Capgemini engineering

THE ADOPTION OF PRIVATE NETWORKS FOR ENTERPRISES

Building the ideal ecosystem for private network deployment

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Introduction

With connectivity applications growing exponentially across industries and domains, industrial networks are becoming more vital and diverse. It is common to deploy multiple technologies on a single site: low-power WANs (LPWANs) for sensors, location and positioning beacon meshes, Wi-Fi, industrial Ethernet programmable logic controllers (PLCs), and enterprise-wide area networks (WAN) for branch and supply chain connectivity. Enterprises that deploy their private cellular networks to comply with specific needs unmet by telecom operators are well aware that industrial networks are complex, fragmented, and costly.

5G is a double-edged sword. On one side, it brings a new set of functionalities that will drive demand for more connectivity and even more critical and vital applications. This includes seamless mobility and connectivity with top quality of services (QoS), quality of experience (QoE), massive IoT connectivity, etc., promising to pave the way for a new generation of connected applications. So will it be another layer of complexity for enterprise networks? Not necessarily, as 5G is also aiming at simplifying private and semi-private network configuration and management.

It should bring high interoperability with legacy technologies and a network slicing technology that can open new collaboration schemes between industrial players and the telecom ecosystem.

But what does it take to develop and deploy a secure private network today?

Based on Capgemini Engineering's experience of deploying breakthrough communications, networking technologies, and innovative projects in an industrial environment, this whitepaper explores the following questions:

- What are the key technical and connectivity features of private 4G and 5G networks?
- What are the critical use cases of such private networks?
- How to make them work? What is the ideal ecosystem to deploy a cost-effective, productivity factor private network?

Key technical and connectivity features of private 4G and 5G networks

Advanced 4G and Long Term Evolution (LTE) radio can already provide reliable wireless connectivity for high bandwidth applications such as video for industrial applications. These networks can also support a smooth migration to 5G radio in the future. The 5G's redesigned new radio for industrial control with 1ms latency assurances with five-nines reliability on ultra reliable low latency communications (URLLC) could enhance future applications of full Industry 4.0 use cases.

Advanced 4G and LTE, and now even 5G, provide a gamut of technological advantages and levers from wireless connectivity that can benefit a host of industries and verticals.

While Wi-Fi is widely used for home and enterprise indoor wireless connectivity, it has several performance limitations for industrial IoT use cases. In this case, the adoption of private wireless 4G can bring better coverage, multi-user capacity, stable latency, support for low power and low cost IoT technologies (NB-IoT/LTE-M), and mobility.

Additionally, 5G technology allows reliability, lower latency, and better spectral efficiency than Wi-Fi 6. It has been designed for URLLC use cases with major industrial players involved in defining the specifications.

Many other factors and trends are also disrupting the wireless ecosystem:

Avoiding vendor lock-in
The telcos that traditionally used services from large network equipment providers (NEPs) are looking for vendors with better flexibility and open networks.

Software-defined networking (SDN), network functions virtualization (NFV), and commodity hardware
The days of custom-made hardware for specialized network functions have been taken over by software-based functions on commodity hardware.

Use of open source
Another dominant trend is to reuse what exists, e.g., banking on the robust ecosystem of open source with enterprise support.

Edge computing
With the expansion of cloud and the need for reduced latency in response, some of the network's functions are moved to the edge of the network, leading to specialized use cases that are helpful for industrial adoption.

Age of artificial intelligence (AI) and machine learning (ML)
Nowadays, everything requires an element of analytics to process data and bring meaningful predictions out of it – still quite critical to many use cases such as predictive maintenance.

DevOps
With the merging of development and operations, deployment cycles for the communication infrastructure have reduced significantly.

Microservices
Service oriented architecture led to the movement of software from monolithic pieces to containerized applications orchestrated by Kubernetes.

IoT and automation
The rise of connected devices, sensors, and data sources required a new connectivity paradigm and management platforms.

Topic	4G/5G	Vs. Wi-Fi 6	LoRaWAN
Applications	Wide variety of applications including: • Enhanced mobile broadband (eMBB) • Ultra-reliable and low latency communications (uRLLC) • Massive machine type of communications (mMTC)	Wireless connectivity in the enterprise, residential, and public spaces for data connectivity	Low power, long-range, low-cost ecosystem designed for IoT, M2M, smart city, and industrial applications
Reliability	99.999% uptime or about five minutes of downtime in a year	While LTE/5G has inbuilt interference management, there is only a primitive scheduler in Wi-Fi	Reliability is designed as per the target application
Security	Intrinsically secure – mutual authentication and encryption	WPA 2/3 vulnerable to hacking	128-bit AES encryption
Mobility/ Handover (HO)	Built on robust 3GPP specs with wireless mobility with speeds up to 350 kph	Wi-Fi has high latency during HO, not suitable for high speeds	Not applicable for mobility applications
Coverage	Widespread coverage from 75 m to 30 km with no line of sight (LoS) requirements – millimeter wave on higher frequency have lower coverage*	LTE/5G have 4-100x coverage over Wi-Fi, significantly reducing the number of access points required	5 – 10 km
Concurrency	Up to 800 users can be connected (in IoT space, up to one million sensors per sq km)	Wi-Fi can typically support 30-50 users	Can support millions of devices
Throughput	LTE 150 Mbps DL/10 Mbps UL, LTE-Adv 300-1Gbps DL/15-50 Mbps UL, 5G 1-10 Gbps DL/50 Mbps UL	Wi-Fi performance degrades rapidly with concurrent user access	Designed for low throughput applications, e.g., utilities (such as gas and water) parking
Latency	Theoretically <1 ms or less for 5G, realistically <10 ms	2-5 ms (much higher latency compared to 5G in high network load scenarios)	Not suitable for low latency mission-critical applications
Positioning	4G cellular,position accuracy of 50 m, 5G cellular, position accuracy of 10 cm - 1 m	~15 m	~20-30 m
Service Continuity	Private/Public LTE	Wi-Fi – cellular handover	Not applicable for a mobility app
Device Ecosystem	Support for various classes of devices including eMBB, LTE-M, and NB IoT . More than 2500 non-phone form factors LTE devices (GSACOM, 03/19)	Limited IoT capabilities	Gradual development comprising devices, gateways, and servers

*5G (NR-U) and LTE (Multefire) provides double cell range and 4x coverage area compared to Wi-Fi 6. 5G on the 3.5 GHz licensed band provides a 4-5x cell range and 20x coverage area compared to Wi-Fi 6. That's because 4G and 5G have more advanced radio layer optimization solutions than Wi-Fi 6.

Table 1: connectivity drivers across wireless technology spectrum

Three broad themes are driving the adoption of private networks:

The urgent need is to modernize the legacy land mobile radio system (LMRS) designed for person-to-person communication in a variety of deployment scenarios such as portable (handheld walkie-talkies), mobile (installed in vehicles), and stationary (e.g., base station units). LMRS is used in the public domain, including public safety (e.g., police, fire, and ambulance), utilities (such as in airports, ports, and logistics), or can be used in the private domain for specific use cases (e.g., taxis and delivery services) and natural resources (such as oil and gas or mining). The erstwhile LMRS systems lack broadband capabilities with limited communication potential or multi-media capabilities and need revamping.

The digitization and automation of the industry, including Industry 4.0 initiatives are driven by the need for higher automation, efficiency, precision, and even safety.

The drive to have communication networks that are flexible using different parts of slicing to support fast scale-up of solutions (microservices).

Key Features	• **Industrial-grade reliability based on technology drivers of 5G** as listed above (security, mobility, wide-coverage, high throughput, and low latency) • **Predictable performance** for industrial automation and real-time asset coordination, such as guaranteeing <5 ms event delivery over the air with six nines reliability even in high interference radio environment, when there is a moving user equipment (UE) among industrial racks, etc. • **High capacity** to easily handle the rapid growth of devices, sensors, and data – both in terms of connected devices and volume of data, including Ultra High Definition (UHD) traffic. This translates to reliably processing events from 10,000+ devices at high frequencies up to one million messages per second • Provides **mission-critical reliability** for continuous operations • Ability to leverage data analytics application in a private enterprise environment with **real-time insights.** This is essential for an end-to-end performance of industrial motion control applications using imaging techniques. The 4G/5G control and user plane separation (CUPS) architecture is designed to handle data more efficiently than any other proprietary operational technology (OT) networks • LTE-based networks create an **evolution path** towards 5G • **Plug-n-play** with small cell and edge cloud server with portal support
Predictability	• Public LTE networks have latency from 20-80 ms, while private LTE networks have latency from 9-15 ms. With 5G, the latency can go below 1 ms
Reach & Mobility	• **Wireless coverage** tailor-made for business needs minimum or no coverage holes even in difficult or remote geographies. The number of access points required could be a fraction of those needed in Wi-Fi, resulting in significant savings in initial deployment costs • **Mobility** allows connectivity to move assets automatic guided vehicle (AGV) – handover between Wi-Fi AP is a major concern for AGV use cases and solved with private wireless 4G and 5G use cases
Flexibility & Control	• Greater **operational control and flexibility** to enhance safety and respond quickly to changing business needs • **Traffic prioritization** for business use cases • **Deployment choices** including on-premises, on-cloud, or as-a-service including data aggregation at the edge – ability to limit data that leaves the enterprise
Spectrum	A variety of **spectrum licensing models** is available, including: • Unlicensed – CBRS (US), MulteFire • Private and public LTE • CSP lease • Vertical spectrum
Applications	Widespread **industrial application** including: • **Predictive performance** to minimize downtime and increase efficiency and effectiveness (real-time data and analytics) • **Monitoring and control** with improved efficiency (object tracking) • **Process automation** and improved productivity (robotics, AGV, AMR) • **Advanced collaboration** (PTT, PTV)

Table 2: characteristics and attributes of private networks

Key use cases of private networks

How exactly do high speed and reliable connectivity aid the business case for industrial?

Sven Hamann, senior vice president of Bosch, says, “With the new automation platform, we are improving the overall equipment effectiveness of machines by up to 10%. In conjunction with NEXEED, another 10% can be added.”

The performance and reliability of Wi-Fi are not enough anymore for many industrial use cases. The most significant advantage of private wireless is the capability to cover almost all of the cases that, today, are based on different wireless technologies such as Wi-Fi, Ethernet, LoRa, and wireless HART.

We see a significant rise in activities in the market, driving private networks adoption in the enterprise space:

- NEPs such as Nokia and Ericsson as well as silicon chipset radio inventors such as Qualcomm are already playing a significant role in the design of enterprise private 5G network equipment
- Several major carriers (CSPs) are targeting industrial 5G centric enterprise services in their 5G offers, e.g., Three Sweden, KPN, DTAG, VZ (in the US), and Vodafone
- Enterprises have already shown interest in private 5G networks for industrial applications, e.g., the VW group, BMW, Bosch, Siemens, and Shell, having explored the German 3.7 GHz spectrum for industrial 5G
- Industry special interest groups such as the 5G Alliance for Connected Industries and Automation (5G-ACIA) are working to bridge 3GPP specifications body and industry adopters to aid 5G use case implementation
- Industrial private 5G motion control robotic and remote real-time critical operations demo have already shown in Hannover 2019

Those set of use cases are very attractive to a number of industries, but have specific requirements towards connectivity, which packaged carrier offers usually don't meet.

- The industrial use cases need flawless quality of service tailored for the relevant industrial applications
- They require more customization and better flexibility, particularly when it comes to reliability and independence versus external constraints. Private networks are often highly redundant
- They convey sensible data, which sometimes justifies the set up of an independent network to ensure data privacy, security, and better access control
- As a strategic development of the industrial company, their financing model may not be adequate for a monthly fee, and more suitable for a Capex investment

Those specific connectivity requirements lead industrial companies to set up private networks, especially when it comes to the detailed use cases below.

Theme	Description
Monitoring and control	Connectivity of machines, people, and systems allow manufacturers to have better visibility and control over the status of their production systems, enabling managers to make better-informed decisions and thus reducing lead times and resource allocation. • **Tracking and control:** connecting all sites to evaluate the relative performance of similar processes, implementing a manufacturing execution system (MES) to have full traceability and visibility on the status of each production batch to anticipate problems and update schedule, connecting different parts of the supply chain to evaluate global performance and anticipate bottlenecks, providing location-based services to track products and assets, etc.
Predictive performance and condition based maintenance	Digital simulations of production processes, labs, factories, or entire networks allow companies to steer processes proactively. Predictive analytics technologies will enable us to understand better how input parameters such as machine settings, operator training levels, or raw material options will affect quality and productivity. • **Predictive performance:** use of advanced stochastic simulation techniques to model the behavior of the factory and predict performance in changing environments (such as new products being introduced, new equipment, change in product mix, increase or decrease in volumes, whole new factories, etc.) or the use of analytics to understand the performance of individual processes depending on the process parameters and then be able to predict the result (good or bad batch) of the production • **Condition-based maintenance:** analyze the behavior of individual components in machines and predict when they should be replaced to avoid degraded quality or machine shutdown
Digital assistance	The shop floor has become increasingly digital, powered by new systems that support operators' daily tasks. • **Augmented reality:** tools such as augmented reality show operators the checklist of steps needed to finish specific processes or confirm that required measures have been completed, along with gathering and reporting data to fuel analytical models or guide technicians during the QC process in the lab through the use of augmented spatial reality • **Virtual reality:** use of virtual reality in immersive environments to facilitate and speed up training for processes in which it is impossible, difficult, or inconvenient to work with the original equipment (for example, if we want to train people before the equipment arrives at the site, if they are in a sterile area and we do not want people to change clothes for training, or if we do not want to stop production for training). Combination of AR/VR and connectivity to facilitate remote expert support to people operating and maintaining the equipment, applications, and wearables to inform the shift leaders of any significant issue in their area of responsibility • **Worker safety:** ensuring worker's safety through wearables measuring fatigue, heart rate, breathing, and motion or sensors detecting exposure to smoke or toxic gas and alerting them
Process automation	Automating processes in manufacturing, assembly, logistics and transactional activities reduce variability, increase throughput, and reduce operating expenses and inventory. The combination of classical automation with collaborative robots, intelligent vehicles and robotic process automation delivers excellent results. For example, the use of **automated guided vehicles (AGV)** or **automated intelligent vehicles (AIV)** connected to the MES or electronic batch record (EBR) to handle material in the plant, specifically customized automation of manual processes (usually handling).

Table 3: key use cases for private networks

Build the ideal ecosystem to deploy a private network

According to the Industry 4.0 whitepaper (Part 4) published by ZVEI-German Electrical and Electronic Manufacturers Association, "Progressing digitization and topics such as Industry 4.0, cyber-physical systems, and IoT will have a drastic influence on the engineering and operation of production systems. This will require strategic corporate management decisions – both by users and providers. A collaboration of users, providers, and system integrators as partners is essential to unlocking this huge potential."

As demonstrated by experts, it is essential to build a robust ecosystem approach to harness the power of private networks in industrial scenarios. The key motivation is the production efficiency or process efficiency that can permit cost gains for manufacturing. Capgemini Engineering plays a crucial role in being the orchestrator of such an ecosystem. The environment of success for private networks delivering the business goals of an enterprise comprises multiple players:

- **The telco,** having in-depth knowledge of setting up networks
- **The core IP** in differentiated radio, access, and compute technology that communications and NEP possess, including the likes of Nokia and Ericsson
- **Process and operations experts** from enterprise, particularly MES and Mechanical Electrical and Plumbing (MEP) experts, who have a deep understanding of process flows, outcomes, and their relationship to input, implications of improvements in input parameters, and manufacturing expertise from the shop floor
- **A system integrator** with cross-functional capability to drive industrial process knowledge-based use cases that can leverage networks. Develop next-generation Industry 4.0 MEP applications that can use the power of unified connectivity in the most optimal way to deliver the benefits for the industry

Case in Point:

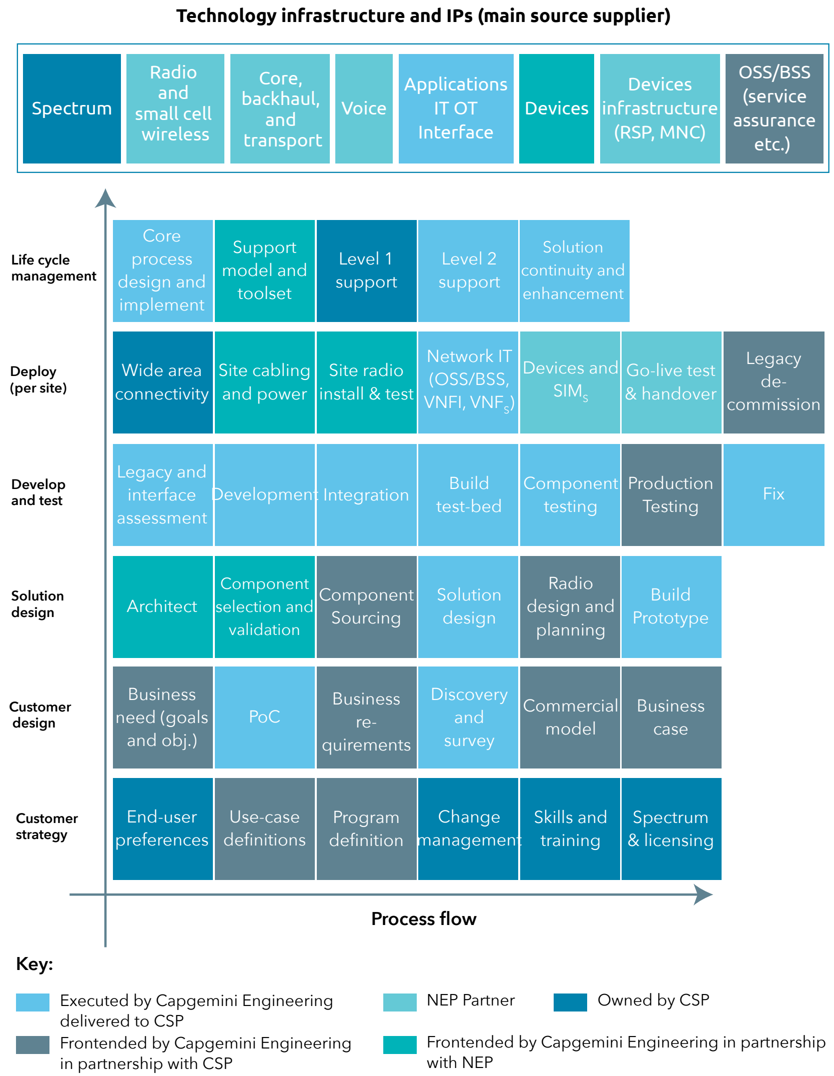


Figure 1: proposed responsibility matrix for NEP, Telco (CSP), and system integrator (e.g., Capgemini Engineering)

The industry is adopting a hybrid approach to deploying a private network. The choice of deployment models is dependent on several factors such as the deployment site (factory campus vs. venues vs. business property/SMBs, etc.), spectrum availability (government regulatory body for 5G spectrum, delicensing spectrum for enterprise use, or spectrum subleasing arrangements, etc.), availability of macro 5G coverage around the site (can organize MOCN, MORAN choices), and sometimes considerations for enterprise data sensitivity, security, and geo-fencing of data, etc.

In principle, most private network deployment can fit into two categories.

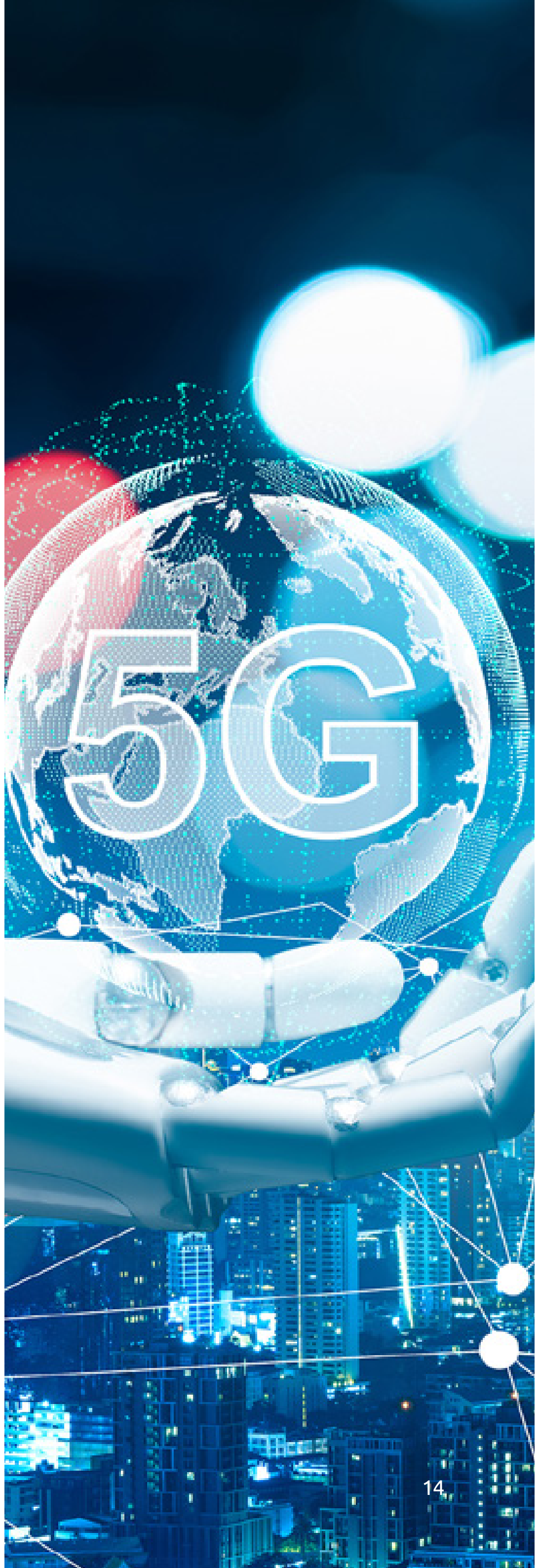
Physically isolated private 5G network (5G island)

- Enterprise deploys 5G network full set (gNB, UPF, 5GC CP, UDM, and MEC) within its premises (site or building)
- This is a constructible architecture in countries where this private frequency is allocated by the government. At present, it is possible in advanced countries such as Japan, Germany, and the United States

Private 5G networks sharing the mobile operator's public 5G network resources

- Enterprise deploys 5G network full set (gNB, UPF, 5GC CP, UDM, and MEC) within its premises (site or building)
- This is a constructible architecture in countries where this private frequency is allocated by the government. At present, it is possible in advanced countries such as Japan, Germany, and the United States

An assessment of various deployment topology options are presented in the table below.



Sr. No.	Type	Sub-Type	Deployment summary	Pros	Cons
1.	Physically isolated private 5G network (5G island)	Standalone mode (greenfield)	• 5g network full set (gNB, UPF, 5GC CP, UDM, MEC) within its premise	• Privacy and security • Ultra-low latency	• High deployment cost • Need skilled engineering
2.		Integrated model (brownfield)	• 5g network full set (gNB, UPF, 5GC CP, UDM, MEC) within its premise • Localized island deployment integrated with existing network infra	• Enables phased upgrade to deployment and new service • Suitable for TSN, closed-loop control, mobile robotics	• High deployment cost • Skilled engineering team required
3.	Private 5G networks sharing the mobile operator's public 5G network resources	RAN sharing	• UPF, 5GC CP, UDM, and MEC are deployed in the enterprise and physically separated from the PLMN	• Subscription and operation information stored and managed in-house	• Enterprise base stations support 'operators' public devices as well & may cause security concern to enterprise authorities
		Concurrency	• gNB within the enterprise is shared between private and PLMN	• Ultra-low delay between device -gNB-UPF-MEC	
4.		RAN and control plane sharing	• Private and dedicated UPF, MEC in enterprise • 5G gNBs in enterprise • 5GC CPs & UDMs in operator's edge cloud shared (control plane sharing)	• Ultra low delay communication between device-gNB- UP +G7F-MEC	• Subscription information of the private network devices are stored in the mobile operator's server rather than in-house

5.	Private 5G networks sharing the mobile operator's public 5G network resources	RAN and core sharing	• gNB is deployed inside the enterprise • UPF and MEC exist only in the mobile operator's cloud	• Least costs to build a private 5G network compared to other cases	• Network latency can be an issue • Traffic transferred to the operator's network
6.		N3 LBO (local breakout)	• gNB is deployed in the enterprise as in the previous case • MEC Data plane local break out module (non-3GPP equipment, ETSI MEC) and MEC applications	• Cost is significantly reduced as expensive UPF is an operator in the operator network • Ultra-low delay application services	• Cannot do mobility management and charging for private network devices • Operational and subscription information is still stored on a mobile operator's network
7.		F1 LBO (Local Breakout) Concurrency	• Little improvement on the N3 LBO • RU/DU is deployed in the enterprise • CU is in the PLMN's edge cloud	• same as for N3 LBO	• same as for N3 LBO

Capgemini Engineering, with its end-to-end, multi-industry domain knowledge and a strong legacy of communications and networking technology, suffices the role of #3 and #4 on the matrix. We created this responsibility matrix for a large-scale private network solution integration project at an industrial enterprise. It shows not only the activity and work items grid, but also the primary and sole ownership between various members of the ecosystem. Moreover, it highlights activities that require joint execution with a primary and secondary role.

Capgemini Engineering has developed this matrix in collaboration with its partners over the past year, working with equipment providers, telcos, and enterprises in leading complex systems trials in several countries in Europe.

Capgemini Engineering expertise

Capgemini Engineering leverages:

- End-to-end, multi-industry domain knowledge and a strong legacy of communications and networking technology
- A deep understanding of manufacturing product life cycle management (PLM) and MES
- Strong expertise related to private 4G and 5G releases 15 and 16 technology spanning new radio, 5G MEC, and 5G new core
- A proven industrial applications microservices platform that enables a 5G application ecosystem to deploy on an enterprise application bus to impact business rapidly
- Cutting-edge technological expertise in enterprise software that manages and controls enterprise business processes from production to distribution and supply chains

Conclusion

Private networks have developed significantly as a response to flourishing use cases of connectivity in the manufacturing space, demanding a diversity of new features for communications solutions. Private networks based on 4G and LTE already bring multiple benefits in the areas of coverage, quality of service, multi-user capacity, hosting of microservices, stable latency, support for low power, and low-cost IoT technologies (NB-IoT and LTE-M), and mobility. But 5G is on the verge of introducing a number of breakthroughs on quality, latency, reliability, and customization of carrier networks for specific applications and slices.

In this context, Capgemini Engineering is continuously collaborating with partners to ensure 360-degree coverage of all facets of the formulation of private networks based on industrial OT networks strategy. This includes telcos with the spectrum and network operations knowledge, and NEPs who have core IP in enterprise radio and connectivity. We can create a technology roadmap to industrial 5G, including building a business case for private 5G networks for enterprises showing ROI models, which can help in decision making.

About Capgemini Engineering

Capgemini Engineering combines, under one brand, a unique set of strengths from across the Capgemini Group: the world leading engineering and R&D services of Altran – acquired by Capgemini in 2020 – and Capgemini's digital manufacturing expertise. With broad industry knowledge and cutting-edge technologies in digital and software, Capgemini Engineering supports the convergence of the physical and digital worlds. Combined with the capabilities of the rest of the Group, it helps clients to accelerate their journey towards Intelligent Industry. Capgemini Engineering has more than 52,000 engineer and scientist team members in over 30 countries across sectors including aeronautics, automotive, railways, communications, energy, life sciences, semiconductors, software & internet, space & defence, and consumer products.

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