Integrating & Operating 5G Use Cases

And Managing Multiple Network Technologies

A Disruptive Analysis Thought-Leadership eBook - June 2023

Disruptive Analysis

iBwave

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Introduction: 5G is Changing On-Premise Wireless

Four years ago, a 2019 iBwave eBook introduced then-new 5G for the enterprise audience. The ebook covered the known abilities of 5G, provided an overview of important technology elements like spectrum bands, and explored uncertainties like potential applications and devices.

It correctly predicted the rise of private 5G and the challenges related to indoor propagation. However, in hindsight it was too optimistic regarding the timelines for more complex features such as network-slicing and ultra-low latency.

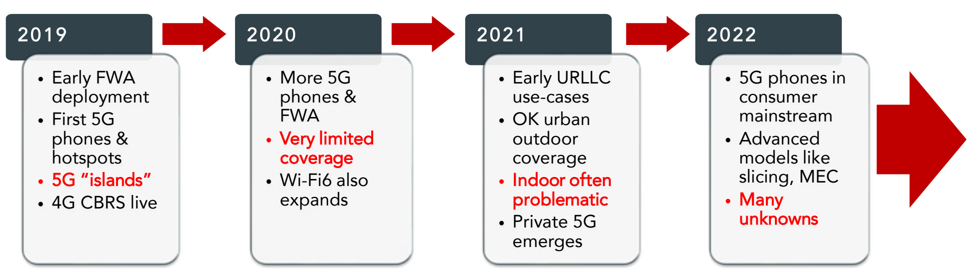
This eBook revisits the state of 5G in the enterprise marketplace, with a focus on indoor/on-campus environments. It examines the broader impact of business, society and technological changes on industry transformation. It also explores how these changes influence the deployment and operation of 5G.

It focuses on three major themes:

- The incredible diversity of the enterprise landscape and its technology choices, and why this makes it difficult to realise the more expansive or utopian 5G visions.
- Summaries of use-cases for 5G connectivity in some key verticals, including mining, transport/logistics, oil and gas, education, utilities, and manufacturing.
- The growing importance of enterprises designing and integrating multiple network types together, including 5G, Wi-Fi, private radio, and various other wireless systems.

Note: This eBook does not specifically cover the ongoing evolution of private 4G/5G networks in enterprise, as these are covered in detail in various other iBwave documents and webinars. It also does not discuss spectrum bands, again detailed elsewhere.

Expected 5G timeline in developed markets, 2019-2022



Source: Disruptive Analysis

5G Comes in Phases

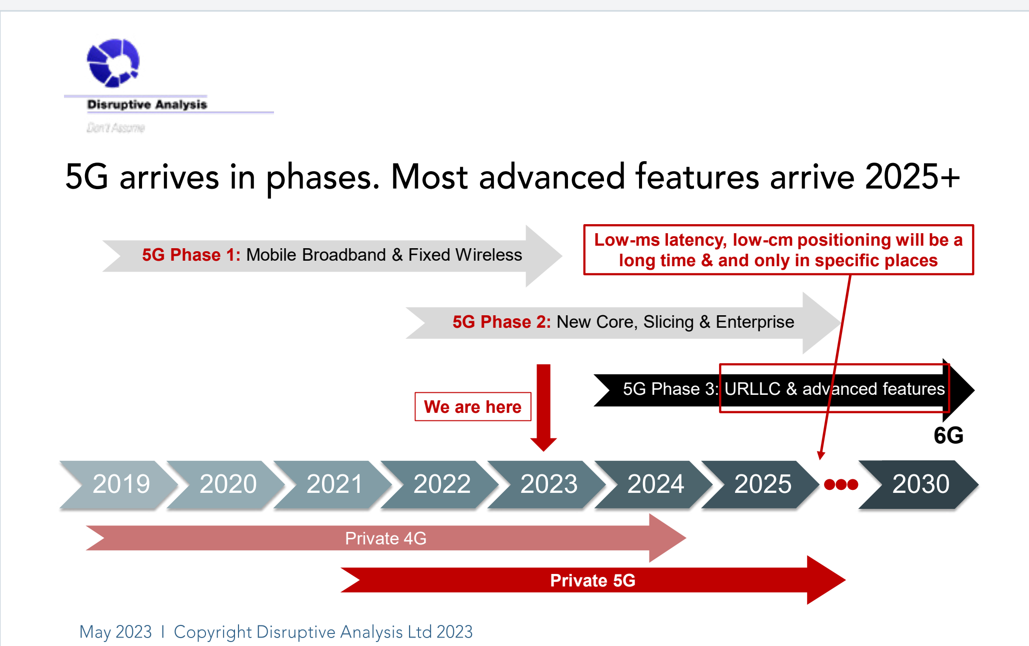
5G wireless technology — more accurately called 3GPP 5G New Radio (5G NR — is the latest generation of cellular technology, following on from 4G LTE and earlier 2G and 3G mobile systems. It launched in various limited deployments in 2019/2020 and has later expanded in geographic reach and features. In 2023, there are over a billion end-users, although the bulk of these are consumer smartphones connected with public network (MNO) subscriptions.

The initial expectations for 5G in 2018-19, which included a fair degree of hype, focused on a future where data speeds would be extremely fast, connection would be reliable with ultra-low latency, and a wide range of IoT and enterprise use-cases would be supported.

The reality is rather more nuanced. What many of the original commentators and forecasters failed to note was that 5G has been arriving in phases. Technically speaking, features arrive in a variety of 3GPP's "releases." The earliest versions of 5G utilized 3GPP Release 15, while the more advanced and enterprise-focused capabilities arrived in Releases 16, 17, 18 and beyond.

It's more useful to think of three broad phases for 5G, with different implications for enterprises looking to exploit and deploy it:

- **Phase 1:** The initial phase of 5G is largely based on "non-standalone" (NSA) technology, where the new radio network parts of the system (RAN) are connected to the existing 4G core networks. While this may deliver higher speeds, given suitable spectrum and sites, it offers little new capability. It allows delivery of an enhanced version of Mobile Broadband (eMBB) and is highly suitable for Fixed Wireless Access (FWA). 5G NSA has mostly been deployed by traditional mobile network operators (MNOs) as it requires existing 4G core and radio coverage as an "anchor".
- **Phase 2:** Starting with the Standalone (SA) version of Release 15, this phase of 5G involves deployment of a completely new 5G core, which has a modular "service-based" software architecture. As a result, the network becomes highly programmable and upgradeable for subsequent generations, enabling supporting for enhanced functions and features like ultra-low latency. However, the transition has proven very complex for MNOs with existing 5G NSA phase-1 networks. In mid-2023 there are about 40–50 public MNO networks around the world with at least some use of 5G SA. That said, many private 5G networks have gone straight to this model.
- **Phase 3:** This is the future for 5G networks, where the new cloud-native core starts acting as a platform for a variety of new features, especially in 3GPP Releases 17 and 18. This involves enhancements tailored for local and private networks across different industries, high-accuracy positioning capabilities, various optimizations in quality and performance, improved integration of satellite connectivity and more. Such enhancements should enable a wide array of more-demanding use-cases, especially for business-critical or safety-critical IoT in industry. Phase 3 versions of 5G will start appearing in 2024 in a limited fashion but become more important during the 2025-2027 period.



During the phasing of 5G variants, there are ongoing parallel releases of different 5G spectrum bands. These help enable the theoretical capabilities of the system to be delivered in different contexts, including wide-area networks, local hotspots, or indoor or on-campus settings.

Realistic use-cases are dependent on both the maturity of 5G technology versions and the specific frequency bands available.

Enterprise Needs are Highly Fragmented

5G—and especially private and on-campus 5G—is entering a highly complex and crowded marketplace. Compared to the early days of enterprise connectivity, many of its potential use-cases aren't new. All company employees already have wireless devices, while most machines, computing platforms, and IoT systems have existing wireless or wired connections. While industrial transformation is bringing in new systems and applications, 5G will need to compete with, or substitute, alternative options.

In addition, due to 5G's broad ambition, it will have very different deployment scenarios and economic considerations depending on the industry and type of facility involved. Certain sectors will primarily focus on human mobile-broadband, particularly smartphones, while others will prioritize 5G for industrial automation, safety/security, or possibly content-streaming.

Warehouses, retail sites, manufacturing plants, hospitals, transport hubs, universities, shared-office spaces, and other locations will have increasingly varied wireless requirements and diverse network infrastructure requirements. Coupled with other adjacent technology changes, Disruptive Analysis expects to see "vertical-specific" expertise and integration/implementation to come to the fore.

Apart from the detailed coverage of industry sectors later in this eBook, it is beneficial to consider 5G scenarios across a few different dimensions:

- **Application scale and scope:** Is the network for local use, or across a wide-area?
- **Indoor vs. outdoor / campus coverage:** This is a major factor determining whether 5G faces significant competition/substitution vs. other options like Wi-Fi.
- **Greenfield vs. brownfield:** Is the network in a newly-built site, or one with legacy infrastructure?
- **Device requirements:** Does the application or environment rely on certain end-user equipment—and is this available with suitable 5G connectivity?

These factors determine if 5G is appropriate for a given use-case and if it's likely to be the only wireless technology used. Later in the discussion, we explore situations where multiple technologies are utilized simultaneously.

Application Scale and Scope

Enterprises require connectivity for applications that operate at different scales, ranging from short distances between local devices to expansive campuses and plants spanning kilometers. They also require connectivity for global supply-chains and processes spanning multinational or multi-site operations.

Currently, 5G networks seem best-suited to campus-scale deployments, or very large individual buildings like warehouses, automotive production-lines, or airport hangars. Campus-scale deployments include examples such as shipping ports, mines, oil and chemical plants, wind-farms, universities, or railway container-yards.

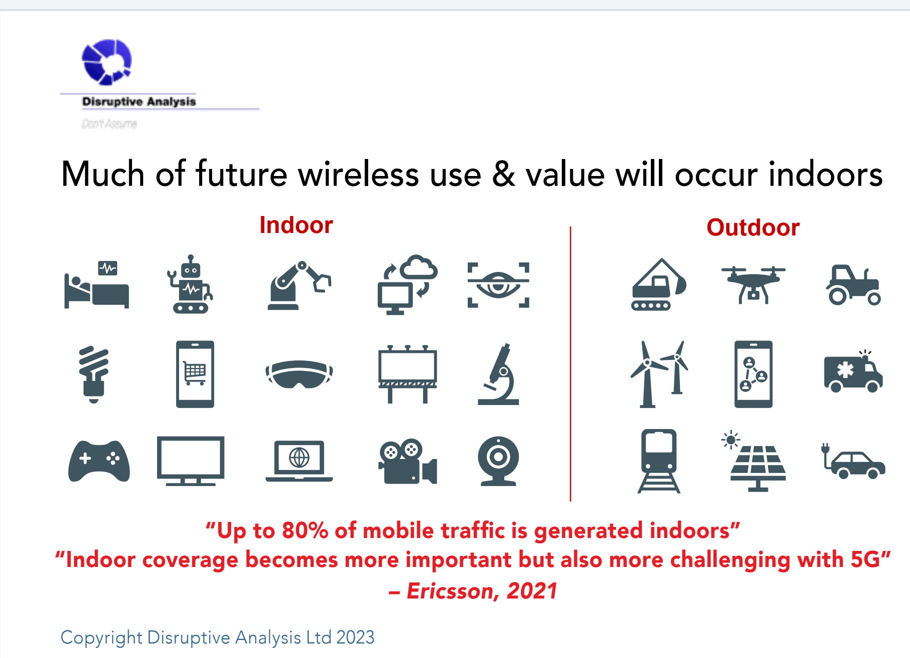
At smaller sizes, connectivity can often be enabled by fiber and ethernet, or Wi-Fi connections. On a larger regional or national scale, 5G coverage may be inconsistent and complemented by 4G networks. There may also be areas with limited coverage ("white spots") where applications, such as those in vehicles, have to work offline until connectivity is restored.

Indoor & Campus Coverage

Understanding whether a given application is used outdoors, indoors, or both is a critical determinant of 5G's usefulness in enterprise. In many cases, the enhanced capabilities of 5G require higher frequencies, which often face challenges in terms of signal propagation, especially in enterprise buildings that extensively use materials like concrete, reflective glass and metalwork.

Outdoor usage plays to cellular networks' strengths. Often, it's deployed in spectrum bands with higher permitted power limits, giving a greater range from each base station. This in turn simplifies backhaul, as it means fewer locations that need fiber or microwave connections. It's well-suited to vehicles and mobility.

On the other hand, indoor usage of 5G requires careful planning, design, and potentially dedicated engineering and custom installations. Due to the unpredictable outdoor-to-indoor signal characteristics, mobile network operators (MNOs) often cannot rely solely on their primary "macro" 5G radio networks. Instead, they must establish localized coverage or extensions. This may impact the cost-effectiveness compared with alternative technologies such as Wi-Fi and limit the use of 5G use to scenarios where it offers clear advantages, rather than as a general-purpose technology.



Greenfield vs. Brownfield

Another factor which will determine the viability of 5G and the extent of multi-technology connectivity is whether a given site is "greenfield" (newly built) or "brownfield", (existing facilities are upgraded or incremented with new IT and OT systems).

Common examples of greenfield sites are newly established warehouse and logistics hubs, "gigafactories" for electric vehicles and batteries, wind and solar energy sites, as well as significant construction projects like airport terminals or urban regeneration districts.

Brownfield developments include enhanced connectivity for existing ports, university campuses, railways stations, established manufacturing sites and oil/chemical plants.

When designing new facilities, there is an opportunity to start fresh and consider the current and future capabilities of 5G, Wi-Fi, and other available options. Handhelds, vehicles, and industrial systems can be specified with up-to-date connectivity options, while also being designed for ongoing upgrades to future standards.

Many existing locations already have a wide range of legacy connectivity solutions in place, such as TETRA/P25 radios, wired ethernet and fiber, older Wi-Fi systems, and possibly various proprietary industrial wireless networks. Often these systems can be gradually upgraded with 4G/5G or transitioned over time, but it is unlikely that they will be entirely replaced overnight.

Device Availability

An important factor in enterprise adoption of both public and private 5G is the availability of suitable devices. Smartphones typically support a broad range of frequencies (with some regional variations), but there are fewer available IoT and industrial-grade devices, especially for the less common bands sometimes used in private 5G networks. There are even fewer chipsets and products that support later versions of 5G, with features from later releases.

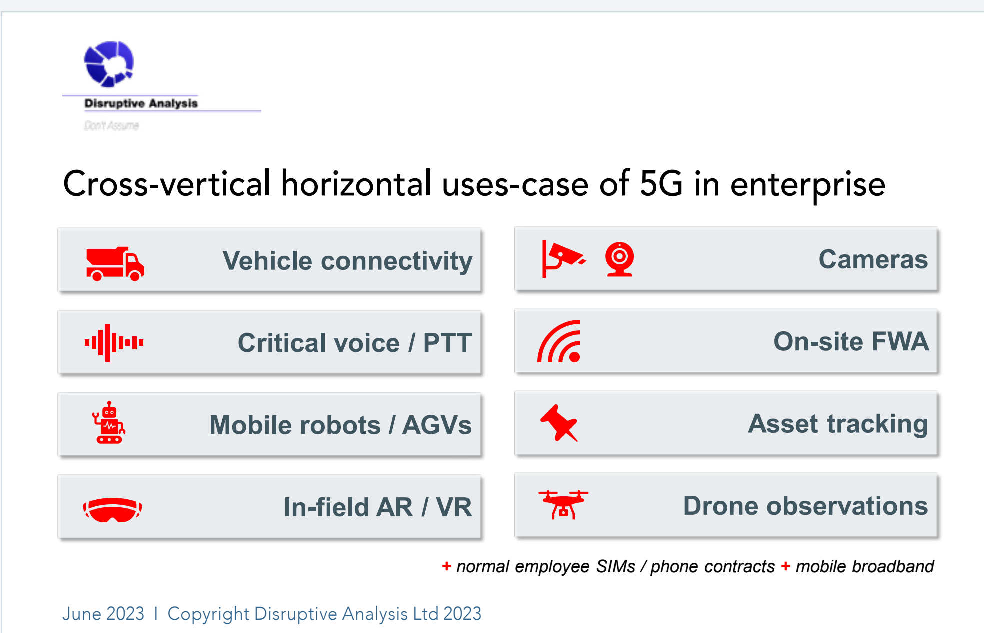
Another consideration here is power consumption. Typically, cellular radios consume considerably more energy than low-power local networks such as Bluetooth or Wi-Fi. For battery-based devices such as sensors, this represents a significant obstacle to cellular use. Power consumption may be partially offset by low-power cellular variants such as NB-IoT, although these have additional constraints.

These factors may drive the use of combined and hybrid “two-stage” networks. For instance, using 5G gateways for vehicles or campus out-buildings, followed by a secondary connection like Wi-Fi, Bluetooth or other means to connect individual end devices.

Horizontal Use-Cases

While much of the enterprise 5G conversation revolves around industry groups (“verticals”) there is a fair degree of commonality across use-cases in multiple sectors.

These “horizontals” are attractive for vendors, integrators, and service providers, as they give the potential for creating replicable solutions, driving scale and experience economies.



- **Vehicle connectivity:** A key target market for 5G is connected vehicles. They obviously benefit from the mobility features of cellular but may also need on-site / off-site connectivity from bridging public + private networks. Economically, most vehicles are expensive assets, so it’s easier to justify the cost of a 5G modem and connectivity solution.
- **Cameras:** This is one of the key device categories using 5G. Wireless cameras are used in multiple different application domains, such as security monitoring, access-control, quality control, and monitoring, remote-control, safety compliance, and much more. The uplink-heavy nature of images and video lends itself well to 5G, especially on private networks that can be configured to suit that pattern of traffic demand.
- **Critical voice / PTT:** Many enterprise and industrial sectors have historically used private radio or walkie-talkie systems for employee push-to-talk communications. However, legacy Private Mobile Radio (PMR) systems such as P25 and TETRA can be expensive or nearing end-of-life. 4G/5G alternatives can be more cost-effective as well as enabling new services such as video communications and cloud-connected apps.
- **Mobile robots & AGVs:** A growing number of sectors are utilizing moving robots, either inside or outside specific buildings. They may be used for carrying and delivering physical products and components, or for undertaking tasks such as assembly, security monitoring, cleaning, or process-automation.
- **In-field AR/VR:** There’s a growing use of immersive technologies for fieldworkers. Although indoor AR/VR will often use Wi-Fi in specific locations like design studios or hospital rooms, there is an increasing demand for these systems to operate on a broader scale, so 5G may be a more appropriate choice. Maintenance workers, field engineers, public safety workers, and others may all need hands-free augmented access to data and applications.
- **On-site FWA:** Many large campus sites have multiple out-buildings, equipment shelters or other remote structures that require connectivity. It may not

be possible to run fiber to all of these, while other wireless point-to-point systems may be expensive or inflexible. Using 5G for fixed-wireless access is growing in importance. Another important sub-category is using 5G to backhaul outdoor Wi-Fi access points.

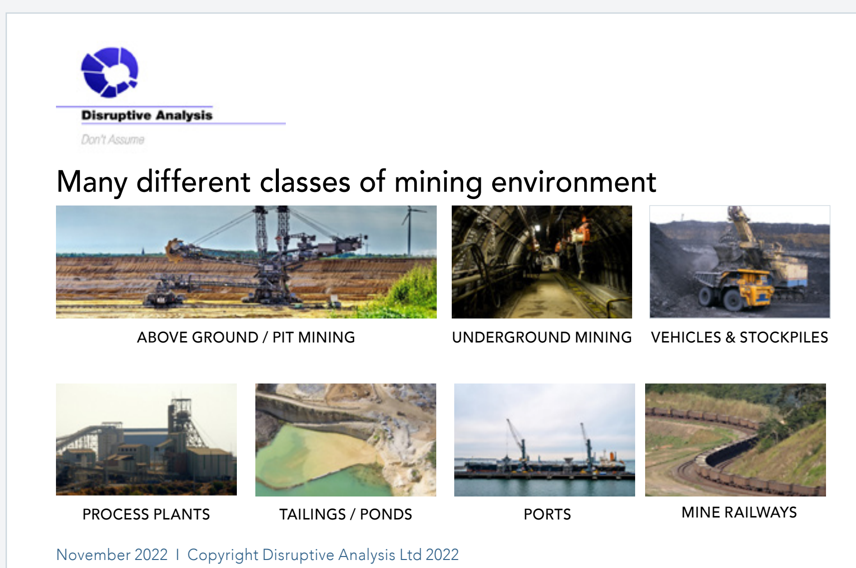
- **Asset tracking:** Many industries have numerous valuable, portable, or mobile assets, from tools to equipment or containers. Wireless location and positioning technology is becoming increasingly important for asset security and productivity / performance-management functions. While there are numerous wireless options, cellular connections offer greater range and higher positioning accuracy, especially with future versions of 5G.
- **Drone observations:** Commercial and industrial use of drones (or UAVs—unmanned aerial vehicles) is growing rapidly across many industries. While many use Wi-Fi or proprietary technologies for connectivity and control, there is a growing need for reliable video communications, as well as legal requirements for registration and monitoring. 5G connectivity is likely to be increasingly important.

Vertical-Specific Drivers, Use-Cases & Practicalities

Mining

Mining is a huge and important sector. It generates around $2 trillion in revenues globally, employing 20 million people across 50-100,000 sites around the world. Some parts of the industry are dominated by giant multi-national mining companies, while other minerals tend to be more localized and involve smaller, national firms.

There are many sub-sectors and site types. Key domains using wireless networks include both underground mines and open quarries, transportation facilities, permanent buildings such as office and accommodation blocks, processing plants, and vehicle maintenance.



Mining operations, which are typically conducted in harsh environments, both above and below ground, require high-performance wireless connectivity. They may have multiple risk factors, dynamic and often "unplannable" working environments, and high levels of mechanisation—and, increasingly, automation.

The mining industry faces a broad set of underlying trends and transformation drivers, shifting it towards connectivity and especially wireless networks such as 5G. Various terms such as "Connected Mining" or "Smart Mining" are used to describe the transformation and adoption of new classes of information and operational technology (IT / OT) and the networks that support them in mining.

Key trends include:

- **Improved employee safety and productivity:** Workers face risks from toxic gases, tunnel collapses, injuries from machinery and vehicle collisions. Safety can be improved by remote control of equipment, proximity awareness, and the use of geotechnical sensors to spot early signs of potential hazards.
- **Climate change and decarbonisation:** The mining sector faces profound change as the planet heads towards Net Zero. Old facilities will close, new ones will be built, and improvements to operations will be widespread. Old and new plants will need more connectivity for monitoring, control, and data-collection.
- **Cybersecurity:** The mining industry is a tempting target for various bad actors, from nation states to environmental activists or ransomware bandits. Security challenges are becoming multi-layered and highly complex. Wireless networks may be used as backups in case of failure of fiber or other links.
- **Data and analytics:** Asset utilization rates have often been low in the mining industry. Mining companies are now rapidly transforming legacy infrastructure and processes, with better-connected equipment, sensors, and video input, often via wireless. Analytics systems can improve productivity and resource allocation, extend mines' working lives, help diagnostics, and optimize maintenance.
- **Geopolitics:** Mining is having to deal with ongoing shifts in the international political arena, such as trade restrictions, taxes, tariffs, and import regulations. Mines must deal with more paperwork and maintain better records and traceability of materials and equipment. This is inherently more data- and network-intensive.
- **Environmental and governance concerns:** Beyond decarbonization, mines are at the forefront of many other aspects of environmental regulations and obligations. Water and air pollution need tight monitoring, for example. Various ESG concerns are driving further data collection (often wireless) and secure archiving.
- **Equipment mobility and reusability:** Mining needs to move equipment around a site, or to a different

site entirely. To maximize asset value and productivity, machinery and sensing/control systems can be redeployed and monitored as specific ore resources near the end of their useful life.

- **Value & supply chain integration and flexibility:** Mining is developing much tighter data- and network-intensive supply-chain monitoring and management, so that diverse input materials can be delivered to downstream processors without the need for huge inventories.

Examples of 5G use-cases, which align with these underlying drivers, include:

- Remote control of drilling, excavation & other equipment, using connectivity for cameras, telemetry, and monitoring systems. High data throughputs and low latency are required.
- Safety-critical communications using push-to-talk, push to video, alerts, and real-time health telemetry data such as heart-rate or blood pressure. Most cellular MC-PTT systems are currently optimized for 4G LTE networks but are being updated for 5G.
- Cameras, sensors, and telemetry for haulage, loading and train operations.
- Asset tracking, positioning & geofencing
- Realtime operational awareness, with data collected via a diverse array of sensors, cameras, and monitoring systems.
- Connecting smart ventilation and water-management monitoring points and associated control systems
- Security and access control systems, including perimeter video and motion-sensing systems.
- AR and VR-based training and assistance, using wearables, handhelds, and other devices.

Mining is a sector with diverse networking needs. In addition to 4G/5G, trunked radio systems like TETRA and P25 are utilized for personal communications. Mesh wireless is widely adopted for IoT applications, while Wi-Fi is employed for enterprise purposes. Satellite links are extensively used for wide-area connectivity. Some industrial systems rely on proprietary wireless connectivity. Fiber is deployed in areas where it can be safely and permanently installed.

Energy and Utilities

The utility and energy sectors have some of the most demanding requirements for communications networks of any industry vertical. They're fundamental parts of every country's national infrastructure, with intense requirements for uptime, reliability, and security. Many areas have health-and-safety impacts, both directly, such as grid short-circuits and fuel leaks, or indirectly, by outages impacting healthcare equipment, or water supply. In addition, other communications networks—including most fixed and mobile carriers—are themselves dependent on reliable power supply.

The sector is diverse in scale and scope, spanning from small local facilities to nationwide grids, plus highly mobile field workers and vehicle fleets.

Key domains covered in this sector include:

- Electrical utilities, from generation (renewable, oil/gas, nuclear, hydro etc) to transmission networks and local distribution.
- Water utilities, including reservoirs, pumping stations, treatment facilities and pipelines.
- Gas distribution and localized storage. (Note: refer to the oil & gas section below for coverage of gas production).

The main underlying drivers for connectivity and 5G reflect several top-level national and global challenges. These include:

- **Infrastructure modernisation and reliability:** Many utility and energy assets have been in place for years or decades, often using legacy/proprietary networks. These systems may not support modern demand patterns, while spares may be difficult to obtain. As utilities modernize their grids, distribution systems and other assets, they are seeking connected systems with real time data collection and control, increased automation, and simplified repair and restoration processes.
- **Improved employee safety and productivity:** Reliable communication between utility workers, especially while in the field or dangerous areas, is essential. As well as voice (push-to-talk) there's an increasing need for video communications and reliable access to enterprise applications.
- **Climate change and decarbonisation:** This sector faces profound change as the planet heads towards Net Zero carbon emissions. Old facilities will close, new ones will be built, and electricity generation and storage will transform. Many assets will be in unusual and unconnected locations, including offshore.
- **Cybersecurity:** Security challenges are becoming multi-layered and highly complex. If old IT and operational systems possess vulnerabilities, they will be reinforced or retired, while networks will be examined for resilience and redundancy.
- **Adverse weather and disasters:** In future, more frequent storms, fires, and other extreme conditions will mandate improved observation, greater network resilience, improved human critical communications and a variety of new protection / emergency systems.
- **Data and analytics:** Utility companies are rapidly transforming legacy infrastructure with better-connected equipment, IoT sensors, and video input. This can improve asset management, enable fault management and diagnostics, and optimize maintenance.
- **New business models:** Utility and energy companies are seeking new sources of revenue, such as electrical vehicle charging, energy-management for customers or even direct convergence with fixed/mobile telecom sectors.

Addressing these trends, some of the key 5G use-cases include:

- Management and connectivity for DER (Distributed Energy Resources), including micro-grids and localized generation facilities.

- Distribution Automation (DA), which involves collecting and processing key grid data and metrics, such as frequency, voltage and current. Applications like Fault Location Isolation & Service Restoration (FLISR) rely on ultra-low latency, extreme reliability, and the capability to operate within local areas of the power grid in isolation.
- Tele-protection is a critical use-case for communications, protecting high-voltage equipment against surges and other problems. Sub 10-millisecond latencies are needed for protection relays. While fiber is optimal, 5G may take a growing role in the future.
- Field Area Networks (FANs), including asset monitoring, safety and security systems and general-purpose IT connectivity.
- Low-Latency Supervisory Control and Data Acquisition (SCADA systems, for monitoring and operational control of sensors, switches and breakers, pumps, valves etc.
- Workforce communications, including mission-critical push-to-talk and push-to-video systems, remote assistance, and cloud access.
- Vehicle connectivity, including for emergency response.
- AMI (Advanced Metering Infrastructure) including sensors, meters, demand-response, smartphone apps and other assets.
- Video surveillance, from both fixed cameras and (increasingly) drones / UAVs and ground-based robots.
- Leak detection and environmental monitoring via cameras and sensors (including infra-red) over wide areas.
- Backup for wireline / fiber networks

While 5G is still relatively new for the sector, it is becoming increasingly viewed as the preferred wireless platform of choice, especially across medium and wide-area deployments. For now, there's still wide use of 4G, but that is expected to migrate over coming years. Often, equipment and other assets are in locations without suitable public network coverage, or with limited connectivity from legacy technologies.

Oil and gas

The hydrocarbon sector is a huge user of wireless networks—and networked IT systems more broadly—on a global scale. Although its future development is gated by the shift towards Net Zero, there will be a lengthy transition period, involving more natural gas production, implementation of carbon capture and eventually rehabilitation of decommissioned sites.

Multiple domains exist within the industry:

- **Upstream:** This covers the exploration for new oil and gas reserves, both on land and at sea, and the commercial extraction ("production") of crude oil and natural gas. It also often includes pipelines connecting to landing facilities, for long-distance transport or shipping terminals. Increasingly, liquified natural gas (LNG) is an important area, involving large plants for liquefaction and "re-gasification", typically linked to marine ports.
- **Downstream:** Collectively called "refining and marketing", this involves refinery facilities separating crude oil into products like gasoline and diesel, storage and distribution of oil and natural gas products, and the provision to end-users (e.g. via retail fuel stations or direct shipments to commercial users). *Local gas distribution is covered in the utilities section above.*

All parts of the oil and gas industry are becoming more automated, more instrumented with sensors and cameras, and more security conscious. The upstream oil industry has always been a huge generator of data, from seismic and other surveying tools. However, operations have been hugely expensive, especially in remote or offshore locations. Realtime connectivity for personnel, IoT sensors, and connected devices can enhance productivity and safety.

The industry is experiencing an increasing adoption of robotics for automated tasks like pipeline inspections. Additionally, video is being utilized in various ways, including security surveillance, anomaly detection (such as leak detection), and collaborative communications for maintenance and other tasks. The use of drones, AR/VR, and other advanced connected systems is expanding.

Many oil and gas facilities are ideally suited for private 4G/5G networks, typically ranging from 1 to 10 kilometers in size. These facilities are often situated in areas with limited public cellular coverage.

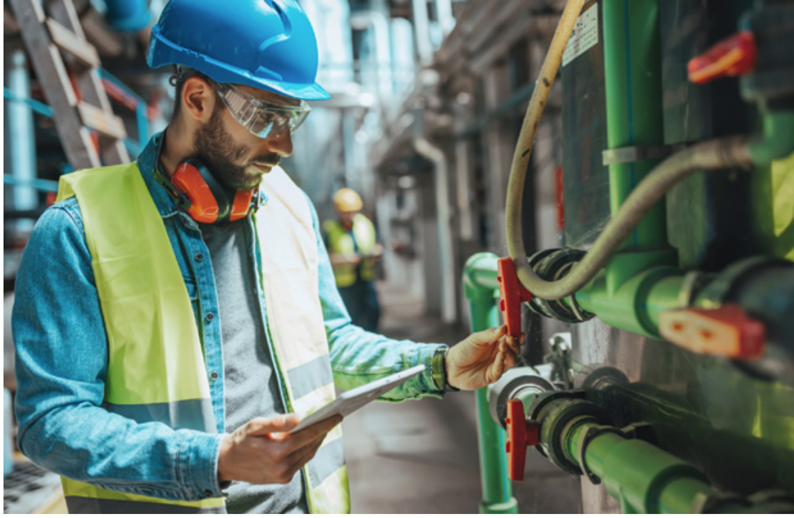
These include:

- Remote exploration sites
- Oil rigs and platforms
- On-land production zones with multiple pumps and local pipe networks
- Oil refineries – large industrial plants with numerous process units
- Storage tank "farms"
- LNG terminals

Wireless connectivity is often essential due to the extensive areas used for oil production and pipelines, as well as the frequent mobility of many personnel and vehicles. 5G (as well as satellite and other networks) is increasingly important for numerous use-cases, although 4G remains a core technology in many instances.

Some of the principal specific 5G use-cases include:

- Localized 4G/5G networks for exploration sites, connecting personnel, vehicles, and production machinery and sensors. Remote locations will often have satellite backhaul and on-site cellular core networks. These networks will cover multiple local applications such as crew push-to-talk, plus data collection for remote analysis.
- Wide-area communications for employees, typically via push-to-talk and more normal voice/video communications with office-based colleagues and suppliers.
- Video communications and telepresence to support field operations, for instance with remote-assistance and connectivity to off-site experts and consultants.
- Video surveillance & security systems—there is a significant need for video monitoring for site security and safety, increasingly linked to analytics and AI/ML capabilities. There are multiple angles here, from site perimeter-monitoring to ensuring compliance with rules on protective clothing and separation between humans and dangerous machinery. Infra-red imaging is also employed for leak and fire detection, while video is utilized by other mobile units to identify corrosion or other forms of site degradation.
- Connectivity for wireless IoT sensors. Oil and gas facilities have numerous types of sensors, ranging from temperature and vibration monitoring to detectors for smoke and gases. In many cases, there is a requirement for low-latency and highly reliable connectivity, often from battery-powered units. Today, many of these will use dedicated wireless IoT systems, but 4G/5G options are becoming more important, especially as NB-IoT and 5G mMTC variants become available.
- Latency-Sensitive Supervisory Control & Data Acquisition (SCADA), which is a specific class of IoT system that is directly linked into industrial monitoring and process-control. They link sensors, displays, analytical systems and actuators in real-time, allowing for both human and automated control. When incidents or emergencies occur, the information flow and alarms-management enable a well-organized response to be coordinated.
- High-accuracy positioning and tracking of assets and personnel. A variety of wireless options are available, with 4G/5G cellular playing a significant role,



particularly when additional interactive applications like telemetry, asset condition monitoring, or remote control are required.

- 5G-connected smart helmets for augmented reality (AR) and hands-free remote assistance have significant potential in the oil and gas sector, where distances are too far for Wi-Fi, and numerous technically complex and valuable tasks are conducted in-field.
- Connectivity for various classes of robots, eg for inspection of leaks & hazards, or firefighting. In addition to onboard sensing and cameras, 5G is expected to become increasingly valuable for remote control, either through a cloud-based platform or remote human operators.
- Drone connectivity for security monitoring, safety inspections, site surveys and other applications. 5G will be particularly important for beyond line-of-sight human controllers, although the timelines may require later releases of 5G to become readily available.
- For petroleum products distribution and retail, a similar set of wireless applications apply as are seen in more general retail store chains. On-site and between sites, as well as with delivery tankers, various services such as payment systems, stock control, security cameras (including real time identification of car license plates) are used on-site and between sites.

Manufacturing

The manufacturing sector is one of the most promising industries for emerging private LTE and 5G networks along with related technologies like Wi-Fi6E/7 versions. Companies are deploying many applications with extremely demanding requirements for wireless connectivity in terms of bandwidth, predictable latency, security, and uptime.

Manufacturers, with their well-defined sites and an expanding supplier ecosystem, are quickly emerging as a primary focus for private 5G vendors, solution integrators, and specialized units within traditional MNOs. The key domains covered within the scope of "manufacturing" include:

- **Discrete manufacturing,** which refers to the production of individual items, such as cars and other vehicles, technology hardware, tools and machines, furniture, electrical and electronic devices, and a wide array of other goods.
- **Process manufacturing,** which relates to plants creating continuous streams of products, including chemicals, fertilizers, cement, metals, plastics, coatings, and some food/beverage sectors.
- **Ancillary services for manufacturing** including product design, specialized software, facility installation, and maintenance.

These span a wide variety of building and site scales, from small light-industrial facilities, to huge campus sites with multiple factory buildings and warehouses. Manufacturing sites may be large-scale plants with stockpiles and heavy transportation functions such as rail terminals.

Some sub-sectors, such as large and highly automated factories producing vehicles or electronics, seem to be most advanced in the adoption of advanced wireless systems. Continual-process plants such as cement and steel production have less adoption so far, but significant medium-term potential. Smaller-scale or artisanal manufacturing will likely lag.

Unlike many industries, some manufacturing firms have long had sophisticated network infrastructure that is often integrated with IoT and automation systems (referred to as "OT" or "Operational Technology"), in addition to addressing conventional IT and telecoms requirements. Historically, there's been wide use of specialist technologies such as Industrial Ethernet, as well as a variety of niche and proprietary wireless systems.

Key "megatrends" for manufacturing, which drive demand for IT, OT, and IoT systems and associated networks, include:

- Automation and robotics.
- New product evolution and customization, including software-enabled solutions.
- Giga-factories in fields such as electric vehicles and their batteries
- Flexible and re-configurable plants
- Improved employee safety and productivity
- Climate change and decarbonization plus other aspects of ESG
- Geopolitics, re-shoring and supply-chain resilience
- Cybersecurity emphasis
- Focus on data and analytics.
- Predictive maintenance & asset management

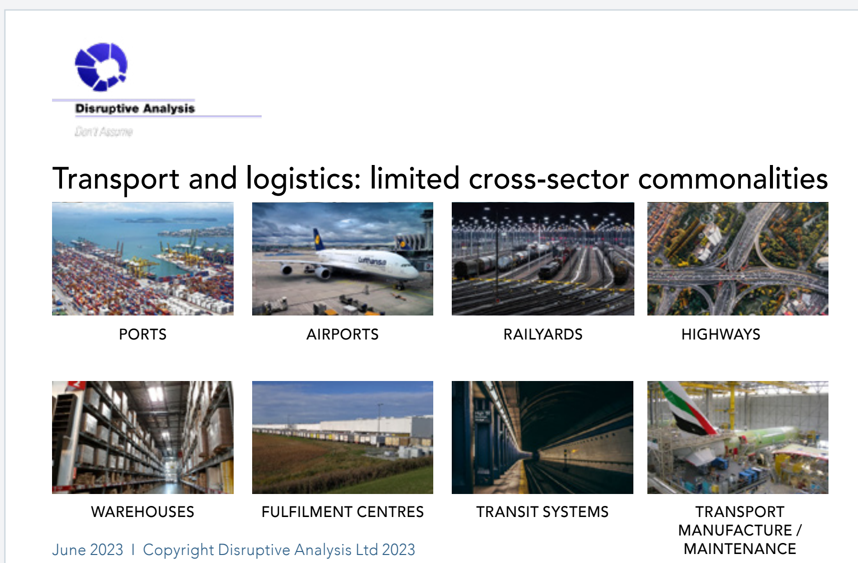
5G use-cases in manufacturing include:

- Handheld wireless "human machine interface" (HMI) control panels, or use of general-purpose tablets for process control.
- Connectivity for automated guided vehicles (AGVs) both inside factory buildings and outdoors between them
- Reliable, low latency / deterministic latency connectivity for industrial automation systems, connecting programmable logic controllers (PLCs) for specific machines, as well as entire production lines.
- Connectivity for production modules in reconfigurable / flexible manufacturing settings, allowing factories' layout to be adjusted without the need for laying new fibres.
- Realtime video analytics for product quality, using AI machine-vision tools to monitor for defects or maintenance issues.
- Wireless-connected safety systems including "stop" buttons with high reliability and low latency, visual recognition of workers' compliance with safety-wear rules, proximity-awareness to separate personnel and moving machines, or real time monitoring of solo workers' vital health signs.
- On-site real time communication using push-to-talk or -video.
- Software downloads and testing for complex products (e.g. vehicles) on the production line, or in storage areas
- Video surveillance of site perimeters and sensitive areas (e.g. R&D facilities)
- AR / VR wearables and handhelds, for training, design, and production-line guidance (for instance, showing steps in product assembly or testing)
- Precise asset-tracking and positioning, both indoors and outdoors in the plant
- Wireless connectivity for sensors feeding into digital twins. By monitoring machinery and other assets, manufacturers can develop and continually update a "virtual" model of their facility, allowing for asset optimisation, predictive maintenance, and higher productivity.

Transportation and Logistics

The transportation and logistics sector holds immense potential for LTE and 5G networks, along with other related technologies like edge computing and the latest versions of Wi-Fi6E/7. It offers opportunities for MNOs and private networks, although some instances are challenging to address for traditional service providers.

Transportation and logistics is a very diverse sector, spanning both scale and scope, as well as a wide array of sub-sectors. It covers everything from fulfillment warehouses to national rail networks, as well as ports/airports. Trucking, aviation, and maritime connectivity take the wireless demands well beyond national borders and beyond the reach of terrestrial cellular or Wi-Fi networks.



The logistics and transport industry is transforming because of a wide variety of industry trends and challenges. These drive demand for 5G both directly and indirectly.

There are many new applications, with demanding requirements for wireless connectivity in terms of bandwidth, predictable latency, security, and uptime. Automation, robotics, worker safety and critical communications use cases are at the forefront of transformation efforts.

Example use-cases of 5G include:

- Automation and robotic systems inside distribution and fulfillment warehouses, especially those oriented towards e-commerce, where hundreds of moving systems may be used in close proximity, needing low-latency control.
- AR / VR applications for both training and operational use. While some are on-site and may use Wi-Fi, others are needed “in the field” (for instance, for maintenance).
- Automated and remotely driven vehicles, both on closed sites and (in future) open roads and waterways. While not all will rely 100% on real time connectivity, many will use 5G for telemetry, video-based control, and other functions.
- Drones will increasingly be used in various aspects of transportation and logistics, including last-mile delivery for retail and B2B users, as well as drone-taxis in the future. These will likely exploit 5G connections, especially for beyond line-of-sight and automated operation, rather than human controllers.
- Ground-to-train wireless connections will exploit 5G for critical controls (using the future FRMCS standard), as well as operational on-train systems like cameras, as well as passenger / crew connectivity.
- Freight management at ports and warehouses increasingly uses remotely driven cranes and transporter trucks, with operators connected via 5G wireless from control-towers.
- Security cameras around perimeter fences, at access-control points, or passenger / cargo boarding points. Wireless connections (including 5G) are used where fiber or ethernet connections are impractical.
- Large-scale telemetry uploads from aircraft, trains, and other vehicles when they arrive on-stand or at a station.
- On-site vehicle connectivity, including for fuel/catering/maintenance/de-icing vehicles at airports, fork-lifts and other machinery at logistics hubs, or trucks in parking areas or loading bays at warehouses.
- Employee communications over medium-sized (maybe 5km) range on large sites, with cellular 4G/5G systems progressively replacing older TETRA or P25 mobile radio for push-to-talk, push-to-video, and other applications.
- Support for future neutral-host coverage in passenger terminals and other areas, where shared infrastructure for supporting MNO 4G/5G networks is required,
- Wide-area coverage (typically on national MNO networks) for vehicle telematics and fleet-management
- Private 5G networks on-board ships and aircraft

Ports, airports, and warehouses/fulfillment centers are leading the way in adopting advanced technologies. Additionally, railway stations, major aviation/marine manufacturers, and other entities are showing considerable interest. However, highway agencies, railway networks, and municipal transit systems have been slower in embracing these advancements. Nevertheless, they are beginning to show more interest in neutral-host infrastructure and upcoming specialized versions of 5G designed for vehicle-to-vehicle communication or next-generation rail connectivity.

Higher Education Campuses

Even though higher education may appear more uniform compared to other sectors discussed here, it still encompasses various types of physical site types, buildings and sub-sectors. There are also different institutions involved in operating

universities and colleges, as well as providing funding for networks and connectivity.

The sector includes:

- Purpose-built campuses, often outside city centers
- Historic universities, often with multiple buildings and sites across a city
- Faculty buildings, lecture halls, common-room and study spaces, administrative offices, operational facilities for power and heating etc
- Student accommodation and purpose-built housing, both on- and off-campus
- Scientific facilities such as labs, research facilities, super-computing centers and major projects such as nuclear/particle accelerators or medical institutions
- On-campus retail, sports and entertainment facilities, such as stadiums
- Buildings or sub-areas constructed in partnership with donors, industrial partners, government and other groups.

University education has witnessed the emergence of several significant trends and issues that are prompting investments in on-campus IT infrastructure, including networks such as 5G and wireless systems.

These include:

- **Technology Transformation:** Universities are embracing new technologies to enhance the learning experience, improve administrative processes, and facilitate research. This includes the adoption of online learning platforms, digital content, virtual classrooms, and collaboration tools.
- **Blended Learning:** The pandemic accelerated the adoption of blended learning, which combines in-person and online teaching methods. As colleges continue to offer hybrid courses, they need robust IT and network infrastructure to support video conferencing, online assessments, and access to learning materials.
- **IoT:** There is a growing proliferation of IoT devices on campuses, both for use by the university itself, and within the context of teaching in faculties such as medical, design, science, and agriculture. Internal uses include as energy management, security systems, smart classrooms, and facilities/operations tasks.
- **Big Data and Analytics:** Universities generate vast amounts of data through student information systems, learning management systems, research projects, and other sources. By leveraging analytics, institutions can gain valuable insights to improve teaching methodologies, improve student outcomes, and streamline administrative decision-making.
- **Cybersecurity:** Universities are investing in robust cybersecurity measures to protect sensitive data, intellectual property, and research findings. This is driving more focus on infrastructure that has secure authentication protocols, effective firewalls and intrusion-detection, and better monitoring than legacy networks.
- **Research and Collaboration:** Universities are increasingly collaborating with industry partners, other academic institutions and research organizations on large-scale projects. These require high-speed networking capabilities, personal/IoT connectivity

with good mobility, data sharing platforms, and collaboration tools.

- **Higher Student Expectations:** Today's students expect a reliable online and in-person experience throughout their academic journey. They demand reliable Wi-Fi and on-campus cellular connections, access to online resources, digital libraries, and interactive learning platforms. They also expect to maintain good connectivity in their accommodation, and in university-run sports / entertainment facilities.
- **Campus Safety and Emergency Response**: Sadly, some campus sites need to invest substantial resources in security and safety systems, such as real-time monitoring, emergency notifications, video surveillance, and integration with emergency services. Reliable networks are essential for ensuring a safe and secure campus environment.

Examples of 5G use-cases include:

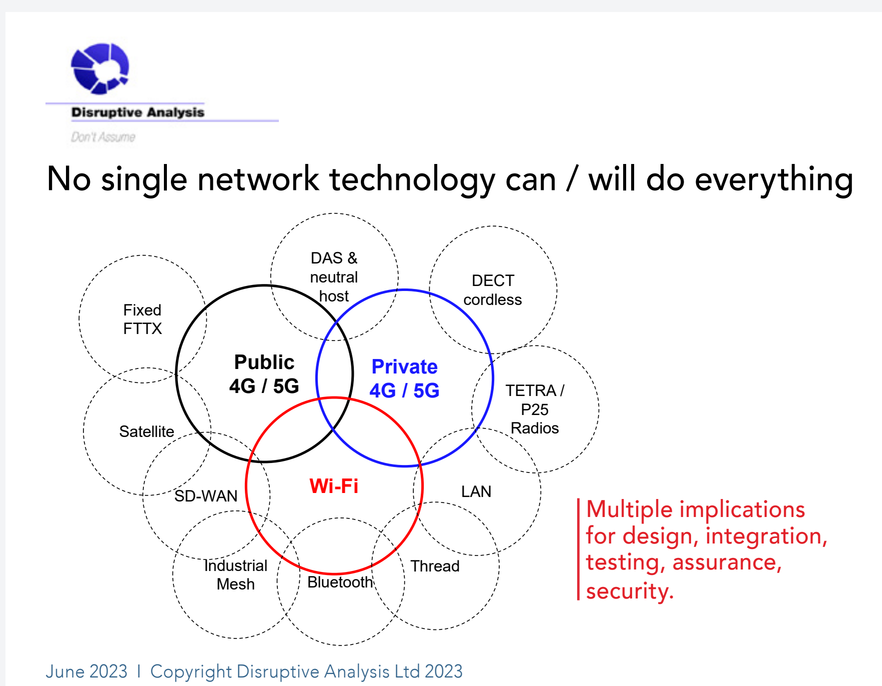
- On-campus communications for staff with smartphones / handhelds
- Campus video cameras for security
- Connected vehicles and charger stations.
- Labs and teaching / training facilities focused on technology, advanced manufacturing, medical, etc.
- Fixed-wireless access to out-buildings without fiber connections.
- Indoor neutral-host coverage in student accommodation blocks
- Asset-tracking
- Backhaul for campus-wide Wi-Fi, including outdoors.
- Niche IoT connections for specialized campuses, such as agricultural colleges

Designing & Integrating Multiple Technologies

Most companies and sites will utilize a diverse range of connectivity solutions, even though the previous sections have outlined potential use cases that can be supported with 5G wireless. They can be kept separate, converged fully, or blended in various hybrid forms.

This section discusses the reasons for deploying and operating multi-technology infrastructures, the typical use-cases, and the most common combinations.

This is not simply a question of choosing between public 5G (delivered via an MNO's main national network) vs. private 5G (with a dedicated system). Although its high-profile marketing has suggested that 5G can be suitable for anything wireless, the real world of enterprise connectivity is much more complex. There are many other technologies – most obviously Wi-Fi, but also numerous IoT-dedicated systems and others – which are also evolving quickly.



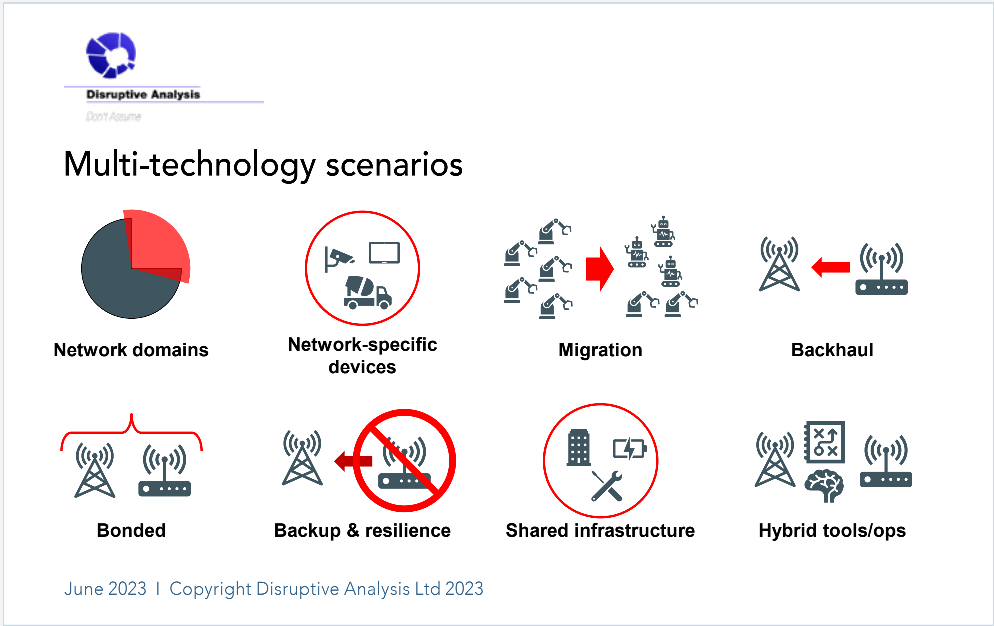
Ultimately, there are relatively few applications that can only be delivered with 5G, whether that is provided by public or private networks. Although the idea of a 5G "monoculture" may seem appealing to some, the truth is that there are various commercial, technical, practical, and, in certain instances, regulatory constraints that need to be considered. These constraints include:

- Existing "legacy" systems which may be hard / expensive to replace, especially while still performing well. Brownfield sites are unlikely to switch-out existing systems across the board.
- Lack of suitable 5G device availability, especially for IoT. Many connected-device categories and products are still Wi-Fi, LPWAN, or Bluetooth-only.
- Unusual 5G frequency bands, or cumbersome spectrum-licensing which limits private network adoption in that country or location.
- Extra cost of 5G compared to alternative wireless options such as 4G or Wi-Fi.
- Requirement for a system to have a wired power supply, which can also be used for connectivity (e.g. using power-over-ethernet)
- Need for specific certification or regulatory approval for new networked devices in a given sector, which may need lengthy testing or extensive paperwork.
- Lack of 5G-related skills in a company or country
- Geopolitical, import or cyber-security restrictions applied to particular technologies or vendors.

Key use-case scenarios for multiple networks

Typical use-cases for multiple networks include:

- Separate networks for indoor and outdoor use, or onsite / offsite roaming
- Using different single-network devices for the same application
- Migration of users and devices from a legacy network to a new infrastructure, over a period of time
- Use of multiple networks for backup and resilience
- Using one network as backhaul for another's access points or radios.
- Using bonded or converged networks for optimal performance
- Deploying multiple networks using shared physical infrastructure, or with combined planning and design tools



Separate network domains

The scenario many observers highlight when discussing multiple-network deployments is combining two network domains and enabling a user's device to cross a boundary between them, while maintaining a connection and application context.

Typical examples of this type include:

- An Automated Guide Vehicle (AGV) or handheld device working on a private network inside a factory, then transiting across an outdoor area of the site, then into a second building such as a warehouse.
- A delivery truck's telematics system switching from the wide area 5G public network, onto a private network at the logistics hub site.
- A mining truck using different network systems above-ground, and then entering a tunnel with a different subterranean wireless system.

- An employee's smartphone connecting to a normal public MNO service while off-site, but then using the private network (and/or Wi-Fi) in the office.
- *[As an extreme example]* An asset-tracking service for a rental company, monitoring a high-value piece of equipment from a warehouse, onto a truck, driving to a port, then into a shipping container across an ocean, and finally arriving at a remote site which can only be connected via satellite.

Device-Led Multiple Networks

There are various instances where a single application may require access to multiple networks because certain end-devices only support one network or another. For instance, many display screens and laptops only support Wi-Fi or wired ethernet connections, while vehicles and AGVs may be cellular-only.

There are many classes of IoT systems that are unavailable with 5G radios, especially if they must support particular frequency bands, or specific 3GPP features from later releases. A worker on a production line may have a connected tool which uses Wi-Fi or a low-power IoT technology such as Bluetooth, but simultaneously could be wearing a 5G-connected headset showing how to use that tool for a given task.

Another situation could involve an automation system in a warehouse, where there are already hundreds of Wi-Fi devices, such as barcode scanners. If the operation staff then add in a fleet of 20 5G-connected AGVs, they are unlikely to replace all the existing systems, but instead might run two networks in parallel.

Migration

Building upon the previous discussion, there will be instances where legacy-network devices are replaced. However, this process is likely to occur gradually over time rather than overnight. This is particularly true when the devices have not reached the end of their functional lifespan or have not been fully depreciated as assets. In such cases, it becomes increasingly probable that new identical replacements are no longer available or economically viable.

This will mean that there may need to be two networks—old and new—running in parallel, at least for a while, until the older platform can be de-commissioned.

A similar scenario is where a new network is rolled out progressively across a site (perhaps building-by-building), or sequentially at multiple sites across a company's footprint. This could make it advantageous to use dual-mode devices which can work in both domains.

Backup and Resilience

An important reason for using two or more network types is the potential for greater resilience. This could be a response to cybersecurity risks, the possibility of downtime because of software bugs, or a backup system in the case of an emergency such as a fire or flood.

- A critical IoT system being able to use a public 5G network, or a satellite connection, if a private wireless system fails. For instance, if a cloud-managed Wi-Fi robot faces downtime if the fiber backhaul is accidentally cut, it could temporarily use a (more expensive) 5G connection until service is restored.

- A utility company using a private 5G network as a completely air-gapped (physically and logically separate) control system for the grid, as a backup for the main fiber network.
- Public safety personnel being able to "opportunistically" roam onto private 5G or enterprise Wi-Fi, for example, when deep in-building or underground.

Backhaul and Gateway Scenarios

An increasingly common multi-network scenario is the use of one wireless technology to deliver connections (backhaul / fronthaul) to the access points of another. This scenario allows one expensive / complex connection to enable the connection to many cheaper or lower-power endpoints.

Examples include:

- Use of private 4G/5G to link up outdoor Wi-Fi access points, for instance, on university campuses or to remote stands at airports.
- Use of public or private 5G networks to connect localized gateways, for instance, for on-campus vehicles in mines or at ports. These can create "bubbles" of Wi-Fi which can be used by multiple devices such as the driver's handheld, an in-vehicle laptop, cameras etc.
- Satellite backhauls for private networks in remote areas, such as oil platform or remote mines.
- Use of mmWave radios as high-capacity backhaul for private 5G cells, where fiber is impossible or uneconomic to install. Various options are available, such as 28GHz 5G or 60GHz variants of Wi-Fi.
- Use of Wi-Fi meshes where the access points also incorporate IoT-centric low-power radios using technologies such as BLE, ZigBee, or Thread/Matter.
- On-vehicle systems using cellular backhaul to a gateway, which then links to onboard Wi-Fi or wired connections. For instance, a bus may use a mobile backhaul for passenger Wi-Fi and ethernet-connected information displays and security cameras.

Bonded and Hybrid Networks

Some wireless systems already use multiple different 4G/5G radios and public MNO SIMs to provide coverage as broadly as possible across different providers footprints. These can also obtain maximum throughput by "bonding" or aggregating across several parallel connections. Vehicle fleet operators, public safety agencies, and broadcasters have been typical customers for this type of service.

This approach can also use simultaneous private 5G and Wi-Fi connections, or various other combinations of technologies. These can be configured either to create a "single pipe" of greater speed or use some sort of controller to direct different applications via separate network paths as a form of wireless SD-WAN. They may also use IP-layer technologies such as multipath-TCP.

- Broadcasters can use public and private 5G networks, simultaneously to obtain the most reliable uplink connections at key venues and events.
- Large campus sites such as ports and mines may have good coverage of private 4G, but perhaps with limited capacity if the spectrum is limited. These could use bonding with Wi-Fi at some specific locations where extra throughput is needed (for instance, for bulk-offload of telemetry data at a docking point or in vehicle maintenance facilities).
- On-train Wi-Fi systems backhauled using a gateway with a combination of public 5G, dedicated trackside wireless systems, and (potentially) private 5G or satellite connections as well.
- A P25 or TETRA public radio system could use the legacy network for voice, together with extra capacity

on 4G/5G for data-heavy applications such as push-to-video or image-sharing.

Shared infrastructure & tools

Some hybrid networks may not involve direct integration of traffic and wireless connectivity, but instead focus on integration in adjacent domains. They may involve:

- Shared physical infrastructure such as indoor ducts and cable-trays, or outdoor poles and equipment shelters.
- Converged network design, planning and monitoring tools.
- Shared network operations centers (NOCs)
- Common security and authentication/identity platforms
- Combined engineering and operation teams (and budgets)

Typical Wireless Combinations

While there are various wireless technologies available, the majority of sites and applications, at least in the near-to-medium term, will typically not attempt to combine more than two of these technologies for a single use-case. That means that although an overall site or company may use 5, 10 or more different wireless technologies somewhere, in most instances they will remain unconnected, at least for now.

Let's take the example of an airport to illustrate the point. Airports utilize wireless networks for a wide range of purposes, including providing Wi-Fi in passenger lounges, implementing private 4G/5G networks for service vehicles on the ramp, and employing specialized systems for air-traffic control communications and radar.

However, as discussed above, there are numerous scenarios where individual applications may require a combination of two different platforms, with the ability to add further options in future.

At the moment, the most common combinations are:

- **Private 4G + Private 5G:** Many sites have started their private network journey with LTE radios and devices, especially in the US with CBRS, where 5G variants only became available recently. Others may have deployed private 4G over the last 3–6 years, and are now adding 5G support for advanced use cases and devices. Yet another group started with early "non-standalone" 5G network, which used a 4G core, and is now moving to full 5G with a standalone core. They'll need to be able to combine the two technologies, either in different spectrum bands, or using some sort of sharing mechanism.
- **Private 5G + Public 4G/5G:** This is likely to be a common scenario where users travel between a localized site and the broader wide-area network. Examples could include:
    - Field workers for utilities or oil/gas industries, visiting multiple sites with private networks, as well as broader areas with only public networks, for instance, while driving. They could use dual-SIM devices, or perhaps some form of roaming model.
    - Sites using private networks as a "neutral host" for delivering better indoor / onsite coverage for public networks. In the US, various CBRS networks are starting to use approaches such as MOCN [(multi-operator core network)] gateways to bridge to different MNO realms.
- **Private 5G + Wi-Fi:** This is probably the most important hybrid network combination, which fits with many of the use cases outlined previously. There are multiple technical architecture approaches, ranging from a complete "convergence" that involves using a single core network/controller and SIMs, to a simpler approach of running multiple independent networks and switching between them. Some important scenarios include:
    - Private 4G/5G backhaul to outdoor Wi-Fi access points across a campus environment.
    - In-building Wi-Fi systems (likely using Wi-Fi 6/7) bridging to outdoor private 5G for campus-wide access. An example could be an AGV in a warehouse moving material between a warehouse and an outdoor stockpile.
    - Isolation of key user groups or applications. For instance, an entertainment or sports venue may use Wi-Fi for the bulk of visitor connectivity but use a private cellular network for business or safety-critical functions such as payment terminals or ticket gates.
    - Industrial automation systems provided by major integrators that use different connectivity options for specific machines.
- **Private 4G/5G + PMR:** Many industrial and transportation sites use legacy private-radio systems for critical voice push-to-talk and alerting. However, various systems are either nearing end-of-life or are becoming uneconomic. They also lack the data bandwidth for new applications such as video. However, it may be impossible to de-commission all

the old P25 or TETRA systems immediately, either for cost reasons or because of innate conservatism around critical systems. There may also be multiple independent companies operating on the same site, with different investment and upgrade timing. Some example scenarios include:

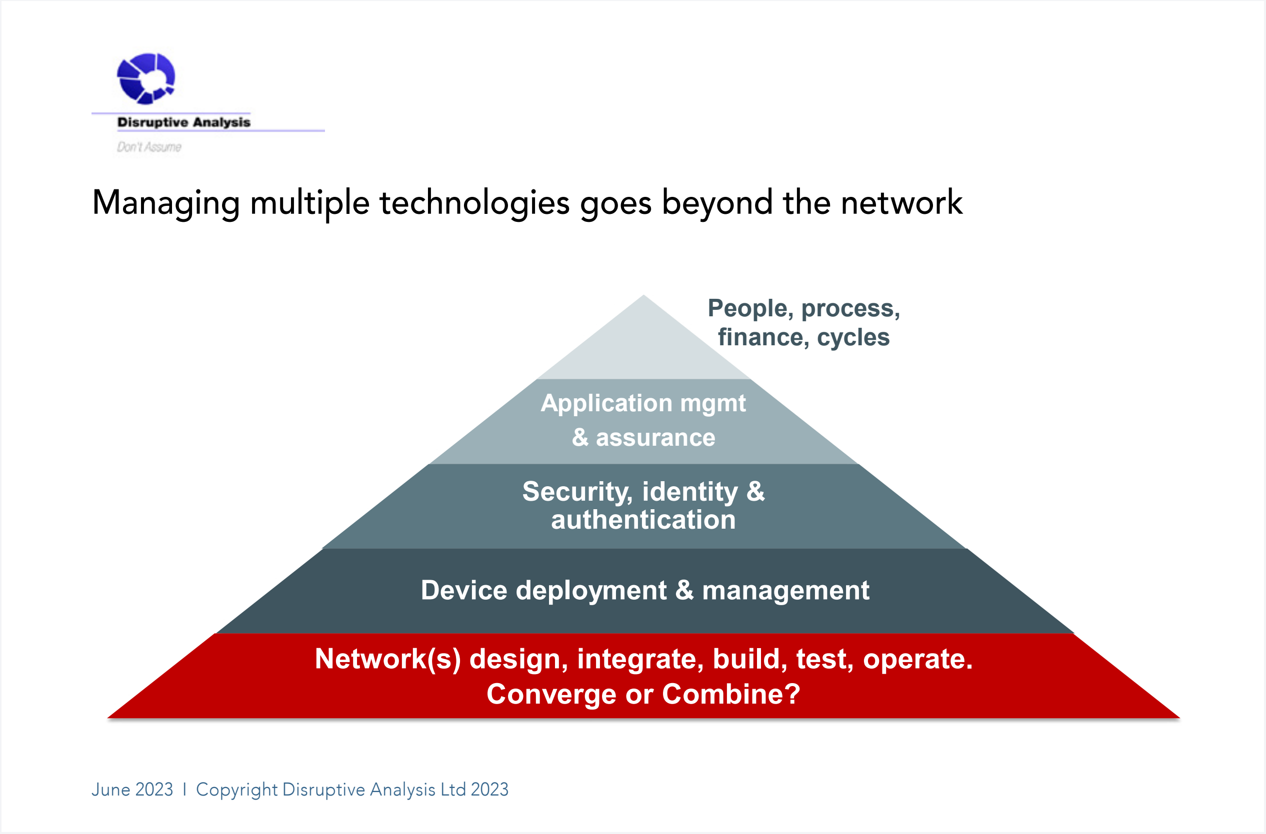
- In certain airports, private 4G/5G networks are employed for specific groups, such as ground staff at the gate, maintenance trucks, and catering trucks. However, other groups within the airport, like baggage handlers or fuel vehicles, continue to rely on older radios for communication. Utility field workers, who use private radios while conducting maintenance on power grids or pipelines in remote areas, and private 5G at newer facilities such as wind farms or power stations.

› **Others:** There are also various less-common permutations of hybrid wireless systems that may occur in specific industrial scenarios. Some examples include:

- Private 5G + satellite for shipping companies, or oil/mining exploration in remote areas
- Wi-Fi + Bluetooth Low Energy for smart buildings, using Wi-Fi for the equipment with ample power supply, and BLE for battery-powered sensors.
- Private cellular + LoRa for large enterprise sites with both high data-rate users (e.g. vehicles) and low-power / low-volume IoT endpoints such as sensors

It should be noted that designing a multi-technology network is only part of the complexity that enterprises will face here. Outside the scope of this eBook, which is obviously focused on the infrastructure aspects, it is important to recognize that combining different platforms for security, device management, identity, and assurance brings additional challenges.

There are also commercial and HR implications as well, for instance where different network technologies have historically had different investment cycle periods, or where separate teams have been involved in management. These are additional reasons why selection of integrators and managed service providers should be undertaken with great care.



Conclusions and Future Trends

This report started with a reflection on iBwave's 2019 eBook on 5G. That introduced the technology to an enterprise networking audience. Now, mid-way through 2023 at the time of writing, the landscape is clearer—but also more complex.

Throughout this eBook, we have explored the gradual rollout of 5G versions and its evolving capabilities over several years. We have also delved into the extensive range of potential use-cases and applications that can leverage 5G technology. Furthermore, we have discussed the likelihood of integrating 5G with other wireless and wired network technologies, along with the associated challenges that may arise from such combinations.

What can readers expect from the next few years? Some of the trends which the author is watching include:

- Continued maturity of Private 5G, as trial deployments evolve to production networks, and the ecosystem allows for quicker / easier deployments – including cloud-based versions of "network-as-a-service".
- Deeper usage of 5G within existing industry verticals and businesses. A common phrase is "use-case stacking", where an initial deployment and business case is extended by adding additional applications or coverage area, either on the same site or across the wider enterprise footprint.
- Continued evolution of 5G with new features and 3GPP releases. In particular, 3GPP releases 17 & 18 bring in some specific extra capabilities for industry, such as precise positioning, true ultra-low latency and lower-power / lower-cost IoT connectivity with the RedCap standard. These "Phase 3" versions of 5G will start appearing in 2024 in a limited fashion but will become more important during the 2025-2027 period.
- Growing innovation around other network technologies, either used on a standalone basis, or in combination/convergence with 5G. Wi-Fi is evolving rapidly from 6E to 7, with the addition of 6GHz spectrum and new features like multi-link operation. There's huge interest in satellite networking as well, which can be linked to 5G via the "non-terrestrial networks" (NTN) specifications in 3GPP Release 17.
- 5G delivery via a growing range of specialist service providers, systems integrators and enterprise/industrial system vendors. Meanwhile, traditional CSPs and MNOs are improving their B2B solutions businesses, providing dedicated on-premises 5G and a variety of managed services.
- While there are already discussions about 6G being more commonplace, this won't arrive commercially for enterprises before around 2030. Currently, work is focused on defining priorities and new R&D domains. Some businesses will be involved in early trials and testbeds for 6G and innovative future use-cases

The document has been prepared by independent research firm Disruptive Analysis, and commissioned by iBwave, for distribution to its customers, partners, and a wider audience.

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