# Private Mobile Edge Computing and 5G

## Private MEC and 5G — A Powerful Combination

Enterprises worldwide benefit from adopting cloud computing. Today, however, there are enterprise applications that must remain on-premises for business, legal, and technical reasons. At the same time, the enterprise networks that connect these applications to users and devices are straining under increasing workloads. Wired ethernet networks provide performance but are expensive to upgrade and extend. Meanwhile, traditional enterprise Wi-Fi is cost-effective and flexible but suffers from challenges in reliability, coverage, and performance.

A solution that combines cellular 5G technologies with mobile edge computing (MEC) can address these enterprise challenges. The unique combination of a high-performance private 5G network with on-premises cloud computing on AWS Outposts can enable new applications that were previously technically or operationally infeasible.

## Addressing On-premises Enterprise Workloads

Cloud adoption among enterprises continues to gain momentum. The cloud begins by providing on-demand computing, storage, and networking and extends to a much richer set of services. Many enterprises now depend on the scale and security of clouds and have learned to leverage a rich set of innovative cloud services, including databases, analytics, AI and machine learning (ML), IoT, and more.

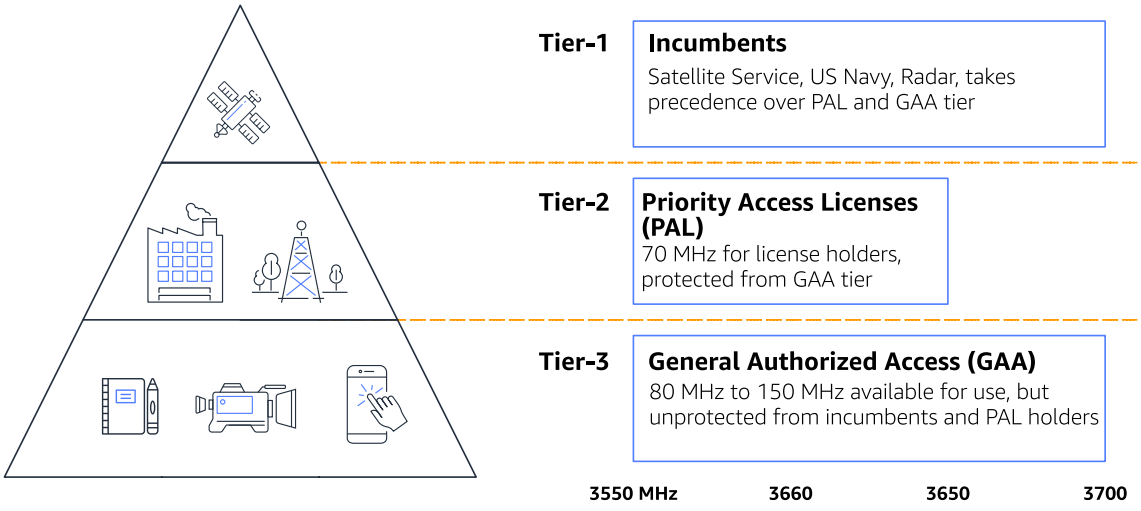
However, there are enterprise applications and data that CIOs and IT leaders have not been able to migrate to the cloud. These may have residency or privacy constraints preventing data from leaving the premises. Other restrictions include strict latency requirements, a need to connect directly to onsite equipment, or the infeasibility of transferring massive amounts of data to the cloud due to time constraints or available network bandwidth.

These on-premises workloads also face onsite networking challenges. Many applications today are dependent on local wired or Wi-Fi networks to transport enterprise data. Furthermore, while wired networks may provide acceptable performance, they are expensive to upgrade, reroute, and extend. Enterprise Wi-Fi has wide adoption due to its simplicity and cost-effectiveness but suffers from coverage, capacity, reliability, security, and handoff issues. As enterprises look to adopt IoT and industrial IoT (IIoT) as part of Industry 4.0 initiatives, or other digital transformation mandates that increase the volume of and dependency on data, they will need to address these network issues.

## What are 5G and Private 5G?

5G is the next-generation of public mobile networks. 5G offers faster speeds and better coverage at the same cost compared to previous generations. 5G, and its predecessor, 4G LTE, are mobile standards defined by the 3rd Generation Partnership Project (3GPP). Unlike Wi-Fi, 4G and 5G have traditionally been used on public mobile networks. However, recent advances in technology, interest from corporations, and enterprise-friendly government spectrum policies worldwide have increased enterprise adoption of 4G/5G mobile technology for private networks.

In particular, the Citizens Broadband Radio Service (CBRS) in the United States is a 150 MHz-wide section of the 3.5 GHz band (3550 MHz to 3700 MHz) available for commercial use under a three-tier spectrum-sharing arrangement. The arrangement protects US Navy radar use and accommodates a commercial priority access band available through spectrum auctions. The availability of CBRS in the US, and commercial enterprises' ability to use shared or private spectrum licenses in other countries such as Japan, Germany, and France, are driving private 5G and 4G adoption.




*Three-Tier CBRS Architecture*

Hundreds of companies, educational institutions, public utilities, local governments, and municipalities worldwide have deployed private 4G and 5G networks. These networks often use unlicensed or shared spectrum. They may also use spectrum licensed to them by communications service providers in situations where more capacity or better coverage is needed. Wireless base station infrastructure — 4G eNodeBs (eNB) or 5G gNodeBs (gNB) — are deployed privately in an office, factory, or outdoor setting for enterprise coverage. They are connected to a mobile core, such as a 4G evolved packet core (4G EPC) or a 5G core (5GC) that provides the control and data management for mobile traffic.

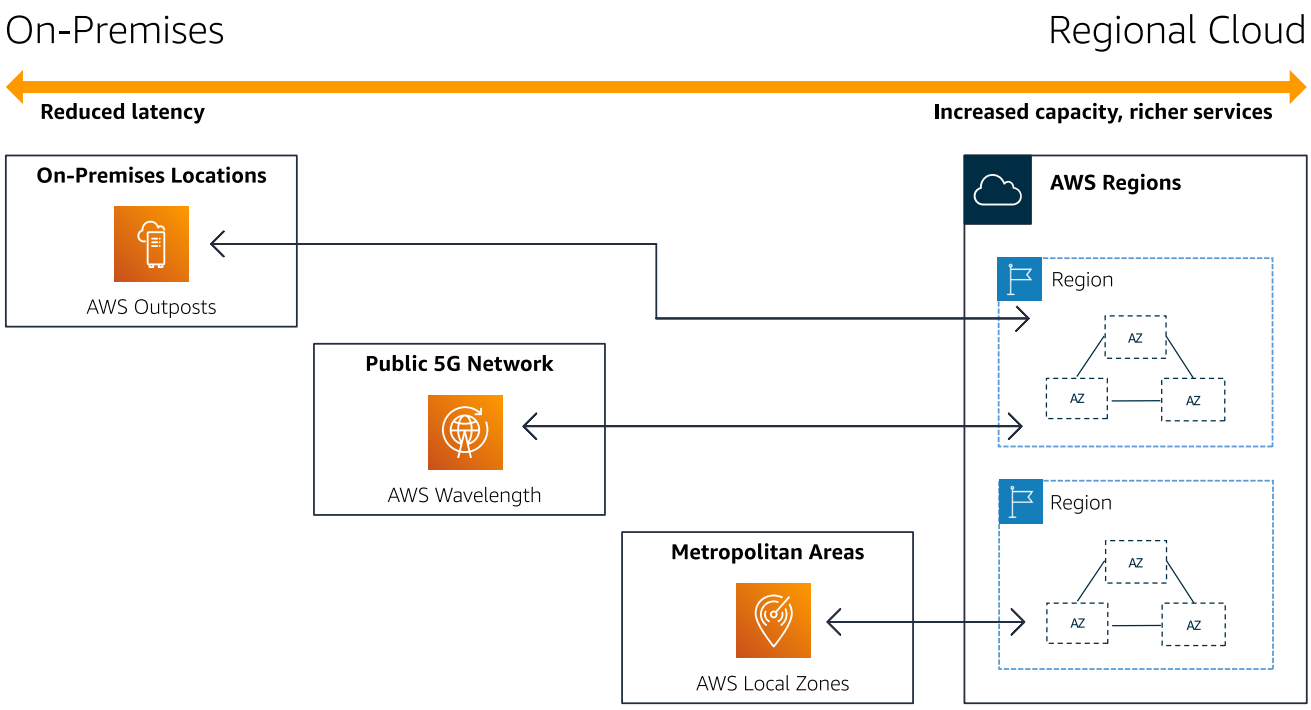
These private 4G/5G networks, like Wi-Fi, are isolated from public mobile networks. However, their performance allows them to replace wired networks and augment under-performing enterprise Wi-Fi. Today, the majority of installed private networks are based on 4G LTE technology. As the technology matures, however, they will rapidly transition to 5G.

Compared to Wi-Fi, private 5G provides improved security (e.g. default encryption, stronger authentication), better spectrum efficiency, and improved handoffs as devices traverse cells. The use of 4G or 5G also provides a path toward public mobility — as devices leave the premises, they can seamlessly connect to public mobile networks.

*Note: For the remainder of the solution brief, we will use the term private 5G to include both 5G and 4G LTE networks unless we're distinguishing between the two.*

## Mobile Edge Computing (MEC) and Private MEC

Edge computing is often discussed in tandem with 5G. The two are not interdependent, yet the combination can bring value to both communications service providers and enterprises. Edge computing involves extending the cloud to locations closer to where devices and users consume or generate data. AWS offers a range of solutions for edge computing. AWS Local Zones bring compute, storage, database, and other select services in proximity to large centers of population, industry, and IT. AWS Wavelength embeds AWS compute and storage services at the edge of the public 5G network, within telecommunications service provider data centers, for improved performance and lower-latencies.




*The Cloud Continuum*

AWS Outposts delivers fully managed AWS infrastructure, native AWS services, APIs, and tools to virtually any customer on their premises. AWS Outposts enables applications that need to run on-premises due to requirements of low latency, local data processing, or local data storage needs, while removing the heavy lifting required to procure, manage, and upgrade onsite infrastructure.

The collection of AWS edge offerings are an extension of the cloud that enterprises have come to trust and depend on. Local Zones, Wavelength, and Outposts support common infrastructure, services, APIs, and tools across enterprises' cloud and on-premises environments. Autoscaling, orchestration, monitoring, and identity and access management (IAM) work as they do in AWS Regions. Specifically, AWS Auto Scaling, Amazon EC2 Systems Manager, Amazon CloudWatch, AWS CloudTrail, and AWS CloudFormation all work across AWS Local Zones, AWS Wavelength, and AWS Outposts. Enterprises that have built their DevOps toolchains on AWS Regions can extend them to edge services.

By offering a  continuum of consistent cloud services, AWS customers no longer have to choose between running workloads in the region or the edge. Developers can simultaneously deploy components at more than one edge location. Latency-sensitive portions of applications can be run on edge locations while the remainder can stay in AWS Regions. By deploying applications and workloads to the right edge location, enterprises can ensure the best application performance experience for end-users while optimizing costs.

## AWS Outposts — Built for On-Premises Locations

Today, enterprises have onsite workloads which could benefit from cloud innovations. These include industrial computing and automation, IoT, medical diagnostics and processing, augmented and virtual reality (AR/VR), and computer vision and AI/ML-based applications. Many of these applications can also benefit from improvements in networking, especially from wireless technologies that achieve most of the benefits of a wired network. The reliability, coverage, security, and performance that mobile 5G wireless provides can augment Wi-Fi and supplant wired Ethernet in commercial settings. Factories that previously had wireless coverage issues, shipping ports and docks with performance and interference issues or hospitals with wired tethered diagnostic equipment can benefit from a private mobile edge computing (MEC) service comprised of on-premises edge computing and a 5G network.

*Note: The acronym MEC originally referred to "mobile edge computing" but has been extended to "multi-access edge computing," accommodating other access methods. For this solution brief, we will use MEC in its original mobile definition. Private MEC refers to an on-premises edge service, like AWS Outposts, integrated with a private mobile network.*

AWS Outposts supports multiple EC2 instance types that can power different types of edge applications — from GPU-heavy AI/ML workloads to analytics applications that need more on-premises storage. Further, to ensure maximum utilization of infrastructure, these instances can host telecom workloads such as the private mobile network core, and other telecom virtual network functions (VNFs) that help scale and secure traffic. With the recently announced 1 RU (rack-unit) and 2 RU options, AWS Outposts also have the flexibility to fit into space-constrained locations while meeting ongoing processing and storage needs.

Enterprises concerned about security in remote locations will be assured by the use of AWS Nitro technology on AWS Outposts. The Nitro System is the underlying platform for the next generation of EC2 instances — across AWS Regions, Local Zones, Wavelength, and Outposts — that enables AWS to innovate faster, reduce customer costs, and deliver added benefits like increased security. The Nitro System provides enhanced security that continuously monitors, protects, and verifies the instance hardware and firmware. Virtualization resources are offloaded to dedicated hardware and software, minimizing the attack surface. Finally, Nitro System's security model is locked, prohibiting administrative access and eliminating the possibility of human error and tampering.

For on-premises workloads, AWS Outposts provide a rich set of services, including:

- **Compute & Storage:** Amazon EC2, EBS, and S3
- **Containers:** Amazon Elastic Container Service (Amazon ECS) and Elastic Kubernetes Service (Amazon EKS)
- **Secure Networking:** Amazon Virtual Private Cloud (Amazon VPC), Local Gateway, Application Load Balancer (ALB), Private Connectivity
- **Database and Caching:** Amazon Relational Database Service (Amazon RDS), Amazon ElastiCache
- **Data Processing:** Amazon Elastic Map Reduce (EMR)
- **IoT:** AWS IoT SiteWise Edge

These services operate in the same manner as in AWS Regions, managed by the familiar AWS Management Console.

Finally, AWS Outposts can be deployed in a near-premises mode, such as in a data center near the desired enterprise campus, factory, or farm; particularly if the primary target location lacks adequate power and cooling, or is otherwise inhospitable to computing equipment

## Private MEC with 5G — a Potent Combination

Combining a private MEC with private 5G can address your enterprise computing challenges. As a foundational use case, AWS Outposts can act as a scalable, secure, and high-performance host for private mobile cores (5GC or 4G EPC), powering enterprise 5G networks on site. Edge applications can take advantage of private 5G benefits, including performance, control, reliability, and density for demanding enterprise workloads such as Industry 4.0, as well as future 5G network slicing capabilities for improved quality of service.

Private 5G aside, AWS Outposts are agnostic to network access methods. They can serve workloads over other access technologies, including wired Ethernet, Wi-Fi, or even Zigbee and Bluetooth. AWS Outposts are connected to AWS Regions to allow for seamless replication and transfer of data while using IAM and granular data control rules to specify what data needs to remain onsite. Data can be encrypted and transferred to AWS Regions for longer-term storage, or processed and filtered data can be transmitted for aggregation across multiple sites.

## Private MEC with 5G Use Cases

Private MEC with 5G addresses many Industry 4.0 initiatives, providing a high-performance, low-latency edge service that can address industrial control and automation use cases, power computer vision for video surveillance and safety, and drive innovative applications of AR/VR to improve productivity. AR/VR applications are data and graphics intensive, especially for use cases requiring visualization of large 3D data sets, such as computer-aided design (CAD) models, point clouds, or digital twins. To support light weight mobile devices (e.g. wireless headsets, tablets, smart phones), 3D data processing can be offloaded from these devices to high-performance private MEC, such as EC2 GPU instances on Outposts. The remotely-rendered output can be streamed on private 5G over a variety of AR/VR/3D streaming protocols.

For manufacturing production, private MEC with 5G facilitates predictable, low-latency connectivity between factory floor programmable logic controller (PLC) systems, computer numerical control (CNC) machines, supervisory control and data acquisition (SCADA) devices and the AWS cloud to enable deeper integration between IT and operational technology (OT) systems. Manufacturing execution systems (MES), materials requirements planning (MRP), maintenance, and quality assurance systems can have on-premises application components to ensure improved performance. This local presence is key for supporting advanced use cases like predictive maintenance and predictive quality.

**In addition to Industry 4.0, private MEC and 5G are applicable across many verticals and use cases, including:**

**Events and venues, such as sports, concerts, performances, and theme parks:** enhanced experiences with AR/VR, live information overlays, multi-camera, multiple angle views, personalized instant replays

**Healthcare:** untether equipment for agile setups, real-time diagnostics over 5G powered by private MEC AI/ML, rapid access to radiological scans on-site, local processing of sensitive patient data

**Shipping ports and Airports:** real-time processing of manifests, luggage, and container processing automation, predictive maintenance, AR-enabled connected workers, autonomous guided vehicle (AGV) control, passenger security, safety monitoring, passenger temperature screening, and social distancing enforcement

**Warehouses:** AR-enabled connected workers, wayfinding, AGV control, inventory monitoring and updating

**Schools and universities:** virtual desktops, private networks for students in rural regions or areas of inadequate coverage, improved campus coverage

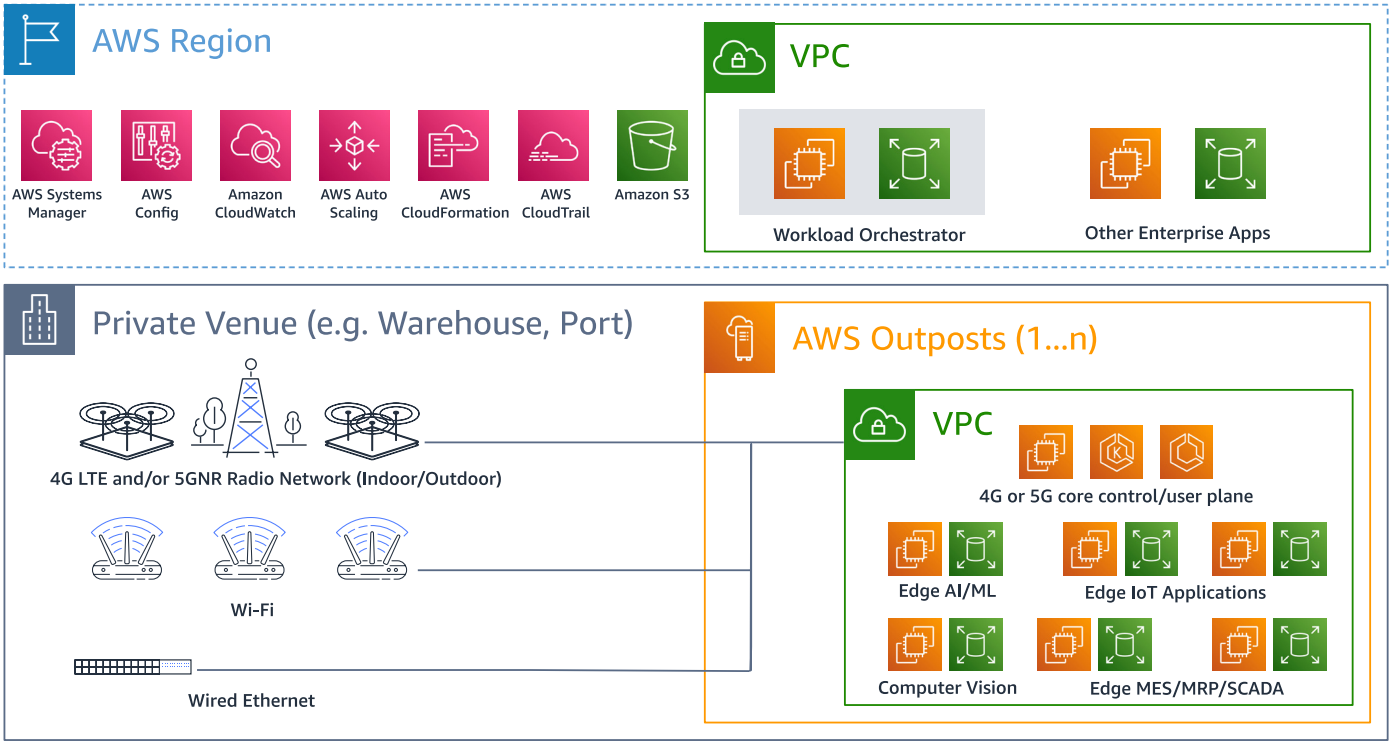
**Smart cities:** real-time sensor-driven automation, safety monitoring, climate controls, and energy saving

## Spotlight on Industry 4.0 and Manufacturing

Industry 4.0 is an initiative to apply digitization, industrial IoT, closed-loop automation, smart production technologies, and agile techniques to evolve existing industrial processes. For example, in manufacturing, companies have the opportunity to use data analytics, real-time controls, and AI/ML to reduce costs, improve quality, efficiency, and safety, and increase scale. Industry 4.0 is also applicable to other production-based industries such as mining, oil, gas, and agriculture.

In a private MEC with 5G deployment, AWS Outposts, in addition to hosting enterprise workloads, can be used to host the mobile core and/or cell-site network functions. Whether a 4G EPC or a 5GC is deployed as EC2 instances or as containers with ECS or EKS, Outposts provides an onsite, high-performance platform for network functions. Additional functions for security, communications, and analytics can be run on Outposts as well. The mobile core can be coupled with 4G and/or 5G radios, enabling a self-contained on-premises private MEC and private 4G/5G network.

You have the option of starting with a 4G EPC (known as a 5G non-standalone or NSA deployment) with 5G radios before upgrading to a 5GC to achieve even better performance in a stand-alone (5G SA) architecture. It would be a simple matter of updating the core components on EC2 instances or ECS or EKS containers on Outposts. There's also the choice of running the entire mobile core on-premises, or hosting some components in the AWS Region for increased flexibility. On the spectrum front, you can choose to use unlicensed, shared licenses, or licensed options, depending on which countries your sites are located in. Also, some enterprises chose to deploy private MEC with 5G on their own, while others do it with the assistance of a communications service provider or a systems integrator.

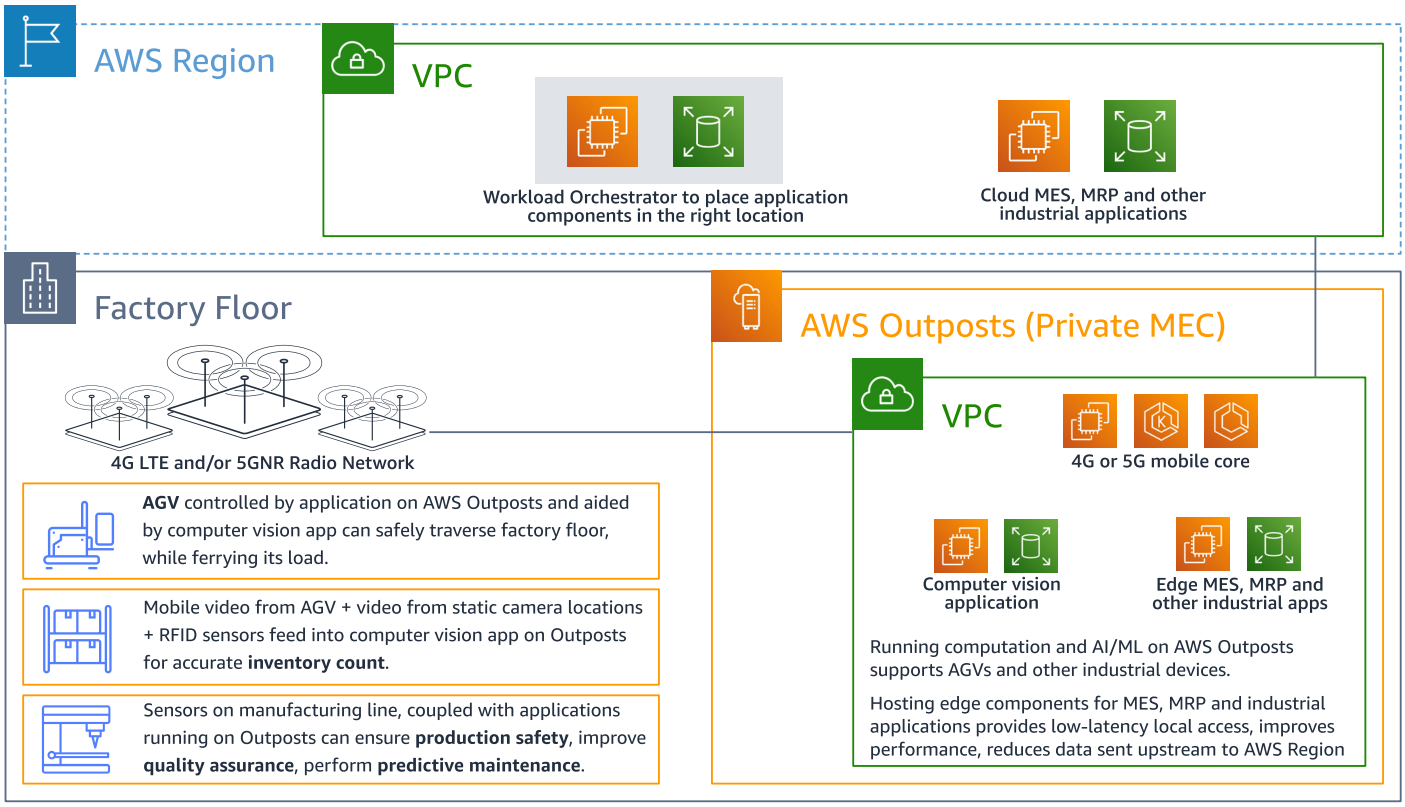



*AWS Outposts as Private MEC*

In addition to a private 5G network, AWS Outposts can integrate with your existing Wi-Fi and wired networks. Its access-agnostic setup and ability to support multi-homing and multiple network interfaces ensure seamless integration with your enterprise IP address management policies and security architecture. Data generated onsite can be sent via multiple network access types to the local AWS Outposts for processing, complying with data residency rules. Or select data sets can be sent to AWS Regions for further analysis and AI/ML model training. AWS Management Console can be used to orchestrate and manage across all AWS Outposts instances, side-by-side with AWS Regions. And by using services like AWS CloudFormation, it's easy for your developers to automate the replication of deployments and updates across multiple enterprise sites.

## A Closer Look at a Private MEC solution for Factory Floor Applications

By deploying AWS Outposts with private 5G in their factories, manufacturers can benefit from optimizing factory operations including productivity, machine availability, and product quality. Private MEC with 5G enables new use cases that include enhancing AGV capabilities, using computer vision for accurate inventory tracking, and increasing safety, quality and uptime on production lines.




*Real-World Manufacturing Example*

## Powering Autonomous Guided Vehicles (AGVs)

Computer vision software leveraging AI and ML can run locally on AWS Outposts. EC2 instances with GPU (such as G4dn) have the necessary computing power to run AI/ML workloads efficiently and provide real-time controls to AGVs that roam the factory floors. The software running on the private MEC service guides AGVs safely and speedily through the factory, avoiding people and obstacles while ferrying its load from point to point.

The use of 5G mmWave, with high capacity and low latency, enables ongoing streaming of high-resolution videos for AI/ML inferencing and remote human operators. Operators can observe in real-time and intervene when necessary. At the same time, the private 5G network ensures reliable transmission of rich sensor data (lidar, vibration, temperature, audio) from these AGVs and other industrial devices located throughout the factory. The superior coverage and spectrum efficiency of private 5G enable better coverage in areas that Wi-Fi has challenges reaching.

Running the computer vision application on AWS Outposts reduces the compute load on the AGV. This allows AGVs to be lighter, lower cost, and they can operate longer on a single battery charge. And because centralizing computing on AWS Outposts is more cost-effective than on-device computing, it also reduces the total cost of ownership (TCO). Analysis and control systems on Outposts can also be more sophisticated than what is possible on limited compute on devices and vehicles, providing opportunity for optimization and richer features. Further, by keeping the majority of logic and state on Outposts, failed AGVs can be swapped, and spares brought online faster, reducing downtime.

### Tracking Valuable Inventory

The same computer vision application used by the AGV for navigation and safety can be used to detect and inventory raw material and finished goods. Mobile video streams from AGVs can be combined with feeds from cameras installed in the factory and onsite sensor input and RFID for accurate counting and tracking. Integration with MES running on Outposts enables real-time monitoring, automation, and optimization, as raw material is turned into the final product through the Digital Thread in manufacturing.

Private 5G provides a reliable backbone to carry sensor feeds and control channels with the necessary level of latency and throughput. 5G product-tagging technologies could allow a seamless transition from a private network to a public 5G network for ongoing tracking.

### Ensuring Quality, Safety, and Uptime on the Manufacturing Line

AI/ML processing of video streams in the manufacturing process can be used for quality control and to spot safety concerns. Computer vision apps can ensure that the output from different manufacturing stages conforms to appropriate quality metrics. Automation allows for higher-quality products with less human intervention. At the same time, manufacturing safety records can be improved through the use of video feeds to spot potential safety violations and ensure that precautions are taken.

The private 5G network's low-latency and reliability ensure the necessary data associated with quality and safety initiatives reach the private MEC system promptly and that the control signals are transmitted with reliability to the robots on the manufacturing line.

Further, by using private MEC to crunch the large amounts of data from sensors, the manufacturer has been able to detect potential failures and perform predictive maintenance and servicing of onsite machinery. AI/ML-driven proactive maintenance can be achieved without the need for specialized on-site hardware or the need to ship massive amounts of sensor data over network links into the cloud.

For a manufacturing company, private MEC with 5G can enable transformation to a digital factory and evolution to Industry 4.0. The unique combination of a high-performance private network with on-premises cloud computing can improve safety, quality, and productivity and unlock new applications driven by onsite analytics and AI. Likewise, the centralization of computation for robots and AGVs reduces operational expenses and decreases the cost of these devices, allowing for a lower TCO. Similar significant outcomes are achievable in other verticals through the use of the powerful combination of private MEC and private 5G.

### GETTING STARTED WITH PRIVATE MEC AND 5G

Getting started with new technology can be daunting. The advantage of private MEC solutions powered by AWS Outposts is that it is a seamless extension of the AWS cloud services that developers know and trust. Enterprise application developers can leverage the same toolchains, continuous integration/continuous deployment (CI/CD) capabilities like AWS CodePipeline, and other AWS cloud services they are already comfortable and productive with, such as CodeDeploy, CloudFormation, CloudWatch, etc.

AWS has communications service provider partners around the world ready to provide a carrier-managed model for private 5G deployments with private MEC. These partners can bring their mobile expertise to bear in these deployments, providing an easy on-ramp for companies ready to bring the power of the cloud and 5G onto your premises.

## Resources:

For additional information on AWS private MEC and 5G, as well as related topics, check out:

- Mobile Private Networks on AWS
- Industry 4.0 with mobile edge network services powered by AWS Outposts
- AWS IoT SiteWise
- AWS Outposts