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Best Practices to Deploy Sustainable and Resilient Data Centers at Scale at the Network Edge

White Paper 80

Version 1

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Executive summary

To support the growth of data-intensive and ultra-low latency applications, local edge data centers must be scaled out in a wide range of environments. Deploying these data centers at scale presents unique challenges for power and cooling, energy efficiency, management, and maintenance. Data center owners and operators must elevate sustainability from a concern, to a core value to minimize energy use, GHG (greenhouse gas) emissions, and waste. These data centers must also be designed to meet resiliency and performance targets. In this paper, we define the network edge, and briefly describe how the telco cloud and IT cloud architectures will converge into a single and complementary architecture. We define the three types of distributed local edge data centers that are the building blocks of this convergence. From here we analyze the unique scaling challenges and propose best practices to help data center owners and operators deploy sustainable and resilient distributed local edge data centers at scale, at the network edge.

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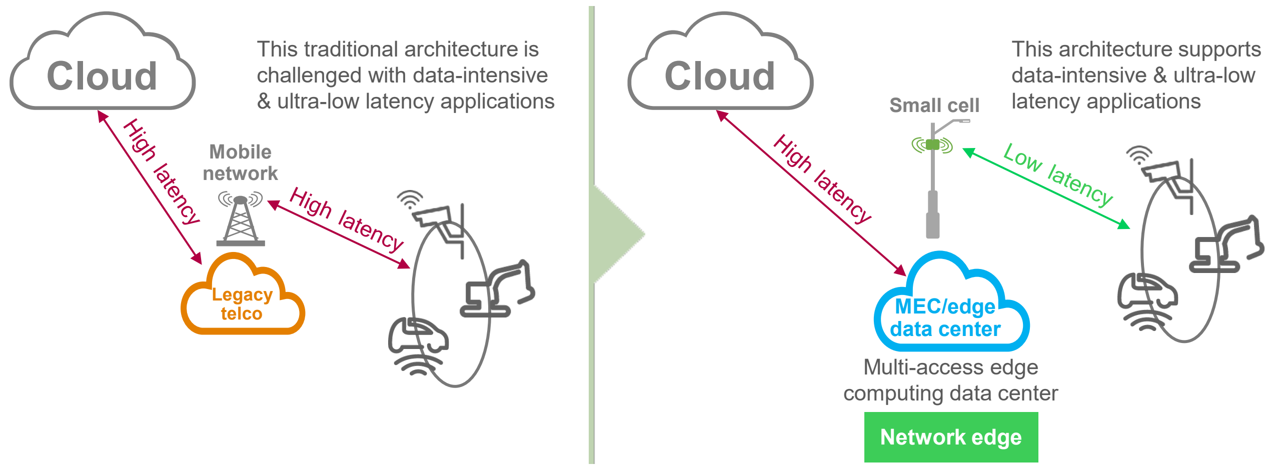
Introduction

The term "network edge" has been in use for decades in the networking community and refers to the interface point of computer networks and the internet and is an important security boundary. This paper focuses on the "network edge", "**a location where a local edge data center interfaces with the Internet/cloud to support data-intensive and ultra-low latency applications.**"[1] For simplicity, we call these data centers "distributed network edge data centers" for the rest of the paper.

As illustrated in **Figure 1**, in order to support data-intensive and ultra-low latency applications such as high-definition streaming media, augmented reality (AR) / virtual reality (VR), autonomous vehicles, autonomous mining, and industrial 4.0, we must place compute and storage resources at the network edge. Bringing these resources closer to the data source or consumers of the data eliminates the latency from the central core cloud data centers or regional edge data centers to the edge devices like IoT devices.[2]

Figure 1

Distant data centers are challenged to support data-intensive and ultra-low latency applications. Placing compute, storage, and telco resources together at the network edge reduces latency (future architecture).



A secondary requirement to reduce latency is to use faster network communications between the network edge data center and the edge devices. The network must also provide high bandwidth. 5G is an example of faster and high-bandwidth communications technologies. When the distributed edge network data center operates both IT cloud services, and telco functions and controls, it is called a multi-access edge compute (MEC)/edge data center.

We see three evolutions at the network edge:

- **General-purpose edge computing** – Also known as on-premise edge computing, includes compute and storage that are owned and operated by end users[3]. Note that general-purpose edge computing is out of scope for this paper.
- **Telco cloudification** – Network edge for telco exists for 3G/4G to control and orchestrate traditional closed and proprietary telecom network architecture such as base stations and points of presence (PoPs). The traditional, closed, and proprietary telecom network architecture is becoming cloudified by leveraging technologies such as network function virtualization (NFV), software defined networks (SDN), open source and DevOps, and 5G. Telco cloudification means to host or use network resources and services from the cloud. In

[1] Schneider Electric definition

[2] For more information see White Paper 226, *The Drivers and Benefits of Edge Computing*.

[3] Telco equipment providers or system integrators may also operate general-purpose edge computing

essence, cloudification decouples network functions from proprietary telco hardware and operates instead on general-purpose IT servers (i.e., commercial-of-the-shelf servers).

- **IT cloud expansion from central core cloud to the network edge** – When the general-purpose edge computing data centers are owned and operated by C&SP[4] to provide cloud services, they are called distributed cloud data centers. Traditional IT cloud architecture is extending from the central core cloud and regional edge data centers to the network edge. For example, hyperscalers are starting to provide cloud services hosted at the network edge. Some of these services include Amazon Outposts, Google Anthos, and Microsoft Azure Stack Edge. Note that hyperscalers are also partnering with telcos to host telco controls. As distributed network edge data centers are deployed, there is an opportunity to incorporate telco functionality in a converged solution.

We believe that the traditional telco cloud and traditional IT cloud architectures are beginning to converge to a single and complementary architecture, and we expect this transformation will continue for the next 10 years. To support current and future edge applications, CSPs must distribute data centers out to the network edge. **These distributed network edge data centers are part of a data center architecture including central core, regional edge, and network edge. However, this paper covers only the network edge portion of this architecture.**

Distributed network edge data centers must be designed with the right availability and maintained to avoid unexpected power outages and other forms of unscheduled downtime that would disrupt critical applications. Furthermore, distributed network edge data centers must be environmentally sustainable in terms of manufacturing, deployment, and operation because of their massive build-out. In fact, one could argue that because they're so distributed, the environmental impact could be much greater than that of core data centers with tens of megawatts of IT load.

In this paper, we define the network edge and the three types of distributed network edge data centers that are driving this convergence. From here we analyze their unique scaling challenges and propose best practices to help data center owners and operators deploy sustainable and resilient distributed network edge data centers at scale. These best practices apply to power, cooling, enclosures, management, cybersecurity, prefabrication/standardization, and maintenance/repair.

Defining distributed network edge data centers

Service providers are creating alliances and deploying the following three types of distributed network edge data centers in order to support the cloudification and convergence of telco cloud and IT cloud architectures.

- Legacy telco data center
- Distributed cloud data center (emerging)
- Multi-access edge computing (MEC)/edge data center (future)

<u>We expect both the legacy telco data center and distributed cloud data center to converge into MEC/edge data centers in the future</u>. We describe these three distributed network edge data center types below:

Legacy telco data center

These data centers act as the functions and controls of traditional closed and proprietary telecom network architecture such as central offices, network aggregation,

[4] C&SP - cloud and service providers, which includes hyperscalers and colocation providers

access network/RAN (i.e., base stations). The telco equipment in these data centers are subject to more regulatory requirements than IT equipment, for example NEBS in the U.S. and ETSI in Europe. Most telco equipment requires -48V direct current (DC) voltage. As mentioned in the section, "Telco cloudification" evolution, telco operators have started "cloudifying" their network which de-couples network functions from proprietary telco hardware leading to the emerging distributed cloud data center described next.

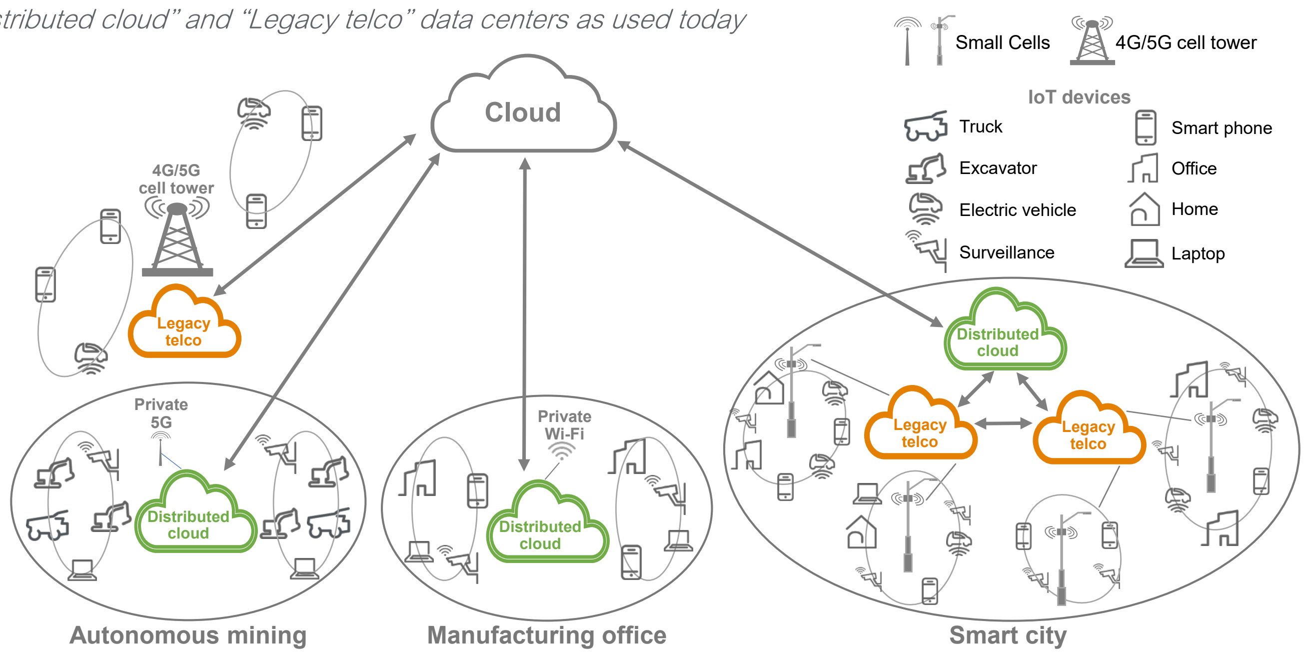
Distributed cloud data center (emerging)

These data centers act as an extension of the IT cloud, owned and operated by hyperscalers, colocation providers, or sometimes telcos. For example, Gartner refers to these as "the distribution of public cloud services to different physical locations, while operation is the responsibility of the originating public cloud provider." Gartner further explains that "Distributed cloud computing is a style of cloud computing where the location of the cloud services is a critical component of the model."[5] Google defines its distributed cloud as "a portfolio of fully managed hardware and software solutions which extends Google Cloud's infrastructure and services to the edge and into your data centers." Google explains that their distributed cloud "is enabled by Anthos and is ideal for local data processing, edge computing, on-premises modernization, and meeting sovereignty, strict data security, and privacy requirements."[6] Note that the ownership of these data centers is evolving to a partnership between hyperscalers, colocation providers, and telcos also known as communications service providers (CSP). This convergence is highlighted in the next subsection, multi-access edge computing (MEC)/edge data center.

Figure 2 illustrates these two types of distributed network edge data centers. The smart city application uses legacy telco and distributed cloud data centers. The legacy telco data centers provide telco functions required by individual smart city services such as firewall security while the distributed cloud data center provides the data processing required by services such as smart parking.

Figure 2

"Distributed cloud" and "Legacy telco" data centers as used today



[5] Hype Cycle for Edge Computing, 2020

[6] https://cloud.google.com/distributed-cloud

Multi-access edge computing (MEC)/edge data center (future)

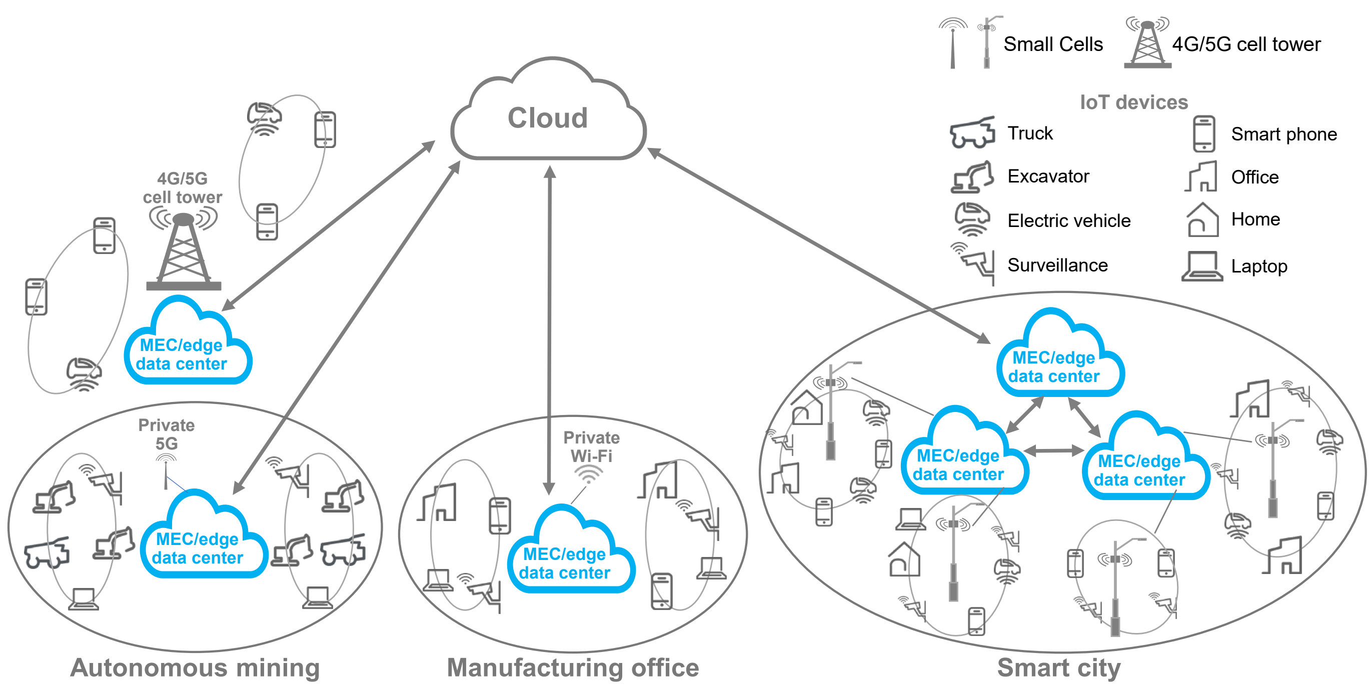
While Figure 2 illustrates how legacy telco data centers are used today and distributed cloud is emerging, Figure 3 illustrates how we envision MEC/edge data centers used in the future. In essence we see the distributed cloud and legacy telco data center functionality converging into a MEC/edge data center. When legacy telco transforms from proprietary to open and software defined (as with 5G), they transform from proprietary hardware to more standard IT server hardware – identical to distributed cloud. This opens up the possibility to host cloud services and telco controls in the same data center.

A MEC/edge data center operates both IT cloud services, and telco functions and controls at the network edge, owned and operated by CSPs. Combining these give rise to certain benefits. For example, European Telecommunications Standards Institute (ETSI) states that a "MEC offers application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the network. This environment is characterized by ultra-low latency and high bandwidth as well as real-time access to radio network information that can be leveraged by applications"[7] Intel states that "by distributing processing, analytics, and service delivery to the edge of the network, MEC also relieves congestion in the core network and conserves capacity in backhaul transmission networks. MEC contributes to higher network efficiency and reduced operating costs."[8]

Figure 3 illustrates how these MEC/edge data centers may be used across three different applications. For example, edge computing with 5G may be used in autonomous mining where onsite machine learning predicts where to search for valuable minerals. Or in a manufacturing facility to control wireless robotics.

Figure 3

Illustration of how MEC/edge data centers may be used in the future



[7] https://telcocloudbridge.com/blog/what-is-edge-computing-and-mec/

[8] https://builders.intel.com/docs/networkbuilders/enabling-mec-as-a-new-telco-business-opportunity.pdf

Figure 4 shows examples of the three types of distributed network edge data centers followed by a summary of characteristics in **Table 1**.

Figure 4

Examples of distributed edge data centers

(a) Legacy telco DC (Base station) (b) Distributed cloud DC (Amazon Outpost) (c) MEC/edge DC

Summary of distributed network edge data centers

Table 1 summarizes the typical characteristics of the three types of distributed network edge data centers such as functions, IT device types, and ownership. We describe the major differences between them in detail as follows.

Functions – Distributed cloud data centers provide data processing and storage functions. Legacy telco data centers provide network functions and controls, while MEC/edge data centers provide both.

IT device types – Distributed cloud data centers operate on commodity general-purpose IT devices or OCP-type servers. Legacy telco data centers operate on costly proprietary telco gear and software. Though some MEC/edge data centers may be deployed today with legacy telco gear, we believe in the future they'll operate on 100% commodity general-purpose IT devices for both IT and telco functions.

Ownership – Distributed cloud data centers are owned and operated by cloud and service providers including hyperscalers and colocation providers. Legacy telco data centers are owned and operated by the telcos, while MEC/edge data centers may be owned and operated by any of these service providers (i.e., CSPs).

Typical rack density – Distributed cloud and MEC/edge data centers have much higher rack density than the legacy telco data centers.

Power physical infrastructure – The IT devices in a distributed cloud data center are powered by AC. Most of the telco devices in a legacy telco data center are powered by -48V DC. The devices in a MEC/edge data center can be powered by both AC and DC, and progressively adopting OCP standards.

Cooling physical infrastructure - Distributed cloud and MEC/edge data centers may need to adopt liquid cooling for high density racks.

Table 1

Typical characteristics of three types of distributed network edge data centers

Attributes		Legacy telco data center	Distributed cloud data center	MEC/edge data center
Functions		• Network functions and controls	• Data processing and storage	• Data processing and storage • Network functions and controls
IT device types		• Telco-type devices	• General-purpose IT devices[9] • OCP-type servers	• Telco-type devices • General-purpose IT devices • OCP-type servers
Ownership		• Telcos	• Hyperscalers • Colocation providers	• Telcos • Hyperscalers • Colocation providers • Partnerships
Typical # of racks		• a few racks or rack units (U)	• a few racks or rack units (U)	• a few racks or rack units (U)
Typical rack densities		• Below 5kW/rack	• 3-30kW/rack	• 3-20kW/rack
Physical infrastructure	Site	• Shared building • Indoor / outdoor	• Shared building • Indoor / outdoor	• Shared building • Indoor / outdoor
	Power	• No MV, limited LV and UPS • No genset • -48V DC	• No MV, limited LV and UPS[10] • No genset • AC[11]	• No MV, limited LV and UPS • No genset • AC/-48V DC/hybrid
	Cooling	• Limited cooling • Air cooled	• Limited cooling • Air cooled	• Limited cooling • Air cooled / liquid cooled

The nature of diverse equipment, distributed physical infrastructure, massive data center fleets, and outdoor conditions lead to unique challenges of deploying at the edge of the network, which we discuss in detail in the next section.

Challenges of deploying distributed network edge data centers

Distributed network edge data centers will be deployed at scale to support new data-intensive and ultra-low latency applications. They will come in different sizes and configurations and will operate in a wide range of environments. As more critical applications are supported by these data centers, we must ensure that they are highly available and properly maintained, to avoid unexpected power outages and other forms of unscheduled downtime that would disrupt critical applications. Furthermore, minimizing the environmental sustainability impact from deploying these data centers at scale is critical. This section summarizes seven key scaling challenges IT personnel and data center designers need to address.

- Diverse equipment makes it difficult to quickly scale-out deployments
- Limited space to build or expand
- Harsh outdoor environments increase risk of damaging IT equipment
- Minimizing environmental impact of scaling out distributed network edge data centers

[9] It could be ruggedized servers for harsh environments.

[10] It could be inverters with 2-4hr runtime battery depending on the site.

[11] Although OCP-type server modules are powered by DC, the rectifiers are powered by AC.

- Reporting environmental impact of scaling out distributed network edge data centers
- Lack of on-site staff for operations and maintenance
- Vulnerability of physical infrastructure equipment to cyber attack

The following sub-sections describe each challenge in detail.

Diverse equipment makes it difficult to quickly scale-out deployments

The continuous evolution of telco at the network edge leads to a complex selection and configuration of IT (and initially some telco gear) as well as the physical infrastructure components such as UPS / inverters, cooling, and racks. For example, 4/4.5G telco controls operate on DC power, 5G operates on DC or AC power, and general-purpose IT servers (used for data processing) are powered by AC or DC. Cooling high density racks may require liquid-cooled solutions when air-cooled solutions aren't feasible. Infrastructure parts must be selected to not only support the intended application, but also be compatible with each other and conditions at the local site. These diverse requirements benefit from standardization. Standardization simplifies production, installation, troubleshooting and maintenance. For more information on the benefits of standardization, see White Paper 116, *Standardization and Modularity in Data Center Physical infrastructure*.

Limited space to build or expand

Space within a building or city sidewalk is a sparse resource. Owners generally want to maximize use of their space to serve their primary business function, while minimizing space used for supporting functions and systems such as distributed network edge data centers. For example, a smart city application may need to install a data center beneath the sidewalk. Similarly, retail storefronts try to maximize the footprint of sellable products. It's common to find small, multi-purpose rooms serving a range of support functions. In the case of the retail, a small back room may be the break room, the office supply closet, the safe room, and the IT room, all in one. As a result, allocating space for distributed network edge data centers is challenging.

Harsh outdoor environments increase risk of damaging IT equipment

Many distributed network edge data centers are deployed in outdoor environments where the temperature, humidity, and dust pose potential downtime risks to IT systems.[12] Therefore, the IT rack enclosure(s) require specific attributes. For example, an industrial IoT edge rack deployed in harsh environments requires a higher physical infrastructure ingress protection (IP) rating (such as NEMA4 & IP 65). Physical security is also a challenge for outdoor environments due to vandalism and theft.

Table 2 summarizes three categories of environments at the network edge including IT, commercial & office, and industrial & harsh, (listed in order of increasing risk from left to right). Distributed network edge data centers can be located in any one of these environments. For more information on these three types of edge computing environments, see White Paper 278, *Three Types of Edge Computing Environments and their Impact on Physical Infrastructure Selection*.

[12] Standard-type IT gear like Intel and OCP-type servers, however, ruggedized equipment tends to lower this risk.

Table 2

Three types of distributed edge data center environments and their environmental conditions with respect to IT equipment unless specified

Aspects	IT environment	Commercial & office environment	Industrial & harsh environment
Temperature	Temperature controlled	Semi-controlled temperature	Wide range of temperature, could be indoor or outdoor
Dust/water	Low risk of dust/water	Low levels of dust	High risk of dust/water
Noise	Low noise restrictions for occupants	Noise restrictions for building occupants	Low noise restrictions for building occupants
Shock/vibration	Low risk of shock/vibration	Low risk of shock/vibration	High risk of shock/vibration
Access	Restricted access	Lacks restricted access	Lacks restricted access

Minimizing environmental impact of scaling out distributed network edge data centers

Service providers must have sustainability as a core value to minimize energy use, GHG emissions, and waste. Customer requirements, government regulations, business value, and ESG (environmental, social, and governance) investment are all driving environmental sustainability. For more information, see White Paper 64, *Why Data Centers Must Prioritize Environmental Sustainability: Four Key Drivers*.

It's easy to overlook the environmental impact of distributed network edge data centers due to their small size. However, the annual power usage effectiveness (PUE) of today's distributed network edge data centers is poor, typically around 2.0, due to the low power density (i.e., ~1kW/rack or less than 1kW/m^2) of legacy IT / telco equipment. In contrast, the annual PUEs of central core cloud data centers can be as low as 1.1. Furthermore, the network edge with 5G will consume three times more energy on average today than 4G[13]. The buildout of large quantities of distributed network edge data centers potentially poses a serious environmental impact from energy use, greenhouse gas emissions, and waste.

Schneider Electric's analysis predicts 7.5 million new micro data centers installed by 2025. By 2040, the global footprint at peak power could reach 192GW, with energy consumption exceeding 1,679TWh, much more than the energy consumed by the central core cloud data centers for the same period. This will also contribute between 450,000 to 600,000 tons of CO_2 emissions per year. Schneider Electric has developed a TradeOff tool, *Data Center & Edge Global Energy Forecast*, to help the data center industry estimate the energy consumption as shown in **Figure 5**.

Therefore, making distributed network edge data centers sustainable at scale, especially with mmWave high band 5G or 6G, is crucial from a resource and cost perspective. For example, the Alliance for Telecommunications Industry Solutions (ATIS) released a White Paper titled, *Green G: The Path Toward Sustainable 6G*, to help address climate change and environmental sustainability for future 6G applications. The TIA-942 standards organization is also working on releasing new standards to improve distributed edge data center sustainability.

Environmental sustainability is a core value for hyperscalers and large colocation providers, leading to optimized energy use, water consumption, waste, and circularity of their central core cloud data centers. They are setting goals and

[13] https://eujournal.org/index.php/esj/article/view/13918/13977 Accessed on March 16, 2022

announcing commitments on environmental sustainability. For example, Google declared, "Achieve zero waste to landfill for our global data center operations, and 24/7 carbon-free energy by 2030." Meta declared, "We are committed to reaching net zero emissions across our value chain in 2030." The four major drivers for data centers to become sustainable include colocation tenant requirements, government regulations, business value, and ESG investment. For more information see White Paper 64, [Why Data Centers Must Prioritize Environmental Sustainability: Four Key Drivers]().

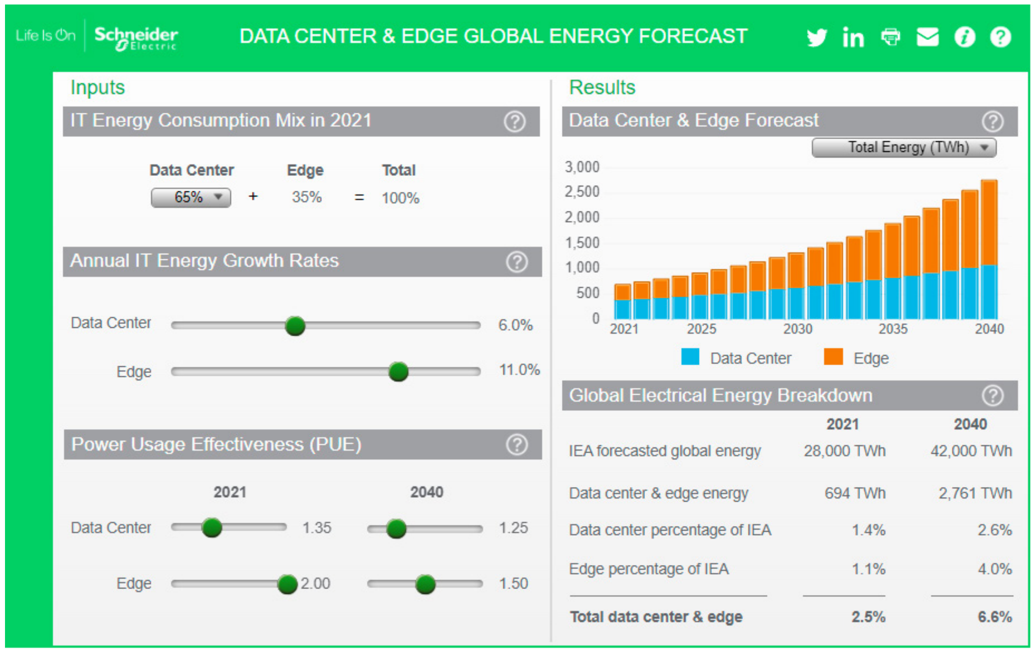


Figure 5

Screenshot of Data Center & Edge Global Energy Forecast TradeOff Tool

Reporting environmental impact of scaling out distributed network edge data centers

Distributed local edge data center owners and operators need to report their environmental impact to show their environmental progress. The environmental impact from distributed edge data center deployments may include energy consumption, greenhouse gas (GHG) emissions, water usage, waste, and land & biodiversity. The main challenge with reporting on large quantities of distributed network edge data centers is that they're installed in a wide variety of locations and environments. For example, we need to meter the energy consumption of each data center continuously throughout the year and also know the carbon emission factors for each location to calculate the GHG emissions. We also need to choose the right metrics, frameworks, and standards as guidance for environmental impact reporting. For more information see White Paper 67, [Guide to Environmental Sustainability Metrics for Data Centers]().

Lack of on-site staff for operations and maintenance

Some equipment in distributed network edge data centers will experience problems, such as equipment failure or IT devices that need a reboot, as is the case with all data centers. It is more difficult to troubleshoot these problems without IT or facilities staff on-site, which is typical of most network edge sites. This challenge is compounded by having a large number of geographically dispersed data centers. This lack of on-site staff is the main challenge in operating and maintaining distributed network edge data centers at scale.

Vulnerability of physical infrastructure equipment to cyber attack

The adoption of 5G technology at the network edge leads to increased cybersecurity risks due to more access points. These connections offer potential points that hackers can attack. This challenge is multiplied further because these distributed data centers are deployed in great numbers across a wide range of geographically dispersed sites. For example, the distributed edge data center located outdoors may have a significant number of points cyber criminals can exploit.

Best practices for deploying distributed network edge data centers

To address the above challenges, IT personnel and data center designers need to implement sustainable and resilient distributed edge data center best practices. This is possible by leveraging best practices implemented in typical IT environments over the past two decades and adopting unique best practices at the network edge. This section summarizes some of these best practices to help IT personnel and data center designers deploy sustainable and resilient distributed network edge data centers.

- Use monitorable power gear with lithium-ion battery backup
- Use air or liquid cooling according to density, environment, and space constraints
- Choose robust IT enclosures designed for distributed network edge data centers
- Deploy resilient and sustainable prefabricated modular solutions
- Implement cybersecurity best practices
- Invest in monitoring and management software
- Leverage an ecosystem of partners for a complete solution

The following sub-sections describe each best practice in detail.

Use monitorable power gear with lithium-ion battery backup

Proper power infrastructure systems like uninterruptible power supplies (UPSs) can minimize the risk of downtime. UPSs, typically integrated into the IT enclosures, provide uninterrupted and conditioned power to edge IT loads.

Lithium-ion batteries for UPSs, rectifiers, and inverters are recommended. Compared with valve-regulated lead acid (VRLA) batteries, lithium-ion batteries have many benefits such as longer life (typically 10 years), much longer runtime for a given size, embedded battery monitoring systems for safety, and lower environmental impact. A lifecycle analysis from Schneider Electric shows that lithium-ion has a lower overall environmental impact compared to VRLA batteries, and we anticipate further improvement in the future. For more information on this topic, see White Paper 71, *Understanding the Total Sustainability Impact of Li-ion UPS Batteries*. They can also better endure harsh environments that experience a broad temperature range – over 40°C. Moreover, battery replacements are reduced thereby eliminating the risk of human error during replacements. White Paper 231, *FAQs for Using Lithium-ion Batteries with a UPS*, discusses the common questions about lithium-ion batteries and their use in UPSs in detail.

Figure 6 shows an example of distributed edge data center systems with efficient and effective power protection at the network edge. Redundant power systems are recommended for critical IT applications to achieve concurrent maintainability.

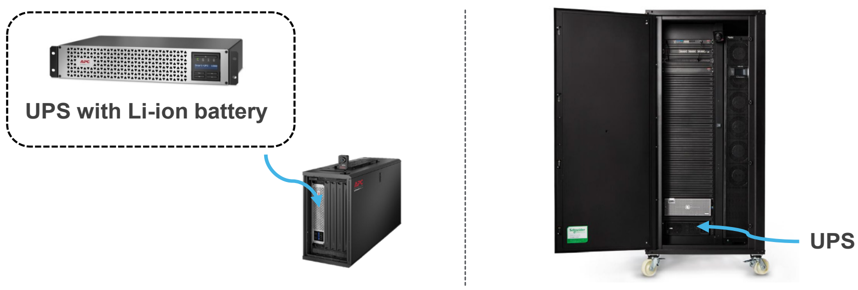


Figure 6

Example of local distributed edge data center system with proper power protection

Use air or liquid cooling according to density, environment, and space constraints

Proper cooling infrastructure like air conditioners can minimize the risk of downtime for the deployments at the network edge. Dedicated air conditioners such as a self-contained air conditioner can be mounted inside a ruggedized IT enclosure (discussed in next section), which can avoid dust and keep the temperature and humidity regulated even when the room environment is not. Figure 7 shows an example of a ruggedized distributed edge data center system integrated with an air-cooled and self-contained air conditioner.

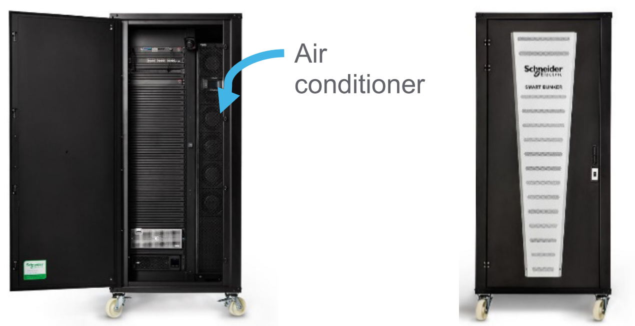


Figure 7

Example of distributed edge data center system with self-contained air conditioner

Compared with air cooling, liquid cooling can provide several benefits such as higher energy efficiency, smaller footprint, lower TCO, enhanced server reliability, and lower noise. Figure 8 shows an example of IT chassis immersive liquid cooling technology, which can be used to cool high density racks at the network edge. For more information, see White Paper 265, *Liquid Cooling Technologies for Data Centers and Edge Applications*. Redundant cooling systems are also recommended for critical edge IT applications to achieve concurrent maintainability.

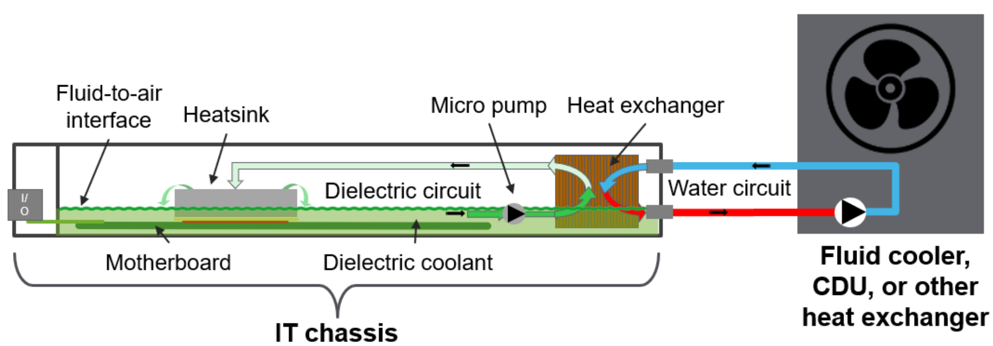


Figure 8

Example of an IT chassis immersive liquid cooling solution

Choose robust IT enclosures designed for distributed network edge data centers

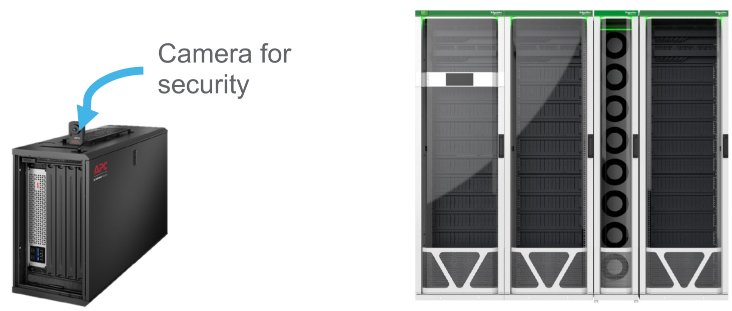
Purpose-built IT enclosures can address many challenges at the network edge such as environmental risks, space constraints, and physical security. The best practices for robust IT enclosures are listed below.

- **Rugged enclosure design** – Durable enclosure material (i.e., stainless steel, aluminum), thermal insulation, coatings or paints, double-wall panels, and robust cable fittings (such as Roxtec) are designed to address environmental risks including dust particles or other contaminants, water leaks, corrosion etc. Ruggedized enclosures should be selected when the environments are harsh and uncontrolled at the network edge. Meanwhile, some IT equipment manufacturers are also developing ruggedized IT servers[14], which are designed to a higher standard for temperature range, dust, vibration, shock, etc. This kind of server will add a premium over standard type IT equipment.
- **Flexible mounting enclosure design** – Wall-mounted enclosures allow placement of distributed network edge data centers high on the wall, addressing the floor space constraint in retail and manufacturing environments. This also adds a level of protection against malicious intent, as someone would have to get on a stool or ladder to reach it.
- **Physical-security enclosure design** – To help avoid malicious or unintended tampering at the network edge lock IT cabinets, set alerts when doors are propped open, use biometric access locks, employ security cameras, or use a combination of these approaches.

Figure 9 shows two examples of purpose-built IT enclosures for the deployment at the network edge.

Figure 9

Examples of purpose-built IT enclosures used for distributed network edge data centers



6U purpose-built IT enclosure   Ruggedized purpose-built IT enclosure

Deploy resilient and sustainable prefabricated modular solutions

A prefabricated modular network data center is a data center that is pre-engineered and has its systems (hardware and software) pre-assembled, integrated, and tested in a factory environment to shorten deployment timeframe and improve predictability of performance and cost. The prefabricated modular network data centers can be deployed in various configurations, defined by standards and options. This type of network data center solution can also scale and adapt to business needs such as turn-key solutions, fast delivery time, and fast deployment. These solutions can be deployed outdoors thereby providing an alternative to retrofitting existing buildings or building new structures at the network edge. Prefabricated modular solutions also allow distributed edge data center owners or operators to: deploy resources as needed; scale as demand grows; and reduce construction waste, etc., which can help meet sustainability goals. More information on this topic is available in this Schneider Electric blog.

All-in-one designs include UPS, cooling, racks, PDUs, etc. **Figure 10** shows an example of a prefabricated modular solution designed for high density racks that are cooled with liquid cooling. The OCP-type servers can also be customized into the

[14] https://www.delltechnologies.com/asset/en-us/products/servers/briefs-summaries/xr-series-brochure.pdf Accessed on March 16, 2022

prefabricated solution. For more information on prefabricated solutions, see White Paper 165, *Types of Prefabricated Modular Data Centers*.

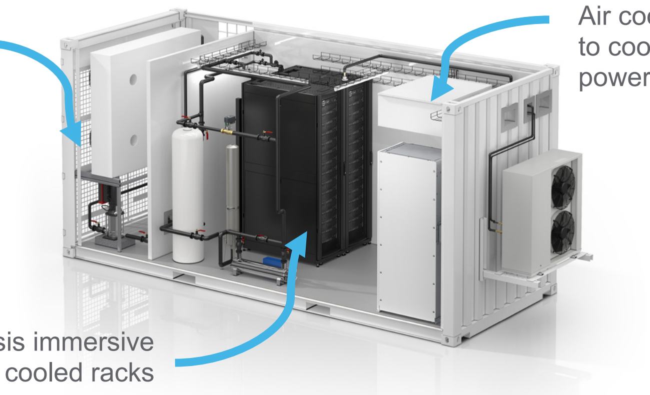


Figure 10

Example of a prefabricated modular distributed data center solution with both liquid cooling and air cooling

Implement cybersecurity best practices

Managing cyber-attack risk requires proper implementation of network segmentation and various security appliances (e.g., IEC 62443 compliancy). It also requires actions on the part of the users to maintain their required level of cybersecurity. The four key elements of an effective cybersecurity strategy at the edge include:

1. Device selection criteria
2. Secure network design
3. Device setup / configuration
4. Operation and maintenance

For more information on each element, see White Paper 12, *An Overview of Cybersecurity Best Practices for Edge Computing*.

Invest in monitoring and management software

A best practice used in typical IT environments is to monitor and manage IT systems from a centralized location or remotely. Data center infrastructure management (DCIM) is a software management platform that can be used to address the lack of on-site staff at the network edge. DCIM supports IT personnel by providing visibility into their infrastructure across hybrid environments, either on-site or remotely, while helping with their work/life balance during distributed edge data center operation and life cycle management. Next-generation DCIM provides big data analytics and AI, making maintenance more predictive by analyzing data in real time. For example, by analyzing UPS age and efficiency, battery age, cooling performance, and more, DCIM can provide IT staff with proactive recommendations, ensuring they have adequate backup in the event of an incident. White Paper 281, *Essential Guidance on DCIM for Edge Computing Infrastructure*, discusses essential DCIM functions for edge computing in detail. Figure 11 shows an example "health" scorecard for a fleet of UPSs with next-generation DCIM.

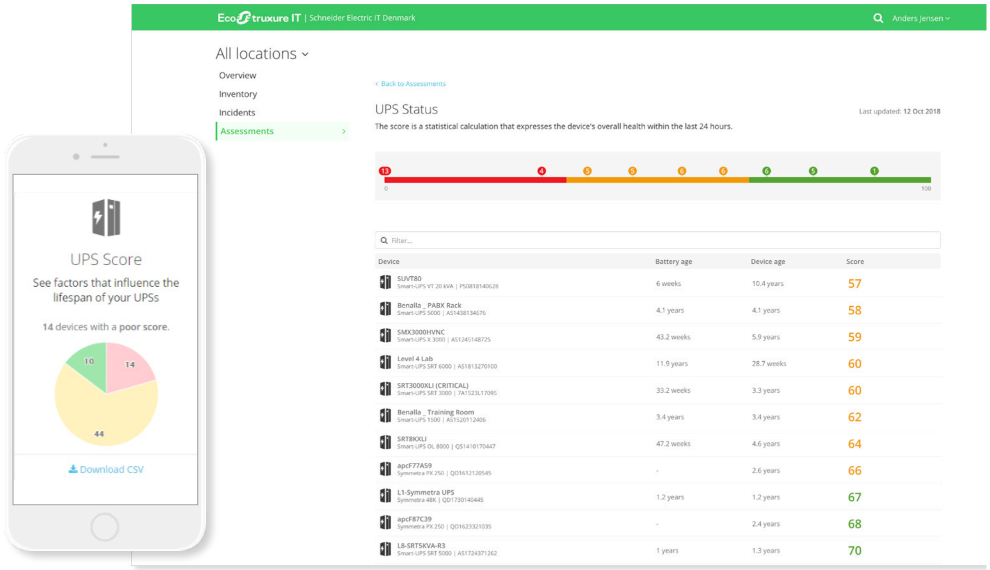


Figure 11

An example screenshot showing a health scorecard for a fleet of managed UPSs

In order to minimize environmental impact from distributed network edge data centers, the best practice is to use software tools to visualize energy use, GHG emissions, and waste recycling. These are essential for visibility, target setting, and reporting. Figure 12 shows an example of a software used to report on carbon and enterprise sustainability data (energy, water, waste, supply chain, etc.) For more information on this topic, see White Paper 54, *Environmental Sustainability Management (ESM) Software for Colocation Data Centers*.

Figure 12

An example screenshot showing a 3-month report of GHG emissions by source type.

(Schneider Electric Resource Advisor used)

Leverage an ecosystem of partners for a complete solution

An integrated ecosystem of partners is crucial to effectively address the many challenges listed above and to reduce the complexity of the technology & solutions, the security requirements, and the services involved for distributed network edge data centers. For example, IT personnel need to work closely with different partners such as system integrators, software providers, physical infrastructure vendors, etc., to leverage a wide range of experience across all disciplines, which can deliver fully integrated distributed edge data center systems.

This ecosystem promises faster and easier deployment and lower defects compared to assembling your own solution from a disparate group of partners. White Paper 277, *Solving Edge Computing Infrastructure Challenges*, discusses this ecosystem in detail. Figure 13 illustrates an integrated ecosystem of partners that work together to provide a total solution for distributed edge data center customers.

Figure 13

The integrated ecosystem of partners for distributed edge data center deployments

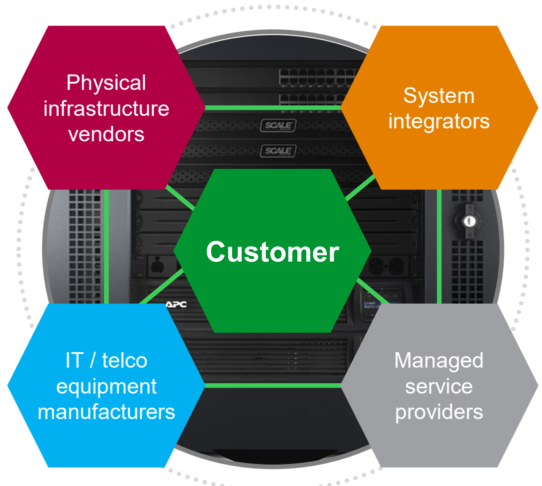
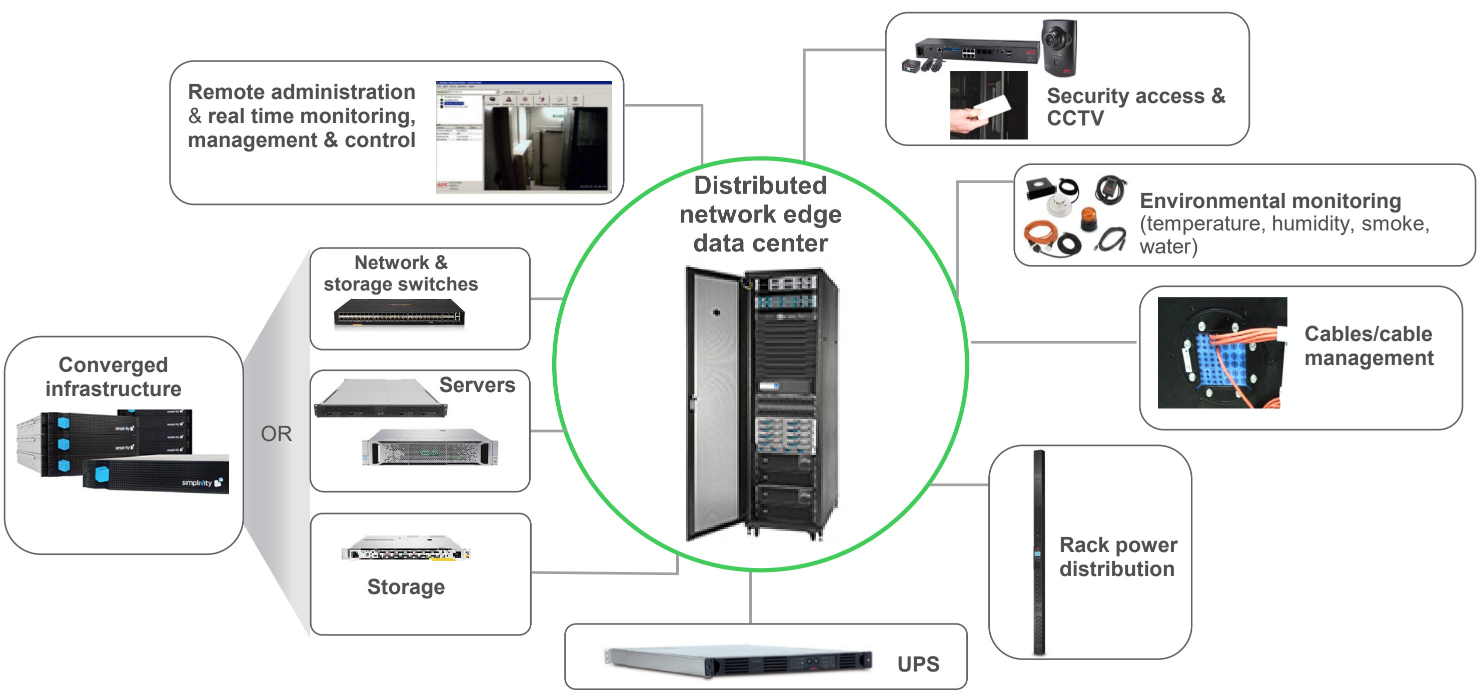


Figure 14 shows an example of a fully integrated distributed edge data center solution that leverages an ecosystem of partners such as IT solution providers, IT equipment manufacturers, and physical infrastructure vendors. According to World Wide Technology[15], integrated and pre-configured solutions "can reduce field engineering costs by 25% to 40%, increase order processing speed by 20%, and reduce maintenance costs by 7%".

Figure 14

Example of a fully integrated distributed edge data center solution



[15] https://www.wwt.com/api/attachments/5d35faae596f240083ddf469/file, Accessed on March 16, 2022

Conclusion

In the future, service providers can potentially deploy hundreds of thousands of distributed local edge data centers at the network edge to power the cloudification and convergence of telco cloud and IT cloud. Deploying distributed network edge data centers at scale has unique challenges related to power and cooling, remote management, environmental impact, and cybersecurity due to and a wide variety of locations and environments. To protect the planet, service providers must elevate sustainability from a concern, to a core value, to minimize energy use, GHG emissions, and waste.

Best practices to support the build-out at the network edge include effective and sustainable power and cooling approaches, ruggedized IT enclosures, robust and sustainable prefabricated solutions, and monitoring and management software. An ecosystem of partners provides fully integrated data center solutions at the network edge.

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