CONNECTIVITY THROUGH PRIVATE NETWORK, KEY CORNERSTONE OF DIGITALIZATION

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Acknowledgement

White paper on decision support when contemplating a private wireless enterprise network solution for industries and asset-rich sectors. This white paper was produced by Edzcom with the valued inputs from partners and customers as follows:

NOKIA ATHONET OMRON analysys mason

KONECRANES PORT OULU BASF We create chemistry KEMIN SATAMA Port of Kemi

Executive summary

Enterprises and organisations are **increasingly dependent on connectivity** to extract data from their processes, control equipment and processes through IoT and data, and communicate with staff on the ground or shopfloor. Communication to these ends is essential and increasingly qualifies as critical rather than “nice to have”; as it drives efficiency and process optimisation, often referenced as “industry 4.0”. As many of a company’s devices, equipment, and staff are always moving, wirelessly connecting those assets and staff is necessary. Thus, **enterprise wireless systems** play an increasingly important role in process control, optimisation and operational efficiency for many industries, notably those with many capital-intensive assets.

In this context, ‘Wireless’ can be any **enterprise wireless network - or service - that allows communicating with staff and assets** in a mobile, thus wireless manner. These solutions may comprise many alternatives of which WiFi, trunked radios, mobile networks are the most common, IoT networks and proprietary systems. When an enterprise endeavours to implement wireless solutions in its processes, it has all these options plus many more that have recently emerged: **private mobile networks, notably in LTE and 5G**. An enterprise faced with such a strategic investment or operational enhancement has to decide between all these alternatives.

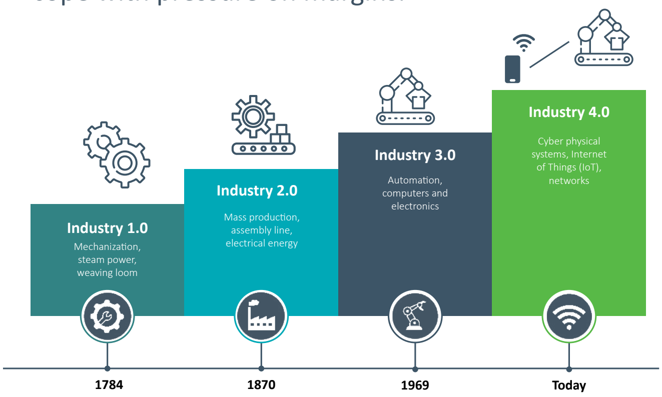
Reading guidance

This white paper will first start with the industry 4.0 context and potential usage of wireless and then investigate the relevance of spectrum. It will also look at prevailing families of wireless standards; look into 5G and then explore user requirements relative to wireless applications. It will conclude various wireless alternatives and qualify those that are close to user requirements. We’ll display where various network alternatives have their distinct place and how private corporate wireless serves the most demanding use cases. A more in-depth version of this paper is available upon request.

Contents

1 Industry digitisation, process automation, and asset control

Industry, manufacture, and production are going through yet another cycle of game-changing innovations, and process adaptations often captured under 'industry 4.0' (with industry 1 – 3 being the mechanisation, electrification, and automation). Industry 4.0 encompasses all the applications of IT, cloud, robotics, AI and any other 'smart' functionality that allows drastic transformation of the production process. The supply cycles are becoming shorter, hence, customers are more demanding. The challenge is to maintain profitability while serving them with scarcity of staffs and supply chain rationalisation. The ultimate aim is to enable industries to withst and global competition and cope with pressure on margins.



Production and manufacturing represents a significant industry generating 16% of global GDP. With its capital deployed in assets, manufacturing offers substantial opportunity for process optimisation, cost savings through smart optimal usage of staff and assets.

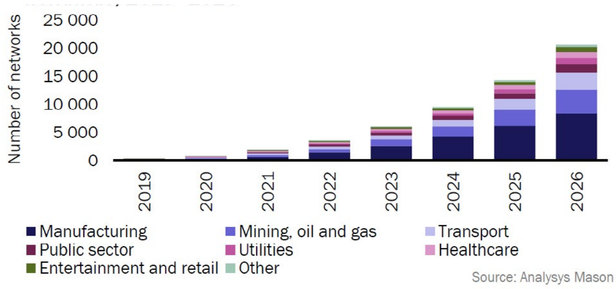
1.1 Wireless and industry 4.0

Assets in manufacturing have often been stationary, allowing them to be wired for automation purposes. Nowadays, equipment is increasingly ambulant or fully mobile; the examples that come to mind are the robot or the AGV (autonomous guided vehicle). Assets like cranes in ports and excavation machinery in mines have, of course, always been mobile. In addition, production lines increasingly need periodic reconfiguring, a task previously associated with much re-wiring. Once the entire process or plant is served by wireless communication, mobility and relocation of machinery are no longer considerable factors.

1.2 Different Uses for Wireless Technology in Digitalisation

The Industry 4.0 market is expected to grow by 16% per annum over the coming years, or even at 21% according to another. According to sources, the market is expected to grow from 100+ bln USD in 2020 to 200 – 300 bln USD in 2028.

Number of private LTE/5G networks by sector, worldwide, 2019-2026



Source: Analysys Mason

The sectors or 'verticals' that may benefit most from wireless and smart production are discrete manufacturing, process industry, warehousing and logistics, ports and airports, mining and excavation, and the energy sector. Tightly controlling the output in real-time is key to efficient manufacture. Wireless data communication to equipment and staff facilitates this, and so does real-time video for control, preventive maintenance, and AGV steering. IoT – Internet of Things – caters for real-time insight into the statuses and operations of hundreds of assets, parameters, buildings, sensors and thus caters for a permanent 24/7 monitoring and control of all parameters related to production. AR and VR enable third parties and company specialists off-site to be consulted in case of errors or breakdowns, without a need for them to travel on-site; thus, saving time and resources.

2 The enterprise use case (industry 4.0 and digitisation)

Further on, we will explore some generic aspects of wireless networks, both private and public. We will look at spectrum aspects and the sheer nature and origin of wireless standards.

But first, we will start the exploration from the user's end: **the enterprise, its processes, its desire for automation and mobility,** and the associated user requirements. We will see that these requirements eventually determine the standard and network which are best suited for a particular use.

2.1. Typical verticals using business-critical wireless

These industry verticals in which critical mobile communications apply are listed in the table below. The table also identifies and qualifies critical capabilities of the (wireless) network; which we explore below per vertical.

Ports and logistics, in which control over time-critical processes, steering of AGV's and cranes play an essential role, while adding versatility to the operations. Typically, leading ports and airports are already deploying private wireless networks. The 365/7/24 nature of operations take tight control of the entire chain and is key to increase efficiency and save costs.

Manufacturing and production[3] ; where automation of production lines, maintenance, robotisation, just-in-time delivery and sensor data can all benefit from wireless, location-independent connectivity. Ever tighter control of processes and cost-efficiency are the two major generic drivers.

Verticals

Users aspects	Ports and mainports	Process Industry	Manufacturing	Utilities and Energy	Mining and excavation	Transportation and logistics	Healthcare
Capacity: high throughput	Video surveillance and steering	Often low data sensors	Video controlled machienery		Video controlled heavy assets		
Capacity: high device density		Large № of devices	Operators savings and cost control			Portable data terminals	Large № of staff and equipment
Coverage and superior indoor penetration	Campus coverage	Campus coverage and hostile environment	Mostly indoor	Coverage along grids and lines	Vast, remote area, and hostile environment	Wide are coverage; indoor warehouse coverage	Typically indoor + some wide areas
Low Latency and round trip delay	Crane & AGC control	Safety critical plant control	Robotics	Safety critical grid control applications	AGV and equipment control		Remote diagnostics or surgery
High Reliability and availability; data security	Crane & AGV control	Plant control Safety management Intrusion control	Product line automation; autonomous factory	Safety and security, potential hazards	Safety of staff	Protection of 3rd party data	Life saving situations
Tailored Uplink -Downlink ratio		UL >> DL	UL <=> DL tailored to types of machinery	UL >> DL	UL > DL in case of video control	UL <=> Dl tailored for applications	Specific UL <=> DL ratios
Embedded IoT enablement	Track and trace; cost control	Sensors and actuators		Sensors and actuators	Equipment monitoring data retrieval	Track and trace; data retrieval	Remote monitoring, telehealth
Low power devices	Unwired objects with IoT	Avoid expensive wiring	Battery powered equipment; periodic relocations	Devices typically powered	Devices mounted on powered assets	Unwired objects with IoT	Portable device and sensors

Index	Utmost Importance	Relevant	Lesser interest

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The process industry is a category within manufacturing where typically equipment is more stationary. Yet, processes run 24/7, and process control is is tightly related to safety and hazards prevention. Here wireless tends to play a role to replace expensive and complicated wiring, even when devices are stationary. Also, KPI's are extremely tight as loss of control can have hazardous implications.

Mining and excavation, where typically extensive and very capital-intensive equipment is used, therefore real-time connectivity can save production time, downtime and maintenance. These are sometimes areas which may be vast and remote resulting in a hostile environment for radio systems. Also, sites are often out of reach of public mobile networks.

Utilities and Energy; As with mining, sites may be remote and connectivity may be required on-site along tracks and lanes. Uptime and availability of the networks are of the utmost importance to the operation. Tracks will often be remote and may be out of reach of any mobile network.

Healthcare and hospitals, where cost optimisation and ageing are universal driving forces requiring tighter control over processes and remote health applications. Since life can be at stake, wireless applications can be demanding in terms of availability and reliability.

2.2. Typical Enterprise wireless usages

2.2.1 Equipment control and remote operations; robotics

This is the category of automated production, plant control and process digitisation, often still wired out of 'legacy' but increasingly wireless due to the ease of relocation and efficiency. Wireless connectivity can also cater to the equipment that was previously out of reach or even off-premises, in a hazardous environment, etc. Robots[5] are finding their way into production, providing fully autonomous physical processes and 24/7 operation. The stakes are high as loss of production is costly; the potential gains are also high, in the approximate range of 10 - 20% of efficiency gain[6].

2.2.2 Equipment control and remote operations; robotics

This category of wireless usage occurs in many industries with mobile assets, ranging from cranes to AGV's, from excavation devices to lorries. Typically, these assets are capital intensive, need to be deployed 24/7, and require meticulous control to ascertain they do the right job and do not collide.

2.2.3 Efficiency and optimised performance

In asset-rich industries, there is an increasing demand for data to improve process management. This requires the extraction and collection of countless data from the equipment, such as location, velocity, statuses, temperatures, pressures, flows, etc. These applications are captured under the term IoT, Internet of Things.

2.2.4 Sustainability and environmental control

In sectors like utilities and heavy industry, there is potential environmental gain in monitoring and controlling processes tightly and permanently. Emissions, noise levels, power consumption, etc may need optimising to maintain the company's societal position and reduce energy bills. Also sensors and IoT are likely to be required. With assets either far out in the field or permanently moving, wireless is often the only alternative for connectivity.

[5] 2.7 mln robots are active in manufacture across the globe, increasing by 12% per annum according to World Robotics 2020 report.

[6] Many researches substantiate such figures

2.2.5 Data distribution & operational process digitisation

In many processes, data and information need to be distributed to either staff, databases or equipment. Typically, on the floor of a warehouse, people need to dispose of large amounts of data for their logistics and inventory; on the apron of an airport, staff needs to dispose of data on cargo, fuelling, bill of lading, etc and the same applies to ports.

2.2.6 Video distribution or -retrieval

In many operational and industrial processes, there is demand for live video streams from the equipment of locations to monitor statuses, the correctness of loading, movements of ambulant equipment, providing an image for operators in a control room, etc. Applications may be new or nascent as wireless networks didn't cater for video distribution with high, constant QoS until recently (as private wireless now does now).

2.2.7 AR and data assisted maintenance

In capital-intensive sectors, maintenance and downtime are costly and need to be avoided. With sensors, the equipment can be monitored 24/7, with video acting as a sensor just as much. Even through video, preventive maintenance can be conducted based on algorithms and machine learning. A digital 'copy' can enable troubleshooting without interfering in real live processes.

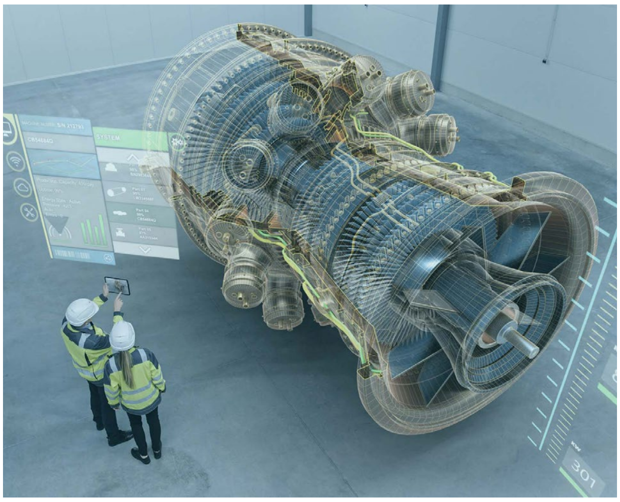
The manufacturing sector will account for the largest share of private LTE/5G networks (40%) in 2026, followed by the mining, oil and gas sector (22%).

*Analysys Mason, **Private LTE/5G networks: worldwide trends and forecasts 2021–2026 (analysysmason.com)***

2.2.8 Communication with operational staff; worker safety and emergency

Typically, in operational processes, in process industries or in manufacturing, there are staff "on the ground" roaming around the premises or the campus. With this staff, communication is eminent, often voice but increasingly also data through tablets and portable devices. This level of communication most often requires voice connectivity as a basis; still today and probably for many years to come.

For the voice part of enterprise communication, there are so-called trunked radio or PMR (Private Mobile Radio) solutions that are still widespread in the industry. Due to a desire for convergence, these services are increasingly combined with data onto one network using mobile standards such as LTE and its successor, 5G.

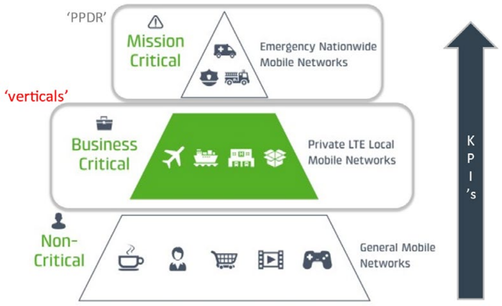


2.3. Requirements on wireless

2.3.1 Criticality of wireless

It is common to designate enterprise wireless as 'business critical', whereas consumer services are typically "best effort". "Business Critical" refers to the large financial and economic stakes involved in these communications. There also is a category identified as “Mission Critical”, usually referred to for public safety organisations where often life is at stake. They too deploy private wireless networks for their blue light operation. A category perceived as enterprise usage yet with mission-critical properties (life potentially at stake) is plant automation in process industries and equipment monitoring in utility sectors.

‘stack’ of wireless requirements



Source: TCCA

2.3.2 Performances or KPI’s of wireless

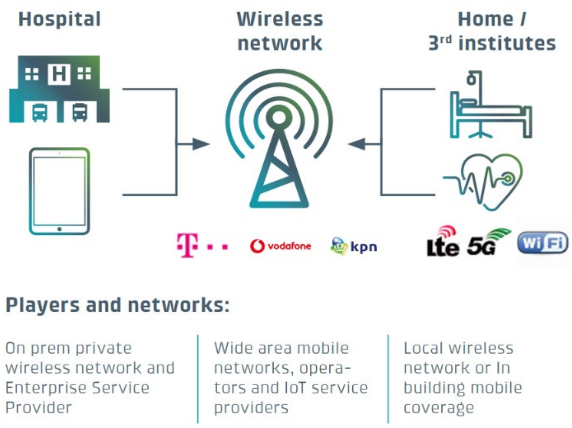
To meet all the above types of applications requires many things from wireless connections. First of all, connections have to be **reliable** (like 99.999% availability, or “5 9’s”), have very short **latencies** (delay), high **throughput** (if video controlling is involved), and may require efficient **powering** (device battery for powering). For machine control, often stringent round-trip delay or latency is compulsory. Also, **asymmetry** between up and downlink will frequently apply. The uplink (data from sensors back to the process) is dominant, which is counter to public networks where download is critical. Device **density** is likely to be another demanding parameter, notably in fully automated plants. In addition, autonomy or battery life for remote or battery-powered sensors can be critical. The voice part of communicating with staff requires high availability, a very low bit loss rate (you don’t want to miss that essential ‘stop’ or ‘don’t’ in a sentence …). Packet loss or bit error rate can be crucial for plant control data, though some protocols make up for lost packets.

2.3.3 Coverage area to facilitate; Campus and Indoor

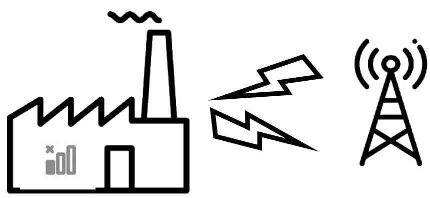
The typical industry case is that of **a factory or campus to be facilitated** with enterprise-grade wireless services. This can then be done ‘on premises’ with private wireless or alternatives, as we’ll explore in chapter 5. However, there may be a need for a **vaster coverage area,** such as for infrastructure operators (public transport, utilities), who seek coverage with high KPIs along their tracks or grid. A private wireless option may also prevail though more capital intensive as the coverage is spread. The industrial use case where remote plants, warehouses, and campuses need to be facilitated with dedicated wireless service, also required when moving between premises, is more demanding.

Here, typically high-performance private wireless can still be the solution on-premises, with coverage along the “corridors in between” provided by an MNO or a specialised IoT service provider or MVNO.

Local or wide area wireless for care applications



Indoor coverage within buildings is a factor to consider as well. For production automation, high QoS wireless coverage will often be required within a factory or warehouse, so indoors. Yet…. public mobile networks are typically designed to cater for outdoor usage and have great difficulty penetrating buildings (especially if these are of steel or reinforced concrete):



Thus, for a high-performance wireless service, an enhancement or extension of any network is likely required. The solutions exist and are plentiful, yet the mobile service provider must cater to them.

3 Spectrum or radio frequencies

In order to implement any type of mobile or wireless network, the enterprise or its provider will have to be able to dispose of the spectrum or radio frequencies to run the service on. This is irrespective of who runs the network, provides the equipment or even the standards it deploys; all wireless networks operate on radio frequencies of some kind. The radio spectrum can be considered the generic and essential 'raw material' of any wireless network or -solution.

SPECTRUM - or radio frequencies - is the most essential building block for any wireless network; be it private or public. Spectrum is scarce and in high demand; national regulators allocate spectrum to many mobile and wireless services. Also for any form of a private wireless network or service; spectrum or access to spectrum is the key 'raw material'.

These frequencies (spectrum) can be provided by the party that is also providing the service to the enterprise. Typically, this applies to mobile operators: they have their own spectrum, most often sourced in auctions. The national regulator has held auctions in which providers of mobile networks and services have been bidding for designated spectrum bands, usually paying millions if not billions for the spectrum assets. This spectrum is tightly licensed.

The opposite extreme is the unlicenced or free spectrum. There are harmonised spectrum bands that are free to access for anyone; most of these are internationally standardised. The best-known example of this is Wi-Fi, a technology deployed worldwide on the license-free or 'license exempt' spectrum. Traditionally it used the 2400 MHz spectrum; due to its success, more spectrum in 5Ghz has been made available for Wi-Fi. Free spectrum, though pleasant to deploy, has its drawbacks, as we will see. There are some variants of free spectrum, depending on country; sometimes, a regulator will let the user of spectrum register its use and location; a lightly licensed regime as it is often referred to. The regulator will control the rate of re-use to ascertain that spectrum users do not interfere one another.

3.1 Spectrum for private networks

The just mentioned regional or shared spectrum regimes can provide for spectrum to be used by enterprises for local, private mobile networks! We'll elaborate on those networks further down; here, it is essential to mention that the availability of such a private spectrum is imperative to developing and establishing one's own private wireless network.

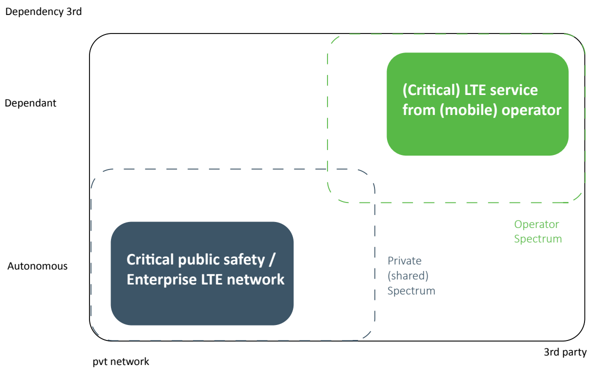
The availability of such private or local spectrum for private networks differs per country and is not yet harmonised between countries in the EU, let alone worldwide. In the markets in which Cellnex operates, the following spectrum has been at its disposal:

Country	Frequency range	Bandwidth	3GPP band	Duplex	Technology	Note
	2.3 GHz	10-20 MHz	B40/n40	TDD	4G / 5G	Preference for Utilities
	698- 703 MHz	2x5 MHz	B68	FDD	4G	Only Mission Critical
	26 GHz	400/800 MHz	n258	TDD	5G	Pending action Q321 / Q122
	2.6 GHz	10-40 MHz	B38/n38	TDD	4G / 5G (test)	100km² minimum allocation, up to 20 MHz 4G, up to 40 MHz 5G (testing only)
	26 GHz	400/800 MHz	n258	TDD	5G	Only Mission Critical
	3.8- 4.2 GHz	10 - 100 MHz	n77	TDD	5G	Primary private 5G band by regulator
	1.8 MHz	2x3.3 MHz	B3	FDD	4G	Local License by regulator (for 5G NSA anchor band)
	2.3 GHz	10 - 100MHz	B40/n40	TDD	4G	Local License (under regulator license for local purposes
	26 GHz	400/800 MHz	n258	TDD	5G	Indoor shared access
	3.4- 3.45 GHz- 3.75- 3.8GHz	50 MHz (2 blocs)	B42- B43	TDD	4G	Regional, semi-proprietary
	1.8 GHz	2x5 MHz	B3 (FDD)	FDD	4G	Guard band, power limitations
	2.3 GHz	20 MHz	B40/n40	TDD	4G	Regulator Indoor only, low power
	1.8 MHz	2x5 MHz	B3 (FDD)	FDD	4G	Regulator Indoor only, low power
	3.5 GHz	40 MHz	n78	TDD	5G	Regulator 40MHz, rules and timing not clear yet
	2.3 GHz	10 - 20 MHz	B40/n40	TDD	4G	Regulator
	2.6 MHz	50 MHz	B38/n38	TDD	4G (/5G)	Regulator via Sale & Leaseback deal with Elisa
	26 GHz	400 MHz	n258	TDD	5G	Regulators, rules note clear yet
	3.74- 3.8 GHz	60 MHz	n78	TDD	5G	Leasing from TT- Network for PN (2 years window of opportunity)
	2.3 GHz	10- 20 MHz	B40/n40	TDD	?	Pending confirmation by regulator
	3.4-3.8 GHz	80 MHz	n78	TDD	5G	Pending confirmation by regulator
	26 GHz	60 MHz	n78	TDD	5G	Allow leasing through an operator

We refer to some sites[7] for recent updates on these (private) spectrum availabilities; the situation tends to develop.

There are alternatives, though, when a country does not dispose of spectrum for private networks. Typically, spectrum regimes allow the holder of a license to either sublet his spectrum or deploy it for networks of 3rd parties. In practice, it may well be that in a country and for a designated purpose or geography, a mobile operator is inclined to make some of his spectrum available for private networks. Most probably, that operator will charge a fee for that. In addition, this model creates a certain dependency for the enterprise on that mobile operator and his willingness to allow the use of his spectrum and the conditions he adheres to that. In a way, this 'lending' spectrum model is almost the opposite of developing one's own network on a private spectrum, as is depicted below.

Basic options for critical mobile service provisioning



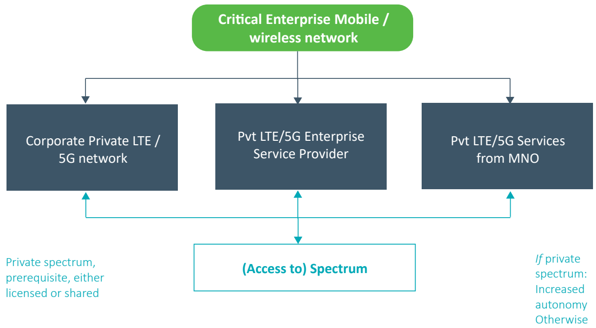
3.2 Spectrum and QoS for enterprises

- On licensed and thus protected spectrum, it is possible to guarantee QoS and enter into an SLA for the quality of the wireless service delivered.

- On an unlicensed spectrum used randomly by neighbouring systems and users, the performance or even availability at any given time can never be guaranteed.

Whether the wireless service for an enterprise is sourced by the enterprise itself, through an enterprise service provider or from a mobile operator, the guaranteed access to spectrum allows guaranteed performances and permits autonomy and sourcing options. Without such a guaranteed, licensed, or 'private' spectrum, the enterprise will depend on 3rd parties for access to their spectrum and any QoS.

Spectrum pivotal role for Critical Enterprise Wireless



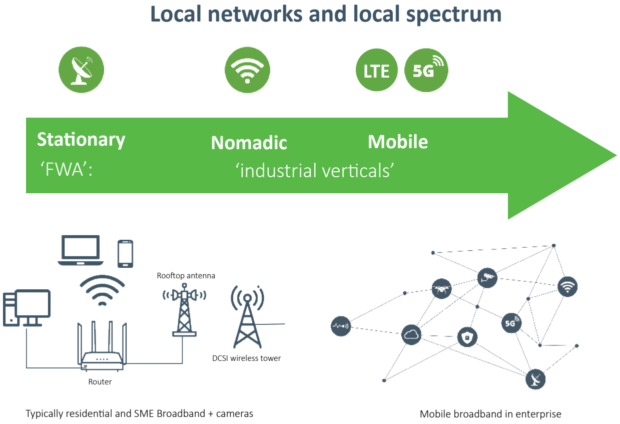
Source: TCCA

[7] Qualcomm publishes regular updates: www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf

4 The fundamental nature of wireless standards

4.1 Stationary, nomadic and mobile usage

Wireless standards were all inherently developed for using devices that displace themselves, that are on the move. That level of mobility, however, can differ; ranging from largely static or stationary, via nomadic to fast-paced mobile:



Stationary use of wireless, also called Fixed Wireless Access, indicates it uses Wireless as a means to create Fixed Access. More on this in our extended white paper (see acknowledgements).

There is so-called nomadic use, where a user or device relocates itself and then stays in that location for a while. Whilst in that location, it communicates wirelessly, and after some time or sessions, it relocates again to be stationary for a while once more. This type of nomadic usage requires a wireless standard that connects to a network and then optimises its performance for the spot it'll be in for a while and coordinates with equivalent nomadic neighbours. The laptop with WiFi is a classic example of this usage. Nomadic industry use cases can also exist in that an asset relocates infrequently and not continuously. Standards like Wi-Fi are optimised for this scenario, with amongst others high data throughput, 'listen before talk' coordination with neighbours, and no or partial ability to hand over a session between cells whilst a session is ongoing. When the device displaces, Wi-Fi does not hand over a session or call from one base station to another as mobile networks do; instead, it just disconnects and then reconnects.

Then there is 'true' mobile use. We all know this usage from smartphones: the device and the user are constantly on the move, either at pedestrian speed or at car/train type of speeds. Whilst on the move, the device must be connected to the network permanently and flawlessly to maintain communication at high quality.

This true mobile use of wireless networks and devices is the kind of use we will come across most often in enterprise mobility and wireless usage within verticals, where either staff or devices and assets are constantly moving.

4.2 Wi-Fi and wireless IT

The Wi-Fi standards were initially drafted in the 80s. Their origin was – many people don't know this – the enabling of moving cash registers without pulling wires. So a cordless cash register[8] was the initial purpose!

The IT industry soon recognised the power of Wi-Fi so countless variants were developed with the primary purpose of making PCs – and later tablets and laptops – cordless. They were initially designated as 802.11. a up to 802.11ax, the latest Wi-Fi standards are designated Wi-Fi 5 and Wi-Fi 6 to make them more amenable. However, the nomadic origins of the standard are still present in its abilities today! The standards are very suitable for high data throughput to relatively stationary devices, typically PCs and office workers. This use is designated 'nomadic' as explained above, and that use is still at the very heart of the standards.

[8] NCR was at the origin of the wifi standard for this purpose of cordless cash registers

4.3 Mobile network standards

Mobile networks as we know them today also originated in the 80s (as did Wi-Fi) and started with analogue mobile phones and networks. Europe used to have 1st generation NMT networks – Nordic Mobile Telephony – in many countries, most often called differently. In the 90s we saw the emergence of the world-renowned GSM standard (2nd generation, or 2G), succeeded in the years 2000 by UMTS/3G. The decade of 2010 of this century saw LTE or 4G, the first truly data-oriented mobile standard, and as many know, we now have 5G networks and services are still under development.

The ecosystem of mobile standards is driven by 3GPP, the 3rd Generation Partnership Project, an association of all the large operators and suppliers of mobile networks that develop and maintain the standards.

Mobile wireless or 3GPP standards were developed as of day 1 for truly ambulant users and devices, moving at high velocities and relocating themselves continuously, either regionally or countrywide and even internationally. This phenomenon implicated that roaming and handover (the forwarding of a call from one network element to another) is inherent to the standards. These features apply to 4G/LTE just as much as 5G, the latest standard.

4.4 Other mobile wireless standards

Related to "mobile" networks, yet targeted at a specific user group, there is trunked radio or PMR - Professional Mobile Radio - as it is often called. These systems are primarily aimed at voice communication. These standards are inherently robust and are used by all public safety bodies worldwide, typically nationwide. The same technologies are often deployed locally as a voice network in an enterprise or industry site.

There are other wireless network standards in the domain of wireless and mobile technologies to be mentioned. Some are true standards; some are industry initiatives. Here we simply mention in addition to the above:

- GSMR; a GSM derivative especially developed for railways
- Meshing protocols using – unsecured! – Wi-Fi spectrum such as WirelessHart in petrochemical sectors and FluidMesh, used in the logistics sector.
- IoT or Internet of Things; standards aimed at communication with and between devices for smart building and sensoring purposes. There are over 10 (!) of these wireless standards.

These beforementioned clusters of standards all play a significant role when it comes to enterprise private wireless networks. When we discuss the features and applicability of network options and standards, we will see that many of the properties relating to the very origin of standards still prevail today.

5 Enabling industry use cases: the 5G 'triangle' of features

The wide variety of industry use cases and requirements have made the wireless standards evolve towards professional users' processes and requirements. 4G and 5G technology now are genuinely meeting these connectivity demands.

5.1 (Private) wireless up to 4G/LTE

Typically, GSM or 2G was a voice-only standard that revolutionised the world with true mobile services and unprecedented reliability and quality. UMTS or 3G was the first attempt to insert data transmission into a wireless standard. With LTE or 4G, the wireless standards moved to data and IP as a basis and could cater for both voice and data over the same network and standard. It is often ignored that LTE already disposes of several features that enable the provisioning of an enterprise-grade service over LTE! In LTE, one can prioritise certain traffic over another; one can adhere distinct classes of service to designated users or traffic. LTE allows an operator of a network – be it the nationwide mobile operator or the specialised service provider for an enterprise or sector – to tailor a network to the specific requirements of an industry. This is a crucial notion here before we 'move on' to 5G.

5.2 5G and industry use cases

5.2.1 The arrival of 5G

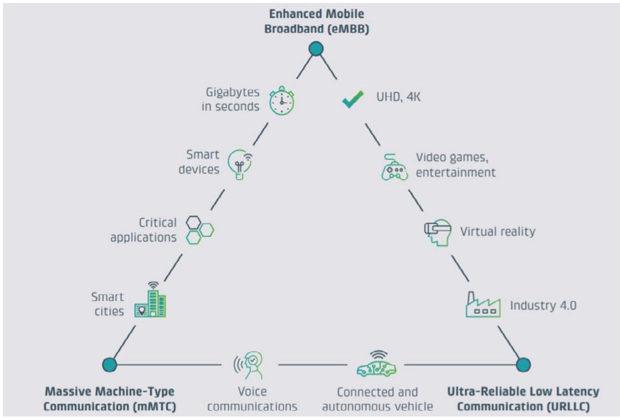
The advancement of 5G is well publicised, and few industries or consumers have failed to spot its presence and emergence. Then again, the most promising feature sets of 5G are not in consumer but in enterprise applications. Undoubtedly, 5G will again offer higher data rates for mobile devices, will allow faster video streams and a better user experience for streaming and gaming. These are the consumer benefits usually captured in 5G under 'Enhanced Mobile Broadband' or eMBB. That, however, is the least performant aspect of 5G.

The two much more relevant two clusters of developments are:

- URLLC or Ultra-Reliable Low Latency Communications
- Massive IoT or massive machine type communication (mMTC)

5.2.2 5G features for verticals

These last two clusters of features, together with the mentioned eMBB, are often depicted as what has become known as the '5G triangle' of features:

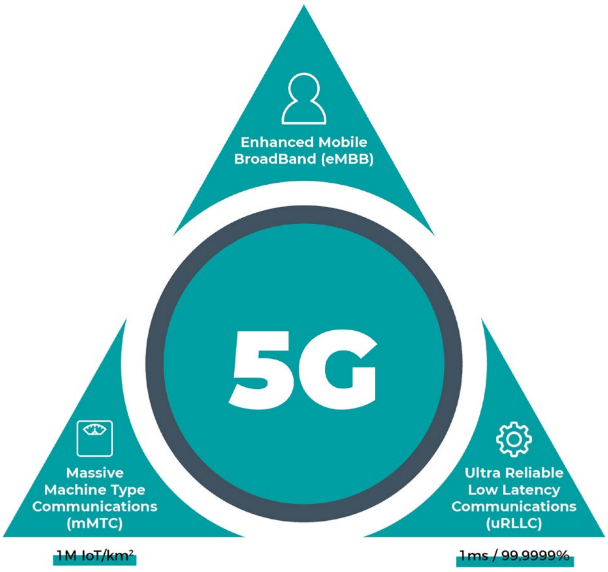


The first set of features to be developed and released were the 'eMBB' ones in the latest release of the standard. The up-and-coming part of 5G – massive IoT and URLLC – are in the process of being standardised and will be released over the following years.

These feature sets – URLLC and massive IoT – are expected to be relevant for industries and verticals more than for consumers, and the real added value of 5G over 4G is expected from these subsets of features. It is through these feature sets that a provider of a service to an enterprise will be able to truly tailor a mobile service with whatever features or KPI's that the enterprise and its processes require!

[8] NCR was at the origin of the wifi standard for this purpose of cordless cash registers

The capabilities of 5G are to become tremendous:



Then again, not every industry use case requires all these individual performances, let alone all of them simultaneously. Data from a leading supplier[9] reveal that almost 90% of implemented systems are still 4G.

Standards versus equipment readiness

It is fair to add that it requires more than just the standards to be ready for a feature set to be available to end-users and industries. After a standard is 'frozen', it needs to be implemented into equipment, wireless networks, mobile devices and then providers of mobile networks need to enable these services to their end-users…!

5.3 4G and 5G features for verticals

5. 3. 1 5G 'slicing' of sub-networks for industries

There is one new feature in the 5G standards that looks extremely promising for verticals and industries: it is called "slicing".

This 'slicing' allows the operator of a 5G mobile network to implement subsegments of a comprehensive network with pre-set features and performances for either a specific user/network or a targeted subset of users. The phenomenon is typically aimed at the verticals or industry segments. Slicing can be implemented by a (nationwide) mobile operator just as much as by a service provider of a specific particular private network. With slicing, the network operator can select and deliver precisely those capacities, latencies, densities of devices, etc., that the designated vertical requires and can guarantee its performance.

Then again, slicing is expected to be a game-changer in 5G and services to verticals. Slicing under 5G has recently been demonstrated in a public EU project[10].

5.3.2 EDGE computing and core networking

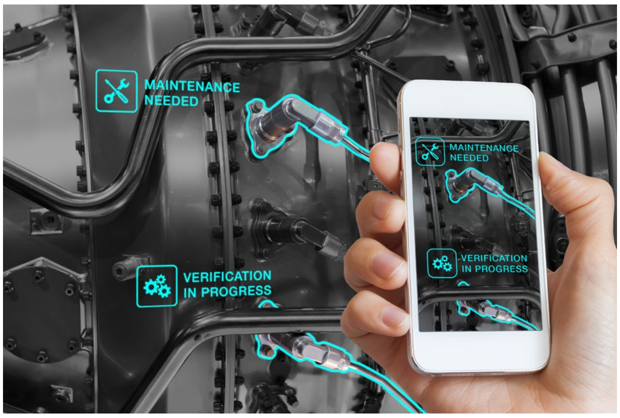
A concept often used in conjunction with private and 4G or 5G networks is that of "EDGE". The term is widely used in IT industries to designate that processing power is brought from the (central) core to the periphery or edges of a network, typically from the data centre to the end-user's premises. In mobile networks, this implies having the 'core' or switching function of a network – the "EPC" in 4G - close to or even on users' premises. Edge reduces the amount of data that has to leave a customer premises and reduces transmissions and distance to the network and back. This, in turn, benefits the resilience of a network, its latency, its throughput and reduces an end user's dependency on 3rd party locations. Edge meets stringent enterprise user requirements and can be applied to any network, private or public. As KPI's required are becoming more stringent, Edge is likely to see more implementation.

[9] Nokia in an announcement on Equinor mention 290 LTE vs 40 5G projects

[10] The 5G MoNArch (Mobile Network ARCHitecture) project in port of Hamburg

6 Converging the options: Mobile network alternatives for verticals

Now, we'll look at the types of mobile and wireless networks that exist, to what extent and how they can facilitate private wireless functionality for enterprises and critical organisations.



"Who does your WiFi?" A private LTE softcore and small cells are simple enough to be done by a WiFi integrator.

*Nanda Menon, **Athonet***

6.1 Private wireless network on private spectrum

These networks are inherently able to provide the highest level of QoS and meet the most stringent KPIs! Here, a dedicated network is established for an enterprise or user with dedicated resources. From the 'core' (called EPC, enhanced packet core) to the radio network (the base stations or 'EnodeB's), the entire network is geared towards the individual use and parameters of the organisation. Redundancy to obtain resilience and availability can be introduced at will: fibre connections can be duplicated and double routed; radio cells can be made to overlap, power backups can be implemented, etc. A large number of many nines can be attained this way. Likewise, a tailored latency, throughput, etc., can be built into the system; there's barely a limit to the level of QoS that can be attained.

This alternative does require local or enterprise-grade spectrum to be available, either obtained from the national regulator or sublicensed from a license holder such as – but not limited to - an MNO. Private spectrum does exist in designated EU countries, as we have identified in chapter 3.

Critical Usage:

These private alternatives are to be used when performance is very critical, at least essential in the business or even mission-critical in the sense that safety and lives can be at stake. The latter may well be the case in the petrochemical and process industry, where plant control and data collection are imperative to safety.

When expensive assets are at stake and can be controlled and monitored over wireless, the wireless network's performance is still business-critical and very costly downtime or damages can occur when performance degrades. Examples here are mining, manufacturing, utilities, and many other asset-rich environment.

6.2 Private wireless network as an MNO ‘slice’ of a public network

In this option, the Mobile Network Operator or MNO sets aside a “slice”- see par. 5.2.2 - on his network for the designated enterprise and warrants a certain performance level to the enterprise by allocating resources (spectrum, equipment) to the service. As noted in the mentioned paragraph, there are inherent limits to what an MNO can deliver as a slice out of his nationwide public network. The MNO can enhance and strengthen his offering by placing dedicated equipment on-premises at the customer’s or EDGE, notably the core (“EPC”) or even some extra radio transmitters (dedicated ‘RAN’ or Radio Access Network). These options have to be negotiated in relation to the desired QoS.

Caution applies here... Mobile operators have historically provided nationwide mobile coverage for mass markets, with no KPIs (so “best effort” only) and aimed at a generic offering. One could call the offering horizontal in that it cuts across all users and basically is the same. Providing services to industries requires a “vertical” offering, with tailored performances to meet individual industry segments and even companies and their specific usages. Even though their networks should be able to provide such bespoke services as through ’slicing’, the MNO at stake ought to also equip its organisation and processes to interface with different verticals and provide network management according to tailored SLA’s (potentially many hundreds). It should be ascertained that the MNO offering an enterprise a critical wireless service indeed equipped and organised for verticals.

6.3 Private wireless service out of a macro network

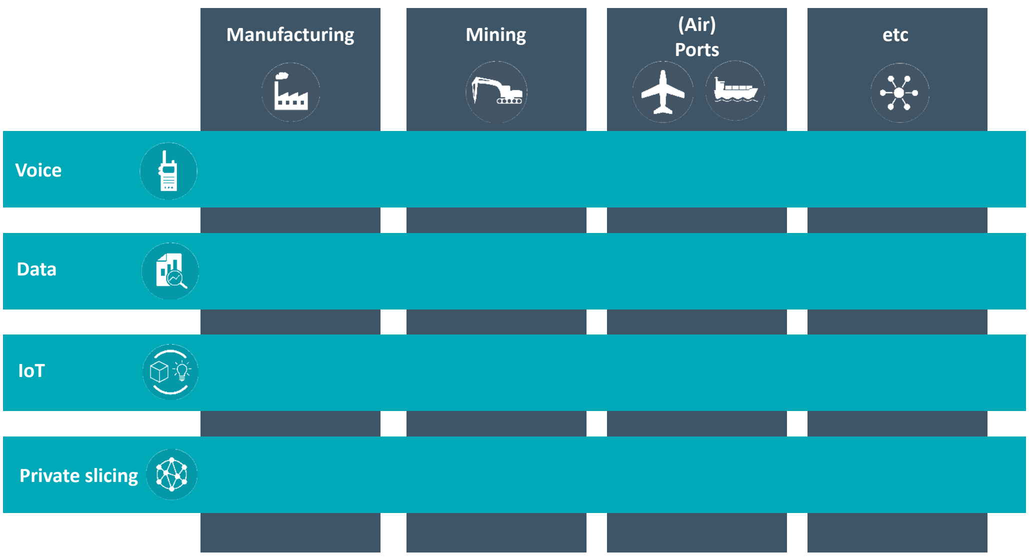
Again, the MNO can provide wireless service to an enterprise, yet here fully based on the public mobile network he has available at and around the premises or campus of the corporate user. The enterprise can then get a service that meets other mobile network users in the vicinity if necessary, enhanced somewhat by extra base stations or extra capacity (EPC). Without applying the above “slicing” it’ll be hard for the MNO to provide service level guarantees. After all, the MNO has to serve millions of subscribers and all the public users at and around the corporate location through the same network.

The mobile network of an operator was and is designed for a “horizontal” offering: a couple of predefined subscriptions for all of the country and millions of users. It wasn’t designed to cater for very many tailored services with differing KPIs for various industries, nor was the organisation probably.

The ability for mobile operators to embrace a multitude of verticals and offer dedicated tailored services is likely to be curtailed by the margins on mobile subscriptions not having grown or even shrunk over the last years for most providers.

Two additional notions with this concept:

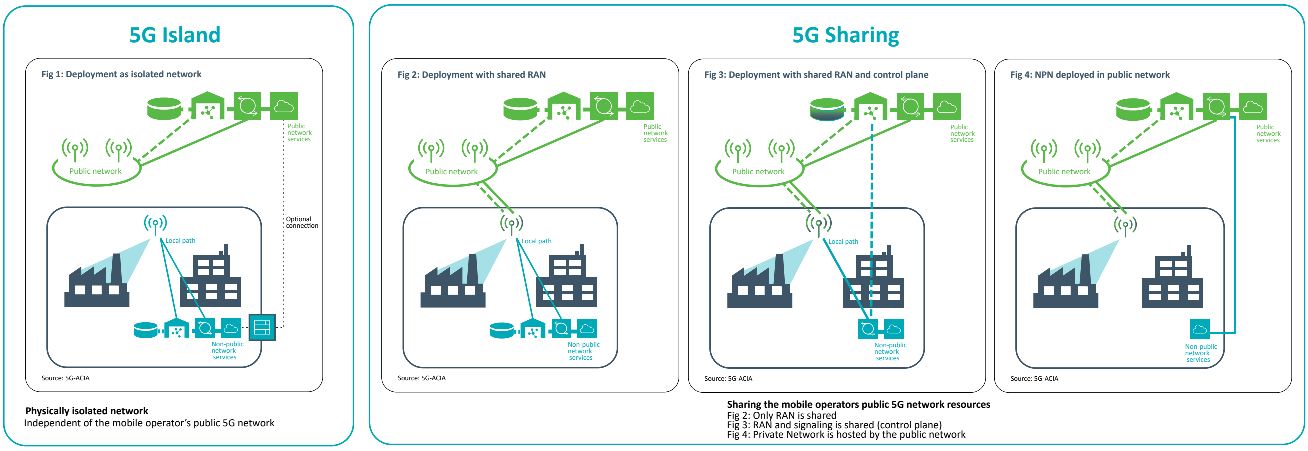
- The enterprise customer – in the absence of a dedicated “slice”- has to share resources in the MNO network with other users; so negotiating performance and resources is crucial, and so is meticulous monitoring of any (degradation of) performance due to load sharing.



- The macro network of the MNO at the enterprise location is designed and sized for outdoor coverage. That may suffice if the enterprise usage is predominantly on an outdoor campus such as a port or refinery but may be inadequate if the enterprise wants to use devices and services within buildings such as warehouses and factories. Remedies exist in the form of an indoor antenna network or signal enhancement system. Still, again, these have to be provided by either the MNO with the wireless service or the enterprise itself[11].

Operators may find it challenging to deliver systems integration and horizontal expertise needed for private networks

*Analysys Mason, **Private LTE/5G networks: operator and vendor profiles and analysis***



6.4 Private wireless options on 'free' spectrum

When there is no private spectrum to be acquired, there are still options for private wireless networks on an unlicensed or "free" spectrum due to the country-specific regulation!

6. 4. 1 Enterprise LTE or 5G on unlicensed spectrum

Wi-Fi is the best-known example of the use of a license-free spectrum. However, there is an "in between" option that deploys the capabilities of international mobile standards such as LTE or 5G yet on license-free spectrum! This is the MuLTEfire alternative, succeeded in 5G by the 5G NR-U or New Radio Unlicensed. In our extended white paper, we will deal with this variant; see acknowledgements.

6. 4. 2 Enterprise wireless on Wi-Fi

This category of enterprise wireless networks comprises all the variants of Wi-Fi that exist, ranging from legacy wifi 802.11 xx variants to more recent Wi-Fi 5 and Wi-Fi 6 alternatives. As presented in par. 4.2, Wi-Fi was intended and built for nomadic use and IT connectivity which is still the remit of any wi-fi network.

Due to the fact that Wi-Fi operates on free spectrum – notably in 2.4Ghz and 5 GHz – there is no option to guarantee its performance as the fundamental bearer – the frequencies - may be jeopardised by neighbours, alien use, and interferences. Nonetheless, the latest wifi6 networks do have some performance/interference mitigation built-in. Wi-Fi typically suffers from the unpredictability of the KPI's, notably latency but also the throughput, predominantly under high loads, which is primarily because of its lesser scheduling ability compared to 4/5G. What Wi-Fi is good at is increased data throughput at mediocre load.

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[11] It is not uncommon for the landlord or building owner to provide indoor coverage, serving his own staff and 3rd parties or tenants with the venue.

7 Summary of wireless options and comparison

Having examined usages, spectrum, standards, and technology alternatives; we'll now condense all relevant considerations into practical guidelines for the enterprise based on three pillars for decision making:

- **Required performances** and network alternatives
- **Provisioning models** for supply of solutions and acquiring spectrum
- **4G vs 5G** weighing of option

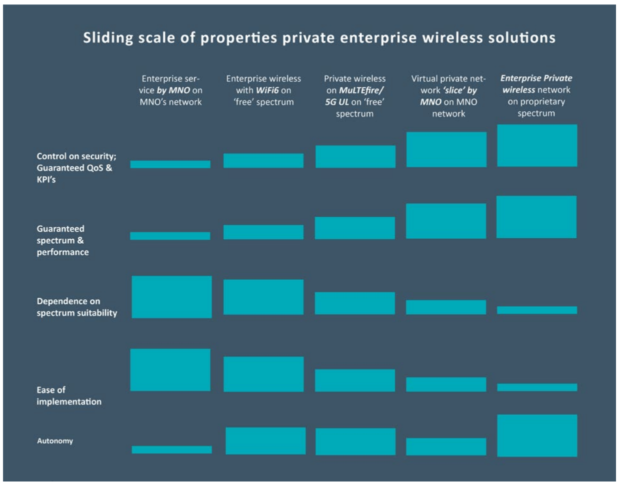
7.1 Evaluation of wireless alternatives

The below table is an attempt to roughly **compare and visualise the above-elaborated options for wireless enterprise networks** based on significant criteria of an enterprise on **autonomy, spectrum availability, and level of criticality**. Such a table does some injustice to many details and intricacies but may still serve to position the wireless options in relative terms.

	GUARANTEED SPECTRUM AVAILABILITY	INDEPENDENCY OF SPECTRUM	AUTONOMY OF THE SITUATION	SECURITY OF ENTERPRISE DATA	ABILITY TO GUARANTEE KPI'S	EASE OF IMPLEMENTATION
'TRUE' PRIVATE ON PRIVATE SPECTRUM	✓	✓	✓	✓	✓	≈
PRIVATE 'SLICE' ON AN MNO MACRO NETWORK	≈	≈	≈	≈	✓	✓
SERVICE FROM AN MNO ON MACRO NETWORK	≈	Ø	Ø	Ø	≈	✓
PRIVATE WIRELESS MULTEFIRE ON LICENSE FREE SPECTRUM	✓	Ø	✓	≈	≈	≈
WIFI ON LICENSE FREE SPECTRUM	✓	Ø	✓	Ø	Ø	✓

The trade-off between essential requirements

There is inherently always a balance to strike between the properties and capabilities of a solution. In an attempt to again **visually position and validate alternatives on some of the above rated key aspects,** we provide the following illustration of the trade-off between features of candidate solutions:



7. 1. 1 Use cases and articulating the industry's requirements and critical KPI's

With all the above clusters of use cases in mind, it is up to the individual enterprise that seeks wireless process optimisation to define its use cases, the level of "criticality" and adhere to the required KPI's. That may not always come easy and is likely to require intense scrutiny with the operational departments. To attribute actual figures to the KPI's of a mobile service requires knowledge of one's own process, benchmarking, and... sincerity. It is all too tempting to call every process 'critical' and adhere the tightest of performances to every transmission. That is likely to be unrealistic and also expensive. There are plenty of processes where an individual data packet can be lost without any consequence : (it gets transmitted again minutes later as in IoT), where latency barely counts (a portable data terminal gets fed with operational data, 200 ms delay doesn't get noticed) or a process is controlled over multiple interfaces. Therefore, a link loss is of relatively moderate risk (for instance 98% availability, provided the service restoration is adequate). To facilitate the profound assessment of KPI's we provide the following template for an imaginary use case of a factory and the - again imaginary - wireless requirements for one designated service, namely on-premises video.

The overall process assessment:

Operational process			User requirements	
Usage	Application	Relevant, (✓) or (+/+ ⇔ -/-)	Nrs of devices, equipment	Level of criticality % or (+/+ ⇔ -/-)
Voice and portable radio's	Security staff	+	10	++
	Machine operators	+/-	30	+
IoT and sensor data	Building ambient control	-	100's	-
	Predictive maintenance production line	+	15	+
Data transmission	Tablets of plant operators	++	40	+
	BOM and ass'y instructions to assembly line	+	15	+/-
Video application	VR support maintenance crew	+/-	10	+
	Video guidance robots	+	60	++
Robotics and AGV's	Logistics autonomous robots	+	50	+
	Terrain AGV's	+/-	10	+

Analysis of requirements per process:

Wire less usage domain			
Usage	Application		
Video applications	AGV, robot guidance		
KPI's	**unit**	**Parameter**	**Notes**
Availability / outage	Nr or '9's'	99,999	
Throughput	Mb/s/pc	1 mb/s	Hi res cameras
Latency	ms	<20 ms	
Device density	Nr/km2	300	In plant as well as outside
Balance UL/DL	../.. %	90/10	Primarily from equipment to control
Powering/Battery life	yrs	n.a.	Robots recharge autonomously
Security level	Life /Safety at stake Fin/ops implications Best effort	☐ ☑ ☐	
Mobility level	Stationary Nomadic Mobile across site Mobile externally	☐ ☐ ☑ ☐	Same robots may move indoor as well as outside => handover
Outdoor/Indoor	Indoor Outdoor Both	☐ ☐ ☑	

When articulated metrics cannot (yet) be derived, then fall back to "+" and "-" or 10's and 100's; anything that forces the operations to substantiate their requirements. Do contemplate on future novel services and demand expansion; allow sufficient margin and room to grow.

We suggest going through such meticulous assessment and inventory of connectivity requirements when embarking on a wireless transformation. Chapter 7 will match this assessment of processes and the criticality of KPIs to the various wireless options in existence! In par. 7.3, we will analyse the supply chain, where again the above KPI's can act as the demarcation with any 3rd party provider of required connectivity.

7. 1. 2 Assessing the enterprise's peripheral requirements

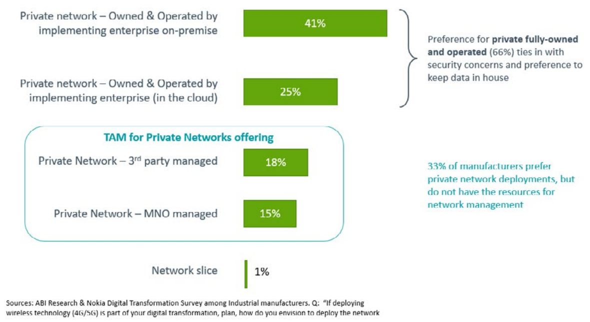
Above, we already assessed how a thorough inventory of one's own process requirements can lead to required KPIs, and in turn, to discrimination between fundamentally different wireless options.
To summarise many of the more strategic considerations we dwelled upon in the chapters before, we provide the below **"checklist" of strategic questions** to address:

ASPECTS	CONSIDERATION
☑ Private spectrum	Do we have access to private spectrum, either from our regulator or through 3rd parties? If not: consider unlicensed alternatives
☑ Location(s)	Is the envisaged application area outdoor, indoor, campus, wide area? If indoor, keep potential partial coverage of public networks in mind
☑ Resources	Do we have adequate skills and resources to staff a private wireless network? Either ourselves or through consultants? If not, consider aaS
☑ Autonomy	To what extent do we value autonomy resp. Can we manage a degree of dependency? Consider 'true' private vs a 3rd party service
☑ Data security	How vital is data integrity and security to us? Do we persist in keeping data on premises? Avoid options with unlicensed spectrum on off-premise storages or shared network elements
☑ Current systems	Can we migrate current usages to new private LTE/5G or do we have to keep legacy systems alive? If so, scrutinise interworking optionand access future migration
☑ Scalability	Access to private spectrum, either from our regulator or through 3rd parties If possible, start small and scale up; LTE/5G scales up and downward limitlessly
☑ Future usage	Can we already envision and plan for the future usage and growth? If not, calculate substantial margin of growth

With the mentioned "inventories" of key aspects, the enterprise is best positioned to interrogate the market and compare alternate offerings.

7.2 Considerations from real projects

Practice proves that considerations related to data integrity and security – also a KPI ! - count heavily for an enterprise when selecting a wireless alternative, in addition to the ability to warrant KPIs on transmission.



Also, due to the required high level of criticality, there is a tendency to prefer 'full' private alternatives over 3rd party models when it comes to provisioning options.

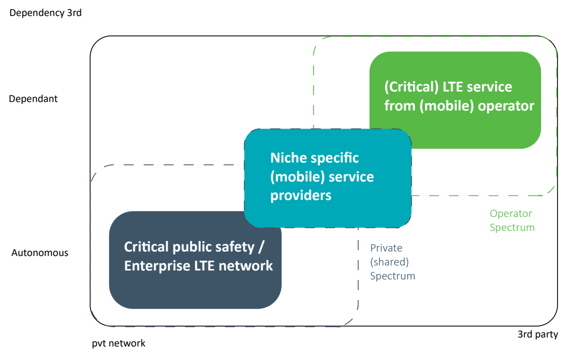
Security almost inherently points at 'edge' oriented implementations, where critical servers and corporate data reside on-premises. The study also reveals that some respondents just don't have the resources to do anything private and need to outsource the solution. Other studies point at the desire to be able to procure from a credible source and ecosystem and be able to assign accountability. In our own interviews (see 'acknowledgements'), we encountered the search for a consistent attribution of responsibility for the enabling wireless environment with an appropriate supplier.

7.3 New Business and Service provisioning models

7. 3. 1 Intermediary, specialised service providers

With the many alternatives to deploy private wireless networks, the service provider has a breadth of options to cater to these networks or services. The classical alternatives would be to either source one's own private network from an equipment vendor and deploy it on a private spectrum OR to source the entire critical mobile service aaS from an MNO on their spectrum:

Emerging (new)business critical mobile service providers



Source: TCCA, 2018

As the picture identifies: there is a 3rd, an 'in between' option: that of the dedicated service provider for a designated niche, vertical, sector, or geography. These new Enterprise Service Providers[13] were once envisaged and are now actually emerging. These 'ESP's' are much more specialised and focussed on the niches and verticals than a mainstream vendor or operator can ever be and can be the trusted extension of the individual enterprise seeking a wireless solution for its processes.

As the above picture in par 7.2 indicated already, for some organisations, the fact that they do not dispose of adequate staff and resources to select, operate and maintain a wireless network themselves leads them to seek the services of a specialised Enterprise Service Provider for their wireless network. Edzcom, a company of Cellnex is a specialised Enterprise Wireless provider.

[13] Identified in a 2018 white paper from the TCCA

> **Many enterprises struggle to describe their requirements on any new comprehensive wireless service.**
>
> Ritva Torikka, Port of Kemi

7. 3. 2 Provisioning models for private wireless [14]

With the advance of high performance, ubiquitous wireless services, entirely new business models are enabled that weren't possible before. Heavy industrial equipment manufacturers already explore their options for providing connectivity with their machinery. Also, the above-identified, specialised Enterprise Service Provider catering for wireless connectivity as a service is finding its way into the provisioning chain.

Enterprise wireless is likely to reveal new business model options that the industry hasn't seen before and allow new added value in industries known as 'traditional'. With every provisioning alternative, there is the aspect of security and data integrity that plays a prominent role in selecting an option.

The sourcing options

In order to source a private wireless solution, there is the option of sourcing equipment oneself from either the well-known ('tier 1') vendors or from one of the many new entrants on the market for mobile equipment. Due to the projects' market dynamics and scale, we have seen many new suppliers enter the market[15].

In case the enterprise wants to limit its exposure to wireless intricacies; there is the option to:

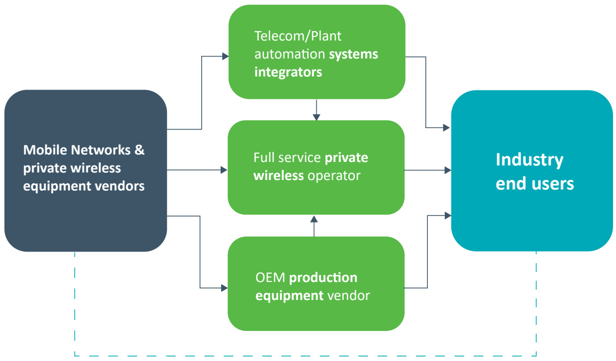
- Source the network or service from a telecom or plant automation system integrator, both of whom will in turn source equipment from the said suppliers.

- Acquire a connectivity service from the mentioned specialised provider for enterprise networks, the 'ESP'.

- For manufacturing and plant automation, there is an additional option. The supplier of production lines or equipment can also provide the required wireless networks, probably through an arrangement with a telecom supplier or a private wireless operator ('ESP').

For each of the options in the flow chart, an enterprise can also turn to specialised telecom consultants.

Private wireless supply chain & provisioning options



Source: Analysis Mason, Edzcom

7.4 LTE or 5G for private networks?

The alternatives LTE versus 5G were already weighed and evaluated in par. 5.1, 5.2. Here we'll just summarise the major conclusion on that choice.

Which 'G' to choose?

As was elaborated in chapter 4, LTE still has and will have adequate capabilities for many use cases, even though 5G is widely introduced. The enterprise should consider:

- Still today and for years to come, many enterprise use cases for mobile communication can be well serviced with LTE, which is a proven, cost-effective, and the most prevalent standard.

- There is an inclination to 'jump' to the latest standard – 5G – for any use case or application. Even though 5G IS the latest and most advanced standard, many applications simply do not require all it enables. Also, the 5G ecosystem is still less developed than that of 4G.

- Generally, it is recommended to start with precise scrutiny of the KPI's and features a mobile use case in industry requires. Only then does one examine whether LTE "does the job", or features required that only 5G can provide. As always, the use case should be the leading, not the latest technology.

[14] This section strongly reflects feedback provided by the users under 'acknowledgements'.
[15] A report from Real Wireless provides useful information, see references '.

4G is often adequate for ‘private’

Undoubtedly, 5G is again more performant than 4G with more devices, higher speeds, far better latency, even more advanced sensing and scheduling, etc. But in a vast majority of enterprise use cases, the KPIs required will determine the choice and often LTE “does the job”, also in private networks with QoS. On LTE, QoS can be guaranteed[16] just as much as 5G, even though the aforementioned ‘slicing’ only comes with 5G. With 4G, the track record of systems and providers is more proven, and the range of network equipment and devices is more extensive as LTE has been in existence for a decade.

Thus, the answer to “4G or 5G” basically is: articulate the requirements, and that’ll determine which is more appropriate.

Get going

Also, it is recommendable to ‘just get started’ and expand over time. An initial deployment of a small core, a ‘radio’ (base station) for confined areas, and some licenses can be very affordable and gets you started. Both the core – often software – and the base stations can be expanded limitlessly as an enterprise gains experience and users experience benefits.

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[i] 3GPP or 3rd Generation Partnership Project was implemented upon the development of the UMTS or 3G standards, hence **3GPP**. It has since developed all the new releases and standards of the mobile network technologies deployed the world over and is still today the body that develops 5G. It comprises of all the vendors of core, base stations, software, intermediate devices and end user devices of mobile networks and currently comprises 100’s of members. Members range from the very largest like Ericsson or Huawei and the mobile operators to very specialised ones. More www.3GPP.com

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[16] LTE has embedded in the standards so called QCI’s or quality class indicators; not deployed though in many public networks

REFERENCE

For further information we recommend the following material:

- Nokia white papers ‘**private wireless for industry**’
- Enterprise IoT insights: ‘**the state of ‘things’ in smart manufacture**’
- 5GACIA white papers: ‘**5G non-public networks for industrial scenario’s**’ ‘**5G for connected industry and automation**’
- Ericsson: ‘**Connected manufacturing report**’
- Real Wireless: ‘**private cellular networks: opportunities, challenges, and future**’
- RCRWireless: ‘**WiFi and 5G; why pick?**’
- **https://community.athonet.com**, for the ‘**Uptime private wireless networks**’ event and recordings.
- **www.5G-encode.com**, for a UK wireless manufacturing program
- **www.edzcom.com** for use cases and propositions
- Ask your contact for Edzcom’s more detailed ‘**extended white paper**’ with elaborations on issues of this white paper.
- **www.cellnextelecom.com** for various materials plus a white paper on wireless for the health sector (‘when connectivity in health really maters’)
- Analysys Mason: **‘Private LTE/5G networks: worldwide trends and forecasts 2021–2026 (analysysmason.com)’**

Gräsantörmä 2
02200 Espoo
Finland

www.edzcom.com

edzcom

a company of cellnex