different public cloud provider clouds to each other to fulfil user requests. They spin up their virtualized routers on demand in different clouds and data centers to provide optimal routing paths for a specific application, and, depending on the application's needs, they can orchestrate security, performance optimization and other cloud-native services into the path of the application. The same approach could be used to connect edge clouds in the future. Such overlay networks are increasingly procured by application developers, not by enterprise networking departments. Enterprise DevOps teams want to add overlay connectivity into their continuous integration/continuous deployment (CI/CD) pipelines so that they can spin up cloud-native applications, (edge-native) cloud infrastructure and cloud-native connectivity at the same time.

Figure 3.3: The pathway for router disaggregation in operator IP networks



Source: Analysys Mason, 2021

Overlay networks are required to connect clouds currently because operator-owned underlay networks are not cloud-native and cannot be orchestrated in a software-defined way. Overlay network providers are therefore able to disintermediate operators and 'free ride' over the internet, but this has implications for operator enterprise connectivity revenue. This threat is incentivizing operators to transform their transport network underlays, but their vendors are less prepared for a cloud-native future than 5G network function suppliers are, so this will take time. Nevertheless, the same edge cloud architecture that operators are deploying for cloud-native 5G can serve the disaggregated transport network. The transport network itself can take advantage of hardware hyperconvergence to provide new locations for edge clouds that could host not only 5G cloud-native functions (such as the 5G standalone core's user plane function (UPF)), but also, for example, third-party streaming applications that have the same need for fast input and output as 5G and transport routing functions.

4. Taking the next steps: planning an edge-native strategy

4.1 Operator edge clouds lay the foundations for business model innovation

Operators that create a common network cloud composed of clouds from multiple providers and including their own edge cloud estate will not only support and strengthen their connectivity businesses; they are also able to participate in the global ecosystem of edge clouds that will emerge to support the new applications and use cases described in Section 2 above. Operators' ability to provide a combination of software-defined connectivity and edge cloud locations will enable them to broker enterprise applications and data flows across a distributed, heterogeneous cloud environment. This is a growing requirement from enterprises that are themselves undergoing digital transformations, and one that is not being met in a satisfactory way by any party today.

Operators also have a unique opportunity, based on their long-standing ability to co-operate with one another on the standardization of interconnectivity and network architecture, to federate their network clouds and to create a differentiated, operator-specific application experience for enterprise customers and consumers. Leading operators are already proving that it is possible to monetize such an experience on their own networks, but as the world becomes increasingly hyperconnected, it will be important that they can extend it to customers and devices that are roaming, or those that are extending their business processes beyond the boundaries of a specific operator's network.

4.2 There are a number of key requirements to enable operators to become edge-native

Operators that are adopting an edge-native strategy must be able to converge networking and cloud compute connectivity across distributed cloud locations that will exist at a far more fine-grained scale than is the case today. Operators will also need the related ability to orchestrate any type of workload across this distributed cloud/connectivity fabric according to location-specific requirements, including workloads that they need in order to run their own business as connectivity providers, such as cloud-native network functions and B/OSS, and third-party enterprise applications.

The steps that operators need to take to prepare such an edge-native strategy overlap heavily with those that they need to take generally to transform themselves into digital connectivity businesses that will thrive over the next decade and beyond. Operators can therefore use an edge-native strategy that covers people, process and network technology change as a unifying principle for their transformation efforts.

Specifically, operators will need to the following.

- **Adopt a modern software mindset.** Leading operators have already embarked upon a journey to master modern software design (cloud-native microservices and containers). Modern software design will be at the heart of their networks, business processes and new revenue-generating services in the future. Critically, operators need to understand and acquire the culture, skills and tools to manage the edge-native cloud infrastructure that will support this software at scale, and must adopt the same approaches, disciplines and techniques as public cloud providers, but with adjustments for an edge-native, telecoms context.

- **Provide a state-of-the-art edge-native cloud environment**. Operators will want, and indeed require, a state-of-the-art edge-native cloud environment to support their own network functions. The virtualization of the RAN, for example, makes particularly stringent demands on edge-native cloud infrastructure, and operators will need to incorporate a variety of acceleration technologies into their clouds to support virtualized/open RANs. Analysys Mason research shows that data- and event-driven edge-native services have similar requirements for low latency, high throughput and high reliability to vRAN functions, thereby making edge-native RAN clouds attractive hosting sites for such applications. Operators should invest in high-quality, modern cloud infrastructure, not only to meet their own needs but also to meet the expectations of potential enterprise app developers who will be used to deploying to such infrastructure from other cloud providers.

- **Acquire edge-native orchestration and automation.** Edge-native cloud infrastructure and services introduce new orchestration demands, so operators will need to evaluate contending systems against edge-native specific requirements.

  — The distributed nature of edge cloud infrastructure means that operators will need high levels of lifecycle management automation for thousands of instances of applications/network functions, as well as for the cloud infrastructure and bare metal hardware that constitute thousands of edge nodes, in order to keep management and support costs low. In other words, edge-native orchestration should provide a single control plane for managing the lifecycle of compute, connectivity and applications together.

  — An edge-native orchestration system should be able to assign applications/network functions to specific edge node locations according to location-based policies. Such policies might address sovereignty concerns, the real-time contexts of end users/devices or access to a particular set of hardware capabilities, for example.

  — An edge-native orchestration system should integrate with and manage not only the operator's edge-native clouds, but also any third-party clouds and devices that form part of the operator's network cloud ecosystem. This enables the orchestrator to deploy workloads across an operator's own cloud estate and potentially also across federated edge cloud footprints.

- **Encourage a developer community that is focused on future use cases.** Edge-native services enabling interactive multi-modal, multi-device experiences that can delight users with their novelty, or which offer an exponential leap in the ability to optimize a business process, depend on the convergence between cloud compute and networking. This is supported by edge-native clouds and orchestration capabilities. Operators therefore have a better opportunity than any other player in the edge-native value chain to support edge-native application developers. Operators can both give developers access to the capabilities of a converged edge-native cloud/networking fabric so that they can develop and test new edge-native services, and support DevOps teams by providing location-sensitive deployment and management of the resulting services across such a fabric. However, operators need to explore ways of attracting and building a developer community.

- **Collaborate with other operators.** Operators are stronger together in the edge-native market, especially when it comes to recruiting a critical mass of developers and to providing a sufficiently broad edge-native cloud footprint to attract enterprises that need to offer new use cases across countries, regions and even worldwide. Operators will progress faster up the edge-cloud value chain and will add further value to their edge locations and edge-native network clouds if they co-operate with their peers. In doing so, operators can potentially create a new operator-led marketplace for emerging edge-native use cases that can make use of operators' unique ability to converge cloud and networking, their cloud agnosticity and their combined footprints.

5. Conclusion

Operators can play a strong supporting role for edge-native services that require a highly distributed fabric of location-specific clouds. Such services, which will make use of AR/VR, AI, computer vision, autonomous mobility and other advanced technologies, are in early stages of development today, but promise to revolutionize user experiences and business process optimization over the next decade. Edge-native services will serve a hyperconnected web of devices and will therefore need the ability to migrate and/or be fragmented across the ubiquitous compute platforms that are available in much closer proximity to devices and users than they are today.

Operators are potentially in a strong position because their networks are, by nature, distributed and ubiquitous across their geographic footprints. Network cloudification necessarily entails building a distributed, edge-native cloud fabric across that footprint too. Operators are engaged in a series of network transformations that will eventually introduce cloud into different network domains (mobile, fixed access and transport). Leading operators have a unified vision for such a network cloud, and envisage that over the next few years, they will put in place a common, distributed and hybrid cloud-based platform to support all software-only network functions and their management and operational systems. The network cloud must extend to the network edge in order to support access network functions, but it will also need to be instantiated in many other locations, and operators will require a holistic way of orchestrating network function workloads across thousands of cloud locations to provide a 'network'. Operators will then have a better opportunity than many other types of infrastructure provider to monetize a distributed fabric of edge-native clouds and common orchestration capabilities to support edge-native services because these services will have similar requirements to virtualized and cloudified network functions. Operators can also rely on a long-standing tradition of co-operating with their peers to extend their network/cloud footprints over partner networks/clouds in order to serve applications that require an extended geographic reach.

Operators that both understand the need for a holistic approach to transforming their networks and align this transformation with investment into an edge-native cloud fabric with appropriate orchestration will be prepared for the coming revolution in edge-native service development and deployment. By planning and executing effective edge-native strategies, these operators will be able to play critical, high-value roles in the AI of Things value chain as it unfolds.

6. About the author

Caroline Chappell (Research Director) heads Analysys Mason's Cloud research practice. Her research focuses on service provider adoption of cloud to deliver business services, support digital transformation and re-architect fixed and mobile networks for the 5G era. She is a leading exponent of the edge computing market and its impact on service provider network deployments and new revenue opportunities. She monitors public cloud provider strategies for the telecoms industry and investigates how key cloud platform services can enhance service provider value. Caroline is a leading authority on the application of cloud-native technologies to the network and helps telecoms customers to devise strategies that exploit the powerful capabilities of cloud while mitigating its disruptive effects.

Prior to joining Analysys Mason, Caroline was Practice Leader, Cloud and NFV, at Heavy Reading. She has over 25 years' experience as a telecoms software analyst and consultant working for research companies including Current Analysis and Ovum. Her areas of coverage spanned cloud services, digital service development and delivery, B/OSS, customer experience management and analytics, Internet and cloud security, professional/managed services and service provider wholesale strategies in such areas as IP/Ethernet, enterprise cloud solutions and fixed and mobile wholesale access. Caroline started her career as a software programmer at what is now BAE Systems. This has given her a lifelong interest in software architecture and engineering approaches, most recently including lean/agile development and DevOps, microservices architecture and model-driven, intelligent software automation.

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