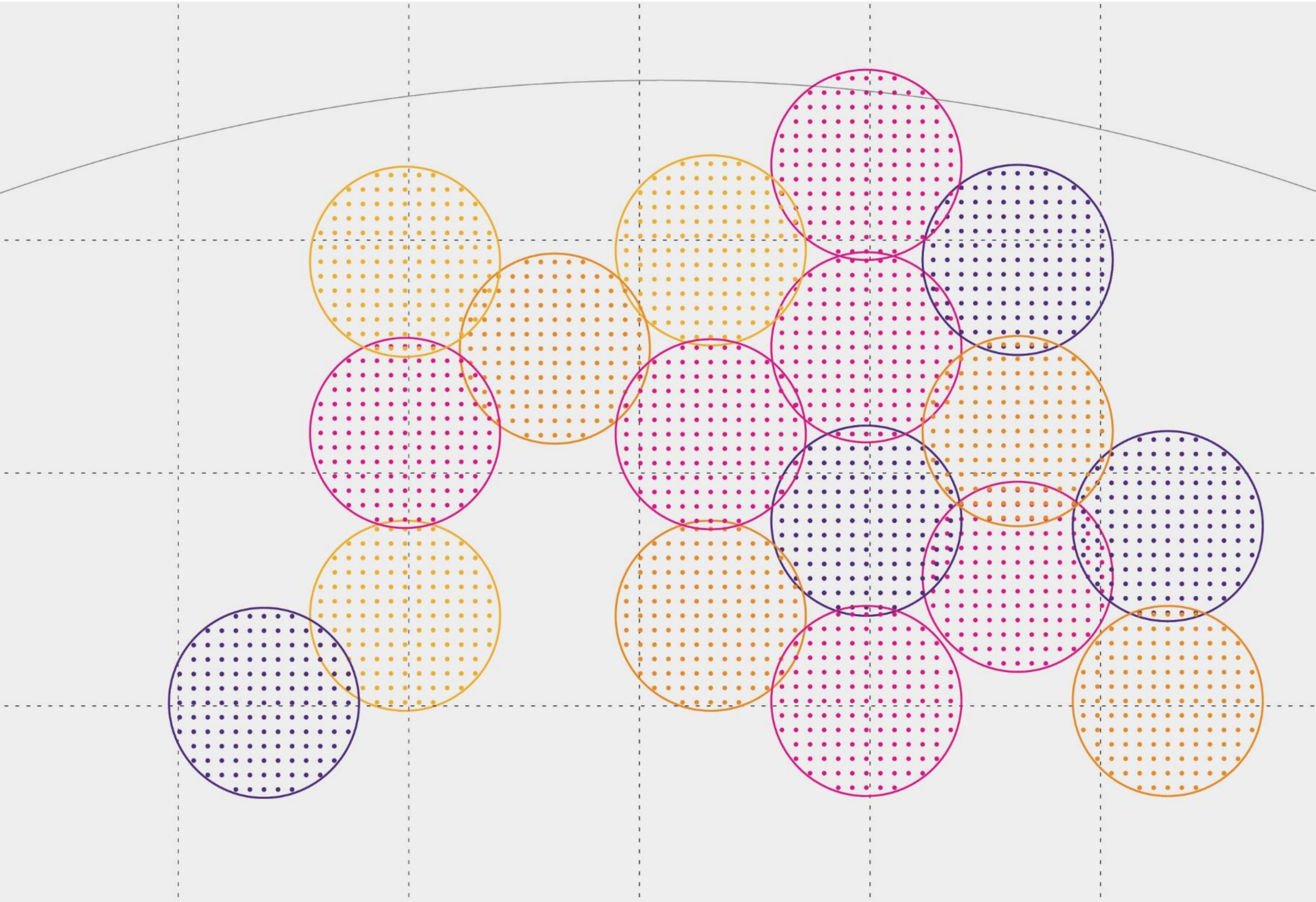
Use cases and spectrum requirements for private LTE

April 2018

Tony Lavender, Val Jervis, Sarongrat Wongsaroj, Ian Corden



About Plum

Plum is an independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply extensive industry knowledge, consulting experience, and rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.

About this study

This study identifies enablers, framers and opportunities for private LTE. Key to these is the identification of use cases and spectrum, on which we make recommendations to governments and regulators.

Contents

1 Introduction

This research study was commissioned to identify enablers, framers and opportunities for private LTE. A description of Private LTE is provided in Section 2. There are potentially many use cases for private LTE ranging from voice, through low speed data and low volume data to more demanding broadband applications, deployed across a range of different and varying industries. These industrial requirements could range from pure M2M networks to a broader range of communications capability. The use of private radio networks is not a new concept, they have been with us for a very long time. However, LTE brings the opportunity for private networks to access an extensive LTE ecosystem and a device, equipment and applications market that will have global scale at a significantly higher pace of innovation. It also provides the potential for users to make significant changes and embrace advanced services facilitated by the high bit rates and bandwidth and low latency of LTE, its evolution and eventually 5G. This innovation opens a broader horizon for vertical solutions over time.

Like any other wireless based system, a key requirement for successful deployment of private LTE is access to appropriate radio spectrum. This report highlights both likely spectrum requirements for different use cases and the state of play in several territories on access to such spectrum.

1.1 Industrial automation

Many recent studies have given considerable focus to verticals such as automotive where there is a great deal of work being undertaken on the functionality required for autonomous vehicles and intelligent transport systems, which will make use of a diverse set of wireless systems, including LTE. The focus of this study is industrial automation, a less high-profile area but none the less of great importance to economic well-being. This is an area that is rapidly advancing with opportunities brought about by the full integration of electronic communications and other digital technology into industrial equipment and processes. These are sometimes referred to as cyber-physical-systems.

The phrase "Industry 4.0" is often used in this context. Industry 4.0 is a concept originally proposed by the German Government in 2013[1]. The context of Industry 4.0 is as follows:

Figure 1-1: "Industry 4.0"

First industrial revolution	Second industrial revolution	Third industrial revolution	Fourth industrial revolution
• Introduction of mechanical production facilities with the help of water and steam power.	• Introduction of division of labour and mass production with the help of electrical energy.	• Use of electronic and IT systems that further automate production.	• Use of cyber-physical systems.

An obvious application is for smart factories or similar industrial environments. The high levels of automation in smart factories will exhibit multiple characteristics including adaptability, flexibility,

[1] Industrie4.0 smart manufacturing for the future. Germany Trade and Invest.

learning characteristics, dealing with fault situations and managing risk. Section 3 provides examples of several scenarios in which industrial automation based on private LTE systems could be realised.

The benefits of industrial automation and its extension into Industry 4.0 include scope for innovation, time and cost savings, creation of new production models and enhanced industrial learning.

1.2 Mega-trends

The study touches on mega trends applicable to the concept of industrial automation. These trends have the potential to change the way in which industry works. Two important examples we focus on are robotization and drones.

- Robotization: Robots are not new, and they have been used in factory and other industrial settings for some time. However, the addition of enhanced communications capability allows a robot to interact with an industrial environment in a more extensive way than hitherto. Robots with LTE mobile broadband capability could, for example, provide more extensive visual and sensor information than devices with simple sensors. They could also be moved to work on different parts of a production process through use of detailed granular mapping information and the ability to transfer large amounts of complex information.
- Drones. Could provide a similar function to robots but with the additional ability to move in three dimensions instead of two.

Both could provide safety and security functions (enhanced by low latency communications) and they could also play an important role in the interaction of machines and people through provision of virtual / augmented reality. Both robots and drones allow to access to and the ability to perform actions in environments that are hostile or extremely hard to reach for humans, typically requiring fast and reliable wireless communication for control and supervision.

- The ability of virtual reality to simulate a user's presence in a situation and / or augmented reality presenting a view of a physical real-world environment enhanced by audio, visual and graphics data opens many new opportunities for interaction and control and associated efficiency gains (including enhanced learning and handling of fault and maintenance situations).

1.3 Approach to the study

Our approach to the study is set out below.

Figure 1-2: Approach

Step 1	Step 2	Step 3	Step 4
• Identification of example industrial automation use cases	• Characterisation of identified environments	• Communications solutions	• Access to spectrum

Identification of example use cases and environments for private LTE

The report considers six examples of the application of private LTE in industrial automation:

- Case 1: Indoor manufacturing
- Case 2: Outdoor processing
- Case 3: Logistic operations
- Case 4: Agriculture
- Case 5: Storage facilities
- Case 6: Nomadic functions.

Characterisation of identified environments

Each case presents a varying set of communications use cases. These could include sensors, control devices, video functionality and safety systems. These are characterised using a set of parameters including:

- Quality of service
- Coverage
- Bandwidth requirements
- Transmission symmetry
- Security and resilience.

Communications solutions

The output of the characterisation is used to identify possible communications solutions[2]. These could range from use of best efforts wireless networks based on licence exempt spectrum, private LTE and in

[2] Communications solutions could encompass network solutions (e.g. device to device communication and/or device to server communication) and software applications that provide aspects of the end to end communication requirement.

some cases, use of a publicly available mobile network. Use cases could also lead to integrated use of more than one of these solutions.

A further consideration is how are private LTE networks provided? There are a range of options from standalone networks, through to virtual provision on wholesale hosts, noting that even in the case of use of shared infrastructure, there may still be a requirement for standalone radio infrastructure.

Access to spectrum

The report then considers the different means by which private LTE could gain access to suitable spectrum resources. To enable the economies of scale that private LTE can potentially tap, the spectrum must be in harmonised mobile bands. If it is not, the private radio infrastructure becomes bespoke and may not be viable as an industrial solution. Key options considered for access are spectrum leasing and spectrum sharing on a primary and secondary basis. For the latter, this could include both licence exempt and forms of "light licensing". The need for harmonised mobile spectrum creates challenges for the methods currently used to assign or otherwise provide access to this spectrum (it is usually licensed to mobile operators on a dedicated national basis).

1.4 Countries covered

The analysis then reviews the possibilities for use of different access mechanisms to spectrum in several countries. These are: France, Germany, Ireland, the UK, Canada, the USA, Australia, Hong Kong, Singapore, Bahrain, Qatar, the UAE, Chile and Peru.

1.5 Structure of the report

The remainder of the report is structured as follows:

- Section 2, describes private LTE networks;
- Section 3, covers use sample cases for private LTE;
- Section 4, covers network solutions and mapping of applications;
- Section 5, considers access to spectrum;
- Section 6, provides an analysis by country.

The report's conclusions and recommendations are set out in Section 7.

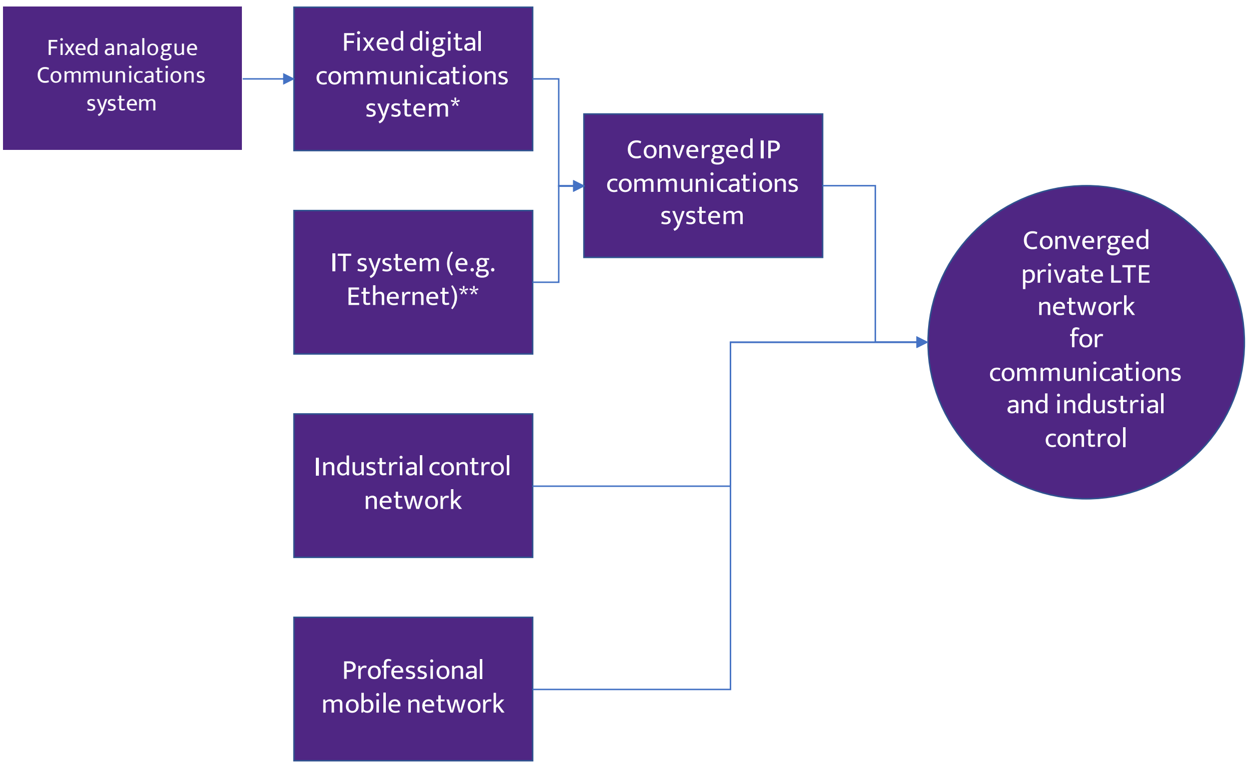
2 Private LTE networks

Private networks are not a new concept and they have formed a key part of enterprise infrastructure for many years meeting voice and data communications needs. Today, wireless solutions are often used in these networks, typically based on Wi-Fi.

Historically, communications systems for automation functions were often separate from other internal communications and IT networks. Networks for automation were usually fixed infrastructure (i.e. not wireless) and if they did provide wireless communication it would be in licence exempt bands or, if licensed, in a band used for professional or business radio purposes (PMR).

PMR has been a key means for provision of many private / industrial services. It utilises dedicated spectrum (often in the 400 MHz frequency range) and it is used for a huge range of applications including sensor, telemetry and control (for example, in the energy industry). Most applications supported by PMR are narrowband, although wideband and broadband systems are being developed to utilise the potential of LTE developments in the 400 MHz frequency range (e.g. 3GPP band 31, and the more recently proposed bands 72 and 73). A key feature of many PMR systems is their ability to deliver highly secure and resilient systems.

Figure 2-1: Convergence of communications technology



- * Developed to have wireless extensions (e.g. DECT)
- ** Developed to have Wi-Fi capability

2.1 Private LTE

As shown in Figure 2-1 systems that could have historically been used in an industrial context are converging into a private LTE platform, that can be used with any standardised 3GPP radio spectrum (or licence exempt spectrum capable of supporting LTE protocol).

The architecture of LTE provides a platform that enables industrial automation on what historically would have been viewed as a communications system. The system can support very large numbers of connected devices, enhanced mobile broadband capabilities and it can offer low latency performance. The IP architecture also allows applications to run at the edge or separate from the network in the cloud. Evolution to 5G will enhance these capabilities[3].

A key benefit of private LTE is that it offers access to a globally harmonised platform (and therefore scale economies), it can exploit the eco-system developed around LTE and it provides an evolution path for future technology development. In addition to the network based capability of LTE, such systems will provide scope for development of common horizontal application services (i.e. across industries) and specific vertical solutions. With appropriate development platforms, there is considerable scope for systems and application development and adaptation to support specific installation requirements.

2.2 Barriers for private LTE

While LTE provides a platform for industrial automation, the key input required for private LTE to work is access to suitable 3GPP spectrum. This spectrum is usually licensed to mobile operators on a national or regional[4] basis. Therefore, means are required to enable private LTE providers to gain access to spectrum, as private LTE requirements are likely to be on a localised basis (e.g. through spectrum leasing or spectrum sharing). This is discussed further in Section 5.

2.3 Realising a private LTE network

Historically, self-provision has been the norm for private networks. Self-provision involves entities having access to licensed spectrum and buying, installing and operating the infrastructure themselves or using it thorough a lease / rental agreement with a third-party supplier that also facilitates access to the necessary frequencies[5]. As a private network solution, sourcing of private LTE networks could be approached in a similar way. In this case it would be critical for the enterprise to acquire appropriate spectrum. Being unable to do so would be a barrier to such an approach.

Self-provision is not the only model for the provision of a private LTE network. LTE forms a key part of public mobile networks and these platforms could provide such services. This approach would utilise an

[3] https://youtu.be/bMaDhf0LKAY

[4] Regional licences are normally awarded and licensed in countries with a large geographic area such as the USA, Australia etc.

[5] This is the typical approach for PMR networks where licences can be obtained on a site or area basis and dealers can facilitate contact with the regulatory authority and assist in obtaining spectrum licences.

existing MNO’s LTE network and its spectrum portfolio. The private LTE network could then be operated as a virtual instance on an MNO’s network. The network could be provided as:

- A separate physical radio infrastructure customised for the application requirements with dedicated spectrum.
- A shared physical radio infrastructure.
- Hybrid models e.g. with dedicated radio infrastructure within campuses of an enterprise and access to shared infrastructure in-between.

The service could be offered as a high-value, highly customised business product by MNOs where sufficient coverage exists or could be readily provided.

Alternatively, the private LTE network could be supplied by a third-party wholesaler not generally providing public mobile services. Under this model, a wholesale network could offer the private LTE service as a virtual instance on dedicated network infrastructure using its own spectrum. The spectrum would be dedicated for the private LTE service. The wholesaler would manage coverage and capacity related spectrum issues to ensure that its wholesale network meets the QoS requirements of the industrial sites / entities it serves.

In both the public network and wholesale models, the creation of a private network over common infrastructure is the primary requirement. Software defined networking (SDN) and network functions virtualisation (NFV) will play an important role for provision of Private LTE. The basis for both techniques is virtualisation that enables network design and infrastructure to be abstracted in software, which can then be implemented through underlying software across hardware platforms and devices.[6]

SDN and virtualisation also allow traditional network structures to be broken down into customizable elements that can be combined in the software plane to provide the required level of connectivity, while each element can be based on the most suitable architecture for it. This means that network can be sliced for different uses.[7]

[6] https://networks.nokia.com/solutions/packet-core
[7] https://www.ericsson.com/en/networks/topics/network-slicing

3 Use cases for private LTE

This section describes six different industrial automation use cases where private LTE could play a significant role. The scenarios are quite different from one another and each will have its own vertical requirements. However, as can be seen below, there are several common underlying functions of a more horizontal nature present across each of the use cases (scenarios).

The scenarios are intended to provide an illustrative snapshot of likely situations and use of communications in an industrial automation setting. While a degree of communications and specific vertical technology may already be present in each of these today (for example with the deployment of fixed data networks and M2M), the scope for more extensive use of wireless communications based on LTE presents further opportunities for flexibility and productivity and associated cost savings and efficiency gains.

While the examples below are presented as single site operations, it is possible that a private LTE network could be required to function across multiple sites. Intelligent machines, storage systems and operational resources (both human and machine) need to exchange information continuously. This maybe a function that occurs across many sites and hence, inter-site connectivity will be a major consideration for the realisation of private LTE services.

Each of the scenarios considered is briefly described below and key points are summarised in Section 3.7. In each of the scenarios the primary interest is in the function enabled by the connectivity provided by private LTE.

3.1 Scenario 1: Indoor manufacturing (factory)

A private LTE network would operate within an indoor manufacturing area, which could require a dense network (high number of communication devices within a relatively small enclosed area). The nature of the factory could mean that while the area is contained (potentially mitigating interference effects) the radio environment could be complex because of internal partitioning and deployment of machinery. A private LTE network could support applications / functions such as:

- Remote operation of machinery
- Remote calibration of production lines
- Sensors (for many purposes)
- Collection of data (for production flow and maintenance requirements)
- Cameras and other imaging devices (for example for monitoring and tracking)
- Control of autonomous vehicles within the factory confines (for example a fork lift truck)
- Control of robots and drones that could be used for a variety of purposed from production activity to maintenance
- Use of virtual reality to enhance control and support maintenance

- Safety systems (general and production specific systems)
- Security systems (physical and personnel).

3.2 Scenario 2: Outdoor processing (oil refinery)

An outdoor processing environment contrasts to an indoor manufacturing environment; it can often be spread out over a wide area and be sparser in terms of devices. There is more potential for interference with other spectrum users, and weather may affect network performance. Examples of outdoor processing scenarios include oil refineries, and outdoor energy generating plants (utility providers). Applications / functions that could potentially be delivered over a private LTE network may include:

- Remote operation of machinery
- Sensors (for many purposes)
- Pollution management (e.g. water pollution, air pollution)
- Production and storage monitoring (e.g. monitor and report flow and pressure of fluid levels or gases)
- Geofencing: tracking and automated restriction/access to areas of outdoor plant
- Weather monitoring
- Condition and corrosion management
- Control of autonomous vehicles (for example a forklift truck)
- Use of robots deployed to complete maintenance work in remote/difficult to reach or hazardous areas.
- Use of drones to collect information and monitor outdoor equipment or infrastructure
- Safety systems (general and site-specific systems)
- Security systems (physical and personnel).

3.3 Scenario 3: Logistics operation (port)

Like an outdoor processing environment, logistic operations (such as harbours and ports) tend to be spread out over a wide area with busy / noisy communications. They can be dense areas for clutter and there is more potential for interference with other spectrum users. There may be demand for private LTE networks to cover wider areas (for example, to follow items on-the-move). Applications / functions that could potentially be delivered over a private LTE network may include:

- Remote operation of cranes and other machinery
- Sensors (for many purposes)
- Tagging / tracking of shipping containers in ports

- Geofencing: tracking and automated restriction / access to specified areas
- Weather monitoring
- Logistics (planning) for ship and vehicle handling (road and rail)
- Control of autonomous vehicles (automated container movements)
- Use of robots deployed to complete maintenance work in remote or difficult to reach or hazardous areas.
- Use of drones to collect information and monitor assets, outdoor equipment or infrastructure
- Customs controls (e.g. automated recognition of consignments) and other bureaucratic processes
- Safety systems (general and site-specific systems)
- Security systems (physical and personnel).

3.4 Scenario 4: Agricultural (crop management)

Agricultural facilities tend to be in rural (sometimes remote) locations, covering large land areas. Three main farming activities are crop-growing, livestock, and pasture. The nature of these facilities means that they are usually low-density communication areas and while building clutter may be less of a problem than in some other environments, terrain and vegetation (e.g. trees) could present issues. Application of private LTE could support:

- Sensing to optimise crop yield (e.g. soil support, seed placement, nutrient monitoring)
- Environmental monitoring and control (temperature, humidity, water level sensors)
- Remote operation of machinery (driverless vehicles, automated irrigation, use of robots for crop harvesting)
- Use of drones to collect information on crops or livestock and to monitor assets, outdoor equipment or infrastructure
- Realtime data requirements for analysis to optimise harvest levels
- Safety systems (general and site-specific systems)
- Security systems (physical and personnel).

3.5 Scenario 5: Storage facility

Storage facilities can vary from small-scale urban storage facilities for individuals / small businesses to large-scale (rural) warehouse for storage of goods or other items. Although generally indoors they can be mixed indoor / outdoor environments in some cases. A private LTE network could support applications such as:

- Sensors (for many purposes)

- Tagging / tracking / management of stored assets
- Geofencing
- Environmental monitoring and control (e.g. sensors for temperature and humidity)
- Control of robots / autonomous vehicles (e.g. for movement of items)
- Safety systems (general and site-specific systems)
- Security systems (physical and personnel).

3.6 Scenario 6: Nomadic (PMSE)

Video / audio production and outside broadcast requires temporary high-bandwidth connections from one or more locations (which are possibly remote). There may also be remote production management, mixing and broadcast control facilities that require wireless support. A major outdoor production or film set could require many (possibly hundreds) of individual audio / video channels on a temporary basis. A private LTE network could support applications such as:

- Sensors (for many purposes)
- Weather and environmental monitoring (e.g. wind, temperature, humidity)
- Audio / video channels for control and management of operations
- Remote operation of site machinery (e.g. camera booms, lighting)
- High-quality / low latency audio / visual link for production purposes
- Control of drones for production and other purposes
- Control of autonomous vehicles for equipment and people movement
- Safety systems (general and site-specific systems)
- Security systems (physical and personnel).

3.7 A world of increasingly sophisticated connectable devices

Industrial automation in all the cases described is characterised by increasing volumes of devices for sensing, control, audio, video, monitoring, processing and so on. In addition, there is a clear requirement in these cases to be flexible to accommodate change (e.g. because the use environment or use requirement changes, or because the nature of the use is temporary / nomadic as in the case of PMSE). Use of private LTE may provide quicker configuration and greater reconfiguration opportunities than is possible with the use of current fixed data communications networks (quicker time and lower cost) or unlicensed radio networks (better interference / QoS management).

There are several common uses emerging across scenarios including:

- Sensing and telemetry

- Control and operation (fixed items)
- Control and operation (robots, autonomous vehicles, drones, enhanced reality)
- Enterprise applications (e.g. tracking, inventory management)
- Device management (e.g. remote firmware upgrades & control)
- Asset management applications (monitoring capital depreciation and undertaking maintenance as and when necessary using enhanced reality)
- Safety
- Security.

The device environment for today's industrial applications is characterised by the use of many intermittent, low data rate sensors and controllers. In addition to these devices there is a growing segment of more sophisticated wideband and broadband devices that provide more complex and extensive information and control functions (in both uplink and downlink). For example, provision of more detailed or continuous measurement data, more continuous control function, constant video feed. Also, video will play an increasing role in human or a machine interaction and the use of virtual / augmented reality systems for operation and maintenance purposes could demand very high bandwidth, low-latency communications to be enabled for devices in the use environment.

It should also be noted in this context that the use of more sophisticated robots and drones and enhanced reality could see a shift from many narrowband sensors to platforms that provide a more sophisticated capability replicating and enhancing the functionality provided by legacy devices.

4 Network solutions and mapping applications

4.1 Types of network solution

Not all applications set out in Section 3 require a private LTE network. In fact, there are four types of network solution that can support industrial applications. They are as follows:

1. Public cellular network provided by existing MNOs
2. Private LTE network customised to deliver specific applications over a closed network using dedicated licensed spectrum.
3. Wireless networks that operate in a licence-exempt band but with some QoS threshold
4. Wireless networks that operate in a licence-exempt band under best-effort conditions[8]

The key differences between the first category and the second category are coverage, the degree of contention in the network and network reliability. Public mobile networks can deliver high bandwidth service, but the variability of network loading means that performance is not guaranteed. In addition, the level of network reliability cannot be specified beyond that set for the public network, which may not be ideal for mission-critical applications. Temporary outages of unspecified duration that could occur in public networks could jeopardise an industrial process. In the case of a private LTE network over dedicated spectrum it is possible to specify the necessary parameters and implement measures to ensure the required QoS.

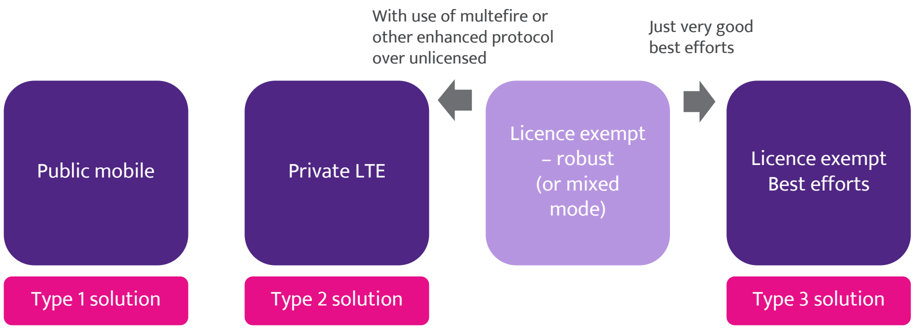
The third and the fourth categories differ again in the level of QoS provided. The use of a licence-exempt band means that interference is not controllable by the user, even if interference mitigation techniques are imposed as a condition of usage. However, some technologies may perform better than others. LTE-based technologies such as MuLTEfire could deliver a cellular quality performance over licence-exempt spectrum, for instance.[9]

In this analysis, the focus is on the scope of LTE network use for industrial applications. Therefore, the most interesting subset of the third category is that of LTE-based technologies such as MuLTEfire and LTE-U/LAA. Other solutions that operate on a best-effort basis but would only provide the necessary network solution under favourable interference conditions are considered as Category 4 solutions. To facilitate the analysis, we have therefore based the categorisation, as summarised in Figure 4-1:

1. Public mobile network
2. Private LTE
3. Licence-exempt wireless network.

[8] These include Wi-Fi solution as well as proprietary M2M solutions such as Sigfox and LoRA.
[9] https://www.qualcomm.com/news/onq/2015/06/11/introducing-multefire-lte-performance-wi-fi-simplicity

Figure 4-1: Three types of network solutions



4.2 Characterisation of applications

To consider which applications are best supported by the three types of network solution, it is necessary to characterise the applications by the properties of the network that are required to deliver them. The key dimensions to consider are[10]:

- **QoS** – This refers to the application's requirement in terms of the network speed and consistency as well as requirements on latency and resilience. High QoS is needed for applications that are mission-critical such as safety measures in an industrial setting, where human and robots may come into close contact with each other. It is a key dimension that distinguishes a private network from a public or licence-exempt network solution. Low QoS may be acceptable for applications where it is possible to repeat send data.
- **Coverage level** – This relates to the setting in which the application is deployed as well as the requirements for mobility on the devices used for the application. Industrial applications can include the use of wireless connectivity in wide outdoor areas such as on large farms or in indoor spaces such as storage facilities.
- **Bandwidth** – Bandwidth requirements refer to the throughput level necessary to enable the application. Remote, tandem operation of machinery in a factory through virtual / augmented reality not only requires high QoS but also very high data transmission rates. This is particularly the case where the processing of a vast amount of information is done in the cloud. Applications with low bandwidth include telemetry for periodic data collection.
- **Symmetry** – In some applications, the relative amounts of bandwidth required for uplink and downlink transmissions differ. Applications that are based on high-definition monitoring will require a very high bandwidth in the uplink direction. However, if only simple commands need to be executed based on the analysis of the information, then the downlink transmission requirement will be low.

[10] It should be noted that at this stage we are not considering issues associated with spectrum access.

- **Security/privacy** – Data transmitted for industrial applications may need to be protected due the sensitivity of the data being transmitted. The primary consideration here is the sensitivity of the data for commercial or security reasons whereas the other dimensions by which the applications are characterised relate to technical requirements.

Security / privacy as a commercial requirement

Imposing a requirement of security and privacy on any application will change the solution over which it should be delivered. A simple telemetry application that requires neither high QoS nor bandwidth could be provided over a commercial M2M network using a licence-exempt band. However, imposing an additional requirement of data security on the service could instead mean that a private network is required if the capability offered by commercial applications running on public networks is not adequate.

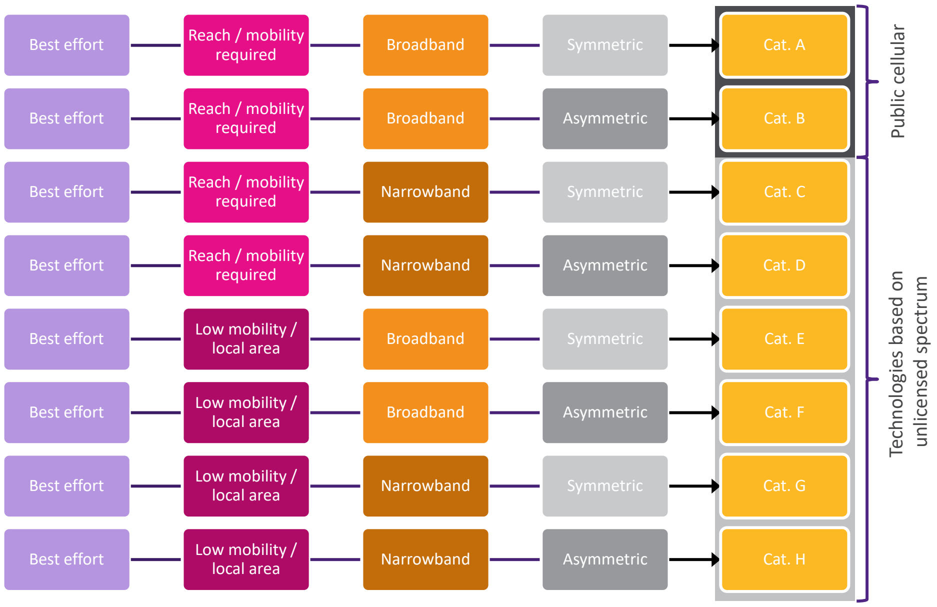
The need for a private network is not the result of a lack of suitability of a licence-exempt M2M network for simple telemetry; it is due to the organisation's need to ensure that the system and transmitted data is protected, and this is only achievable over a closed network. In fact, if this requirement is mandated by the user, all applications will require an instance of private network regardless of other requirements. For this reason, privacy/security as a dimension is regarded as a switch and is not explicitly considered in the mapping of applications to network solutions in the following section.

4.3 Mapping network solution to application

We consider the two ends of the spectrum along each dimension, to ensure clarity. For QoS, we use the labels High QoS vs Best effort to categorise the applications. Similarly, for coverage, bandwidth and symmetry dimensions, we use the labels Reach/mobility required vs Low mobility/local area, Broadband vs Narrowband, and Symmetric vs Asymmetric, respectively. This results in a total of 16 distinct categories of applications. These 16 categories are detailed in Appendix A:.

A number of categories can be efficiently supported by unlicensed-spectrum technologies including Wi-Fi and M2M (e.g. Sigfox and LoRA). This is the case for the clear majority of applications that only require best-effort connections. The exception here is where full mobility and high speed are also required. A wide-area mobile network such as a commercial mobile network will then be required, assuming that coverage is not an issue. Therefore, best-effort applications can be supported by 2 types of solution: 1. public cellular network and 2. unlicensed-spectrum technologies. These are Type 1 and Type 3 solutions defined in Section 4.1.

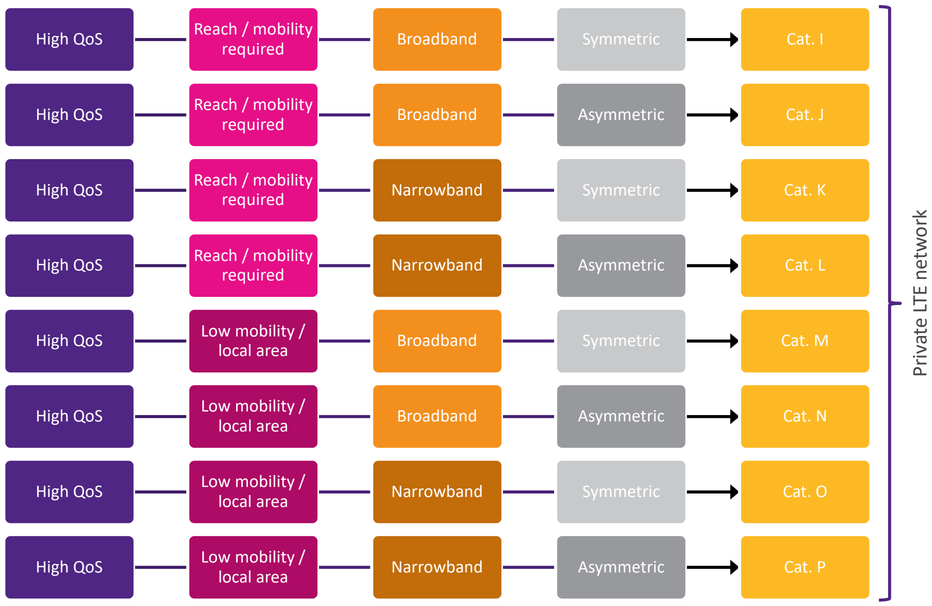
Figure 4-2: Applications for public mobile and licence-exempt network solutions



Source: Plum analysis

The most efficient solution for high-QoS applications is a private mobile network, such as a private LTE network, because it offers guaranteed QoS. In addition, many high-QoS applications require different speeds, reach/mobility and types of transmission symmetry, which creates different spectrum requirements. For instance, field use of drones in agricultural settings will require a frequency band that offers good wide-area coverage, whereas a remote-controlled forklift in warehouse will not have the same requirement and can be served with a high-frequency band that offers a large bandwidth. This is Type 2 solution defined in Section 4.1.

Figure 4-3: Applications for private LTE network solution



Source: Plum analysis

Furthermore, a large number of bands with different properties have been harmonised for LTE. This makes it an especially suitable technology for the types of industrial application discussed in this report given that a wide range of bands with different transmission properties could be required.

Appendix B: gives specific examples of industrial usage discussed in Section 3 that fall in each of the defined categories.

4.4 Other considerations

In the analysis above, we assume that the timescales for access to spectrum will be optimum for the private LTE network. This is another dimension that requires consideration and will apply to all the industrial usage examples.

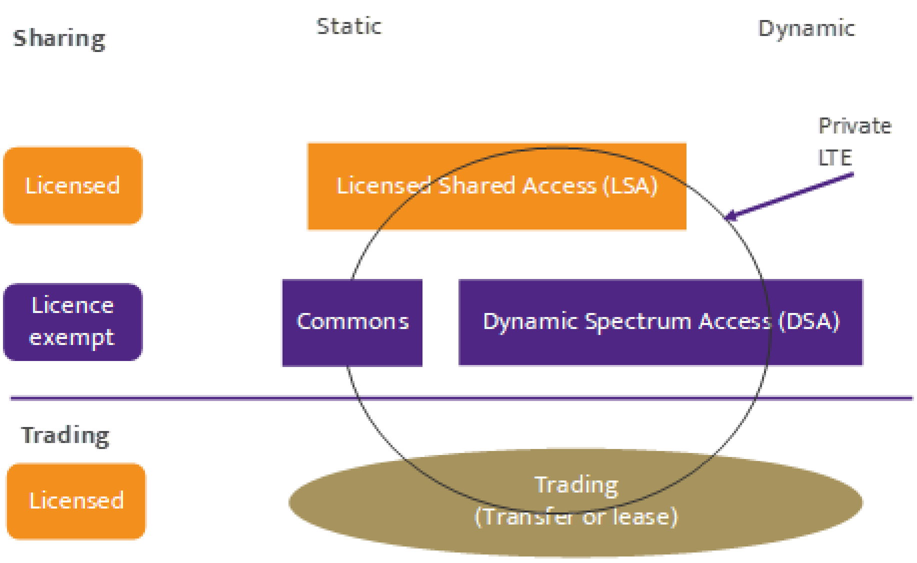
In the case of service supply from public mobile networks, supply will depend on the mobile operator's planned network roll-out. This may or may not be optimum for a private LTE installation. For a private LTE installation, access to licensed spectrum therefore may depend on spectrum trading or more likely spectrum leasing or spectrum sharing agreements. This is discussed in the next section.

5 Access to spectrum

5.1 Options for access to spectrum

An essential requirement for delivering private LTE systems is access to suitable harmonised mobile spectrum that can support the necessary technical requirements for each application. In Figure 5-1, below, we show the different options available to access spectrum in general and those that might specifically be applied to private networks.

Figure 5-1: Options for access to spectrum



5.1.1 Licence exempt

Licence exempt spectrum is readily available for private networks provided they can meet the necessary standards, such as transmitter power, geographic location (indoor or outdoor), bandwidth etc. that are applicable to the different frequency bands. As licence exempt bands (e.g. 5GHz Wi-Fi) operated on a commons basis are not limited in terms of users / uses beyond the standards[11] it is not possible for the private network to manage the interference environment. It is therefore unlikely that services which require guaranteed quality of service will be able to effectively utilise such spectrum.

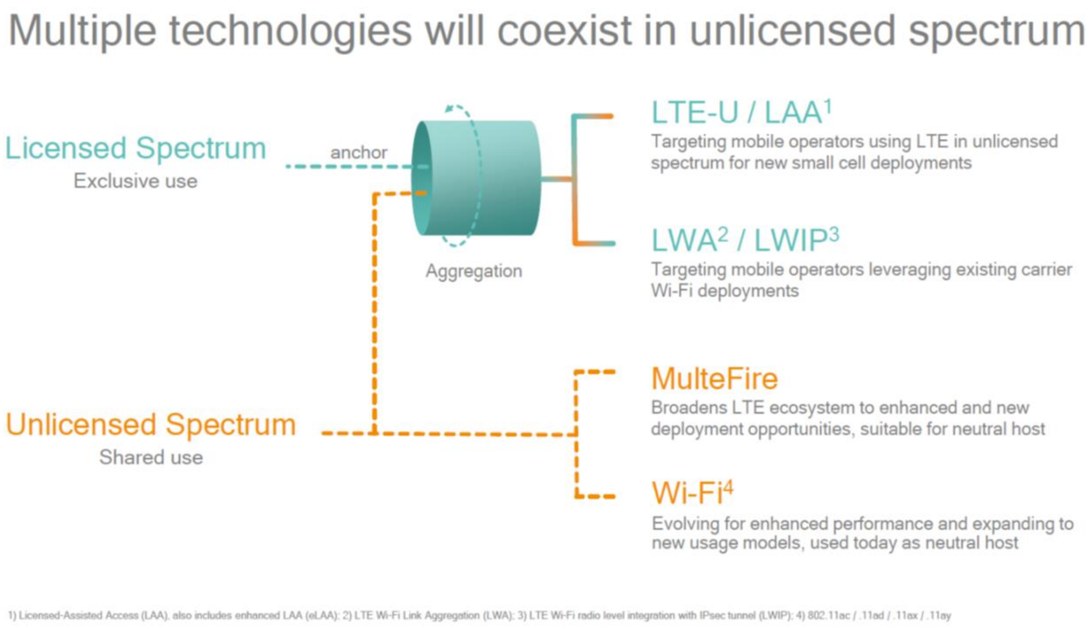
Spectrum could also be accessed on a licence exempt basis using a database approach, such as dynamic spectrum access (DSA). In this case a geolocation database would identify useable spectrum, which would be accessed on a secondary basis (i.e. no or limited protection). The likely outcome with this approach is like the commons approach in that it is not suitable for services which require guaranteed quality of service.

[11] These standards are generally those established for short range devices.

In the case of indoor private networks, such as a factory environment, there is a possibility to establish a more controlled interference environment for use of licence exempt spectrum. This of course will depend on the frequencies that are utilised and the associated absorption loss through the structure of the building (i.e. from outdoors to indoors) and whether it will be sufficient to limit the potential for interference from other users.

Licence exempt frequencies have the potential to support a number of techniques for LTE including LTE-U (LTE unlicensed) and LAA (Licensed assisted access), and MuLTEfire as shown in Figure 5-2.

Figure 5-2: Different technologies identified for licence exempt spectrum



Source: Qualcomm

LTE-U, a proprietary solution to address immediate market needs in some countries, and LAA provide the benefits to mobile operators of being able to aggregate LTE on their licensed spectrum with unlicensed spectrum. LAA was standardised as part of 3GPP Releases 13 of the E-UTRA specifications (LTE-Pro) – it was finished in August 2016 and relates to the downlink. In Release 14 the requirements for the uplink are provided. LTE-WLAN Radio Aggregation (LWA) was also standardised as part of Release 13, but in this instance access to the unlicensed spectrum is based on IEEE 802.11 standards.

The exception is MuLTEfire which does not require licensed spectrum to anchor to other carriers and so can support private high-performance LTE based networks. It is ideal for those with no access to licensed spectrum. The MuLTEfire specification 1.0, specified by the MuLTEfire Alliance, is based on 3GPP standards Release 13 for the downlink and Release 14 for the uplink and can be deployed in 5 GHz spectrum globally and in the United States in the 3.5 GHz CBRS band. The next versions of the specification will address other frequency bands such as below 1 GHz and 2.4 GHz to provide the possibility for improved coverage and lower power consumption.

5.1.2 Licensed spectrum

A significant amount of the spectrum already identified for IMT / LTE by the ITU is licensed to mobile network operators. Access to this spectrum by private networks currently appears to be only possible through spectrum trading and spectrum leasing agreements where these are allowed by the individual country's administration. There is currently very little consideration given by regulators to local licenses and facilitating access to unassigned IMT spectrum for applications like private LTE.

For trading, the presumption of many administrations is that any trades will be between mobile network operators and will typically be assumed to be on a national basis. There have been few real instances of mobile spectrum trading[12], except in the case where spectrum has had to be released to meet the rules established to allow for mergers of mobile network operators.

The possibility of leasing is also an option but there are no relevant examples to date. Typically, mobile network operators are unwilling to lease access to their spectrum for any reasonable period in case it is required for their network and service roll-out. Mobile operators also see limited benefits, relative to the effort involved in setting up leasing agreements and gaining the approval of the administration, of a lease that might only cover a limited geographic area. Also in the case of leasing the lessor normally remains responsible for compliance with licence conditions. This currently makes spectrum leasing difficult for enterprise users.

5.1.3 Wholesale networks over licensed spectrum

There is a recent move by some administrations to encourage the entry of wholesale network providers. For enterprise purposes, this approach has been particularly successful in the 450 MHz band where a network can be rolled out by a wholesale licensee to provide access to a mix of enterprise users who want to provide their own services and have control of their portion of the network.

A specific example of this is AINMT who has successfully deployed wireless broadband solutions supporting Business Radio, PPDR and public use (MFCN) in UHF2 frequency spectrum in several European countries (Norway, Sweden, Denmark). The operation started as a CDMA network, but it has evolved into one of the first in the world to fully adopt LTE.[13] Other countries are adopting similar approaches. The LTE450 network provides a national wholesale network, supporting multiple user types and business models. In Scandinavian countries, users include consumers, rural businesses, the transport sector, military, security, surveillance and other public-sector applications. Users either buy wholesale service direct from the network wholesaler or through a partner / retail provider that interfaces with the network wholesaler. The wholesale business model can be adapted to suit national circumstances and could support a range of different vertical industries such as those discussed in Section 3.

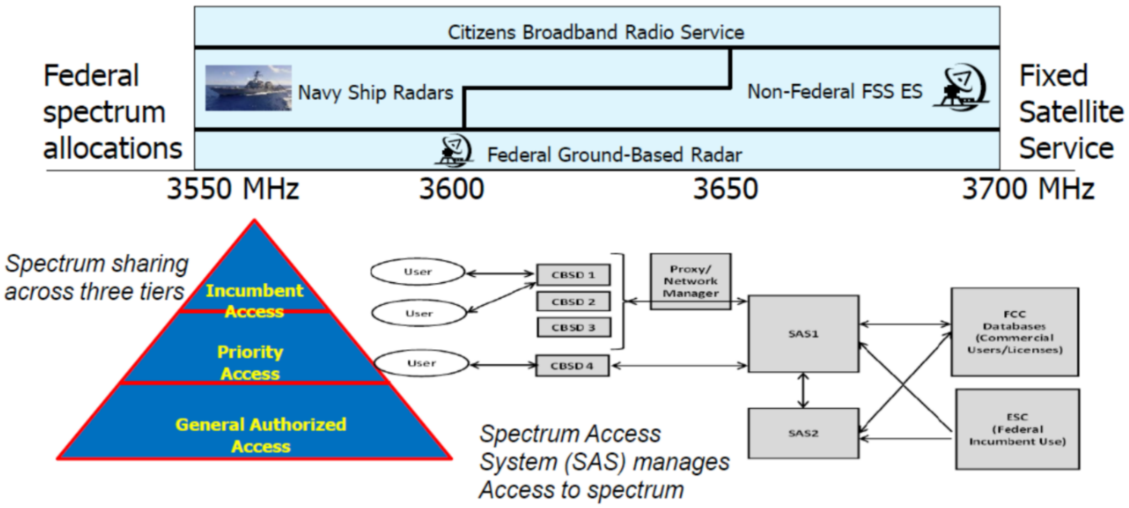
[12] There is an example of spectrum transfer in Sweden that was associated with restructuring and refarming of the 900 MHz band and involved partial transfer of spectrum usage rights (each of 2 x 2.5 MHz) from 2 of the incumbents to the mobile operator (HI3G) that did not have access to 900 MHz spectrum. https://www.gsma.com/spectrum/wp-content/uploads/2012/07/refarmingcasestudysweden900mhz20111129.pdf .

[13] The service is provided using LTE technology operating in Band 31 (452.5-457.5 MHz paired with 462.5-467.5 MHz).

5.1.4 Spectrum sharing

There is increasing emphasis on facilitating sharing between different services and users. However, sharing has been rarely implemented with nearly all new 3GPP bands being licensed on an exclusive basis to date. There are examples of dynamic sharing access such as TV White Space (TVWS) where a dynamic database is used to allow access to spectrum unused for broadcasting to be accessed by other users. There is also current work in the USA on Citizens Broadband Radio Service (CBRS), shown in Figure 5-3, which is specifically conceived for the 3.5 to 3.7 GHz band and is based on three tiers of sharing[14].

Figure 5-3: CBRS



Source: FCC

In 2016, the FCC finalised rules for CBRS, shown in Figure 5-3, above. This type of authorisation framework involves incumbents having permanent priority and site-specific protection at registered sites. It introduced the "light-touch" leasing process to make the spectrum use rights held by Priority Access Licensees (PALs) available in secondary markets. Under the light-touch leasing rules, PALs are free to lease any portion of their spectrum or license outside of their PAL protection area (PPA) without the need for the FCC oversight required for partitioning and disaggregation. This allows lessees of PALs to provide targeted services to geographic areas or quantities of spectrum without additional administrative burden. Coupled with the minimum availability of 80 MHz General Authorised Access (GAA) spectrum in each license area, these rules will provide the increased flexibility to serve specific or targeted markets. Furthermore, the FCC will let market forces determine the role of a Spectrum Access System (SAS), and as such, stand-alone exchanges or SAS-managed exchanges are permitted.

[14] https://www.fcc.gov/rulemaking/12-354

In Europe, there are a significant number of studies that have been undertaken within CEPT[15] addressing spectrum sharing and shared access[16]. Licensed Shared Access (LSA) is endorsed by the Radio Spectrum Policy Group (RSPG) as a potential access mechanism for the 2.3-2.4GHz band. Adoption should be based on national needs.[17] Under LSA, the incumbent spectrum user enters into an agreement with a sharing entity on a voluntary basis to allow it to share the spectrum. The scope of and conditions for sharing will be clearly defined and the sharing Framework needs to be enforced by the regulator. Both the incumbent and the sharer enjoy protection.

There are also proposals to make this type of shared access more flexible by using a dynamic spectrum database. Instead of a database containing static assignments for geographic areas and time, a real-time database that is updated with actual use at any given point in time could be introduced. This would allow access to take place as and when spectrum becomes available in real time at different geographic areas, potentially giving the sharers increased access to spectrum.

ETSI has produced several standards that address the systems and network requirements to facilitate sharing[18]. A new study has been approved in ETSI looking at reconfigurable radio systems and temporary spectrum access for local high-quality wireless networks. An early draft of ETSI RRS, DTR/RRS-0148, version 0.0.6 June 2017[19] shows it is of interest to Public safety but could be applicable to other industrial sectors needing high QoS.

5.2 Analysis of frequency bands

As noted in Section 5.1 there are two possible options for a private LTE network – licensed or licence exempt spectrum. In Table 5-1 and Table 5-2 we compare the key properties of the associated frequency bands. The higher the frequency band the greater bandwidth that is available but the smaller the potential geographic coverage and depending on the requirements of the application there may be a preference for access to specific frequency ranges.

[15] European Conference of Postal and Telecommunications Administrations.

[16] For example: ECC Report 205 addresses Licensed Shared Access (LSA). New bands and potential for sharing are discussed in ECC Report 254: Operational guidelines for spectrum sharing to support the implementation of the current ECC framework in the 3600–3800 MHz range.

[17] http://rspg-spectrum.eu/wp-content/uploads/2013/05/RSPG16-001-DSM_opinion.pdf

[18] ETSI (2013) TR 103.113: Mobile Broadband services in the 2300–2400 MHz frequency band under Licensed Shared Access regime.

ETSI (2014) TS 103 154: System requirements for operation of Mobile Broadband Systems in the 2300 MHz–2400 MHz band under LSA.

ETSI (2015) TS 103 235: System Architecture and High-Level Procedures for operation of Licensed Shared Access (LSA) in the 2300 MHz–2400 MHz band.

ETSI (2016a) TS 103 379 version 0.0.5: Information elements and protocols for the interface between LSA Controller (LC) and LSA Repository (LR) for operation of Licensed Shared Access (LSA) in the 2300 MHz–2400 MHz band.

[19] The Work Item "focuses on creating a feasibility study and a related technical report that will address the different technical possibilities for local high-quality wireless networks (nomadic or fixed) to access spectrum temporarily on a shared basis. Application domains envisaged for such networks are typically deployed by vertical industries (e.g. Creative- and Culture Industries, eHealth, Factory and Process Automation, Public Safety) stipulating demanding QoS requirements (availability, reliability and latency) for wireless communication. The technical report will document high-level use cases, review the feasibility of existing spectrum sharing frameworks, and if required propose evolved, extended or new technical solutions for spectrum sharing, and network architectures addressing different network topologies and device types. This includes systems using spectrum access grants for operation under certain restrictions, e.g. spectrum availability duration or (geo-)location. The objective is to identify whether current sharing frameworks, e.g. Licensed Shared Access, Spectrum Access System, etc., are appropriate for localized, high-QoS systems and to identify possible enhancements and/or alternatives on the technical solutions as appropriate".

Figure 5-4: Comparison of call range and frequency (assumes line of sight propagation)

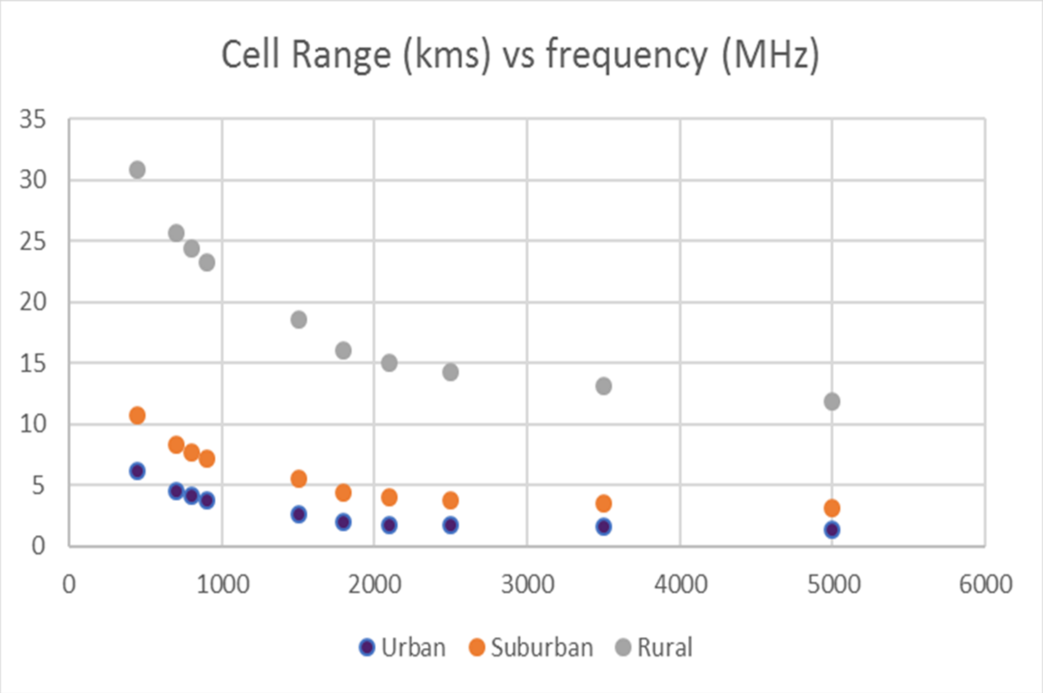


Table 5-1: Comparison of licensed frequency bands

Requirement	Below 1 GHz	1 GHz - < 2.3 GHz	2.4 and 5 GHz	2.3 - 6 GHz	mmWave bands
Wide area coverage	√√√√	√√√	√√	√√	x
Bandwidth / capacity	√	√√	√√	√√√	√√√√
Spectrum availability	**Licensed MNOs generally**	**Licensed except 1500 MHz band which is being awarded in some countries**	**Licence exempt**	**Spectrum being awarded. 2600 MHz band awarded most countries**	**Future**
Ability to support asymmetric traffic	No. FDD	FDD except 1500 MHz		Yes. TDD available at 2300, 2600 and 3500 MHz	Yes TDD planned.

Table 5-2: Comparison of licence exempt bands

Requirement	2.4 and 5 GHz	Lightly authorised (e.g. 3.5 GHz)	Lightly authorised (mmWave)
Wide area coverage	√√	√√	x
Bandwidth / capacity	√√	√√	√√√√
Spectrum availability	Licence exempt	?	Future
Ability to support asymmetric traffic	TDD	TDD	Yes TDD planned.
Indoor coverage only	√√√	√√	√√√√
Coverage indoors from outside	√	√√√	√

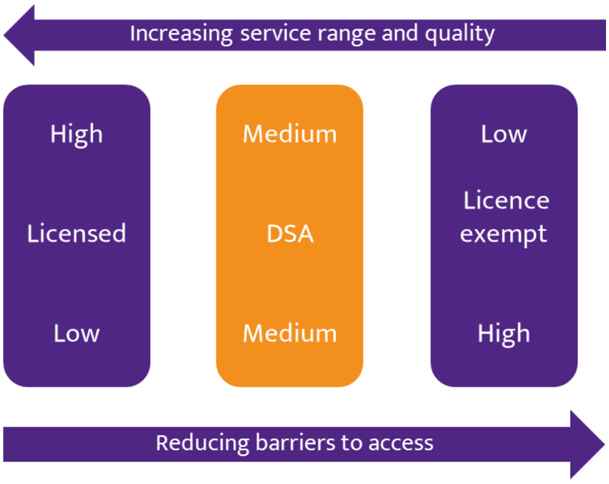
Possible opportunities for private LTE in licensed bands could come from underutilised mobile bands (e.g. 2.3 GHz, 2.6 GHz TDD in Europe) or higher frequency bands such as 3.4 GHz and above.

We anticipate that there will be an opportunity to deploy private networks in the mmWave bands provided the necessary regulatory approaches are implemented. This is based on the nature of propagation in these higher bands such that the potential for sharing is increased as well as the expectation that network operators will not use the spectrum on an exclusive national basis, so providing the potential to access spectrum on a shared basis. There are also 5G pioneer bands where trials are already being proposed, such as 26 GHz, where earlier access might be possible. The 3.4 to 3.8 GHz band which is identified for 4G / 5G is also a potential band for private networks where it has not already been licensed to the mobile network operators or where operators perceive benefits of leasing frequencies.

5.3 Time to access spectrum

This report has highlighted the requirement to access spectrum to meet the need for private LTE. Sharing may be a possible option as shown in Figure 5-5 below but with the increasing complexity of reducing access to spectrum barriers, licence exempt provides the fastest solution but potentially the lowest quality solution. MuLTEfire is an option to potentially address quality, which, although it has currently been developed for the global 5 GHz band (also 3.5 GHz in the United States), could be deployed in any licence exempt band as it is a frequency agnostic solution.

Figure 5-5: Sharing



Source: Ofcom

The 3.4 to 3.8 GHz band, and potentially 3.8 to 4.2 GHz bands, could be an attractive option but it will be necessary to act quickly to influence thinking as the lower band is currently planned for award in a number of countries[20]. It is an ideal band to provide for a number of options to support private LTE including:

- Identifying spectrum for wholesale network(s).
- Providing access to part of the spectrum to enable in-building communications not necessarily provided by the mobile network operators.
- Sharing on a tiered approach similar to the US.

Regulators should consider the possibility of reserving some spectrum for local deployments to meet new market demand and opportunities, such as private LTE, as we move towards 5G. An approach of this sort is being proposed in Germany.

Finally, the mmWave bands offer opportunities but apart for the pioneer bands most will not be determined until after WRC '19.

[20] There have been consultations and / or announcements of planned awards in Austria, Australia, France, Greece, Switzerland and UK.

6 Country analysis

The ability to offer private LTE networks depends on the availability of spectrum. Entities that currently have spectrum access to the relevant bands such as mobile network operators are an obvious candidate for a private LTE network provider. For non-mobile network operators, this requirement raises a number of important questions about spectrum access.

As discussed in Section 5.2, different bands have different requirements for access. Most LTE bands are licensed, generally on a national and sometimes on a regional basis, and so a non-MNO will need to either acquire their own licences for bands that they need for private LTE service, or gain access to existing licences by leasing / sharing them with the original licensees.

Acquisition of a licence could take the form of:

- participation in the competitive process such as an auction or beauty contest (**direct acquisition**)[21], or
- entering into a transaction with the original awardee of the licence to purchase it (**trading**).

Meanwhile, shared access to the spectrum could be gained by:

- entering into a transaction with the original awardee of the licence to access the spectrum for a fee over a period shorter than the licence duration or over some geographic areas (**leasing**)
- entering into an agreement with the incumbent user of the spectrum band to use the spectrum across both time and geography dimensions (**sharing**).

Under spectrum sharing (the second shared access option), the incumbent referred to is an existing licensed user. The agreement then involves specifying the level of protection required by the incumbent at different locations, which then determines how much of the spectrum and where the sharer can use it. The sharer's access is subsequently protected for this agreed level of use. The determination of access could be made through a spectrum database maintained by the regulator. CBRS in the US and LSA in the EU are instances of such sharing.

6.1 Starting questions for research

It is important to understand whether any of the spectrum access mechanisms above are available. If none of them are, it means that mobile operators are likely to be the only potential providers of private LTE networks. The option of direct acquisition of mobile spectrum by a private network operator is generally impractical. Non-MNOs would have to compete with MNOs for spectrum in a competitive process, against whom they are unlikely to be able to succeed. Hence, trading, leasing and sharing are the access mechanisms of greatest interest.

[21] Unlikely to be an option for a localised network. While regional licenses have been awarded in some territories, the use of these mechanisms for localised licences is a significant overhead.

We investigated the following questions to come to a view on what spectrum supply options for private LTE are possible:

- Is spectrum trading allowed? If so, can a private LTE network operator be the recipient?
- Is spectrum leasing allowed? If so, can a private LTE network operator be the lessee?
- Is shared access to spectrum possible in suitable licensed and licence-exempt bands?
- If sharing is possible, what (if any) is the sharing framework? (DSA, CBRS, etc.)
- Is it possible to operate a wholesale business that supplies a private LTE network?

In all questions, the private LTE network operator refers to a non-public mobile network operator. The investigation was conducted for selected countries across five regions:

- Europe – France, Germany, Ireland and UK
- North America – Canada and USA
- Asia Pacific – Australia, Hong Kong and Singapore
- GCC – Bahrain, Qatar, UAE
- South America – Chile, Peru

6.2 Regional overview of findings

The research led to a number of interesting observations, which confirm that shared access to spectrum is still largely the exception rather than the norm outside of North America and Europe[22]:

- Information found on spectrum access to mobile bands generally relates to presently used award methods e.g. auction, direct award, etc.
- Transfers of licence, which can include trading and leasing, are often mentioned. However, in many cases no further elaboration is made about the nature of the transfer that is allowed in the respective country's legislation / regulation. Therefore, it is not always clear what exactly is possible.

Other significant findings are:

- Where transfer (trading/leasing/sub-leasing) is allowed, there is no clear restriction on the type of companies with which the existing licensees can engage.
- Trading is generally subject to approval by the regulator (especially for frequency bands allocated to mobile). This requirement for regulatory approval could be a barrier to acquiring spectrum by non-public mobile network operators unless there is a recognition that private LTE use will be used at specific geographic locations (and that a nationwide trade may be inappropriate).

[22] Even though trading is possible in the EU, there have not been many trades:

- Following transfer, the original obligations on the licences need to be fulfilled. This means that it can be harder for anyone other than an MNO to be in the position to acquire the licence.
- There are mechanisms in place (LSA in the EU and CBRS in the USA), but they are either not yet adopted by the regulator or restricted to certain bands.
- We are not aware of prohibition on a wholesale-only business model anywhere.

Regionally, there are some differences, which are highlighted in Table 6-1.

Table 6-1: Summary of regional findings

Region	Summary of findings
Europe	Generally, transfer is allowed. Trading is allowed in all jurisdictions we researched, but leasing is still being consulted on in Ireland. Following the publication of CEPT Report 205 on sharing, RSPG published an opinion on sharing through LSA in 2013, but implementation is not mandatory.
North America	Trading of licences is allowed and quite common. The US has a lively secondary market. Partial transfer such as leasing is allowed. Transfers are well documented at least in Canada. CBRS is allowed for the 3.5GHz band in the US.
Asia Pacific	Transfer is allowed in Australia and Singapore. Though in Singapore, it is stated in the licence that transfer is subject to regulatory approval. Hong Kong is currently looking at trading. There have been TV white space trials in Singapore for sharing. Singapore recently consulted on 5G and access options. Australia is interested in DSA and monitoring the situation.
GCC	Generally, very little information is available. Trading is allowed in Bahrain and possibly in Qatar. In the UAE, it doesn't seem to be the case that transfer of spectrum licences is possible.

6.3 Detailed country findings

This section describes the detailed findings for each region in relation to the questions we asked, with specific country references.

6.3.1 European Union (France, Germany, Ireland and UK)

In the EU, the Authorisation Directive allows the provision of electronic communications networks and services (ECNS) subject to a number of obligations known as General Authorisations. However, to use some frequency bands for ECNS, in particular those that are designated for IMT, individual rights need to be assigned, usually in spectrum licenses.

The changes to the EU Electronic Communications Framework Directive 2009/140/EC, which came into effect in May 2011, include provision that Member States shall ensure that undertakings may transfer or lease radio spectrum to other undertakings. (Article 9b of the Access Directive). The implementing measures produced in 2012 by the Commission brought this obligation into force. Member states were then required to allow spectrum transfer including trading and leasing in key mobile bands including the 800, 900, 1700 and 1800 MHz and 2.1, 2.5-2.6 and 3.4-3.8 GHz bands by 2015 (RSPP harmonised bands).[23]

Rights transfer including trading and leasing are also enshrined in the Communications / Telecommunications Acts in the UK[24] and Germany (TKG)[25]. In 2014, the Irish regulator, Commission for Communications Regulation (ComReg), established a framework to facilitate transfers of spectrum rights of use in Ireland between undertakings in the Radio Spectrum Policy Programme bands. Presently, ComReg is consulting on the framework for spectrum leasing[26]. In France, transfer and partial transfer of rights is allowed, and the rights can be subdivided in frequency, time and licence duration[27]. France also allows spectrum leasing.

There are generally no restrictions on the transfer of rights other than that the original conditions attached to the use of the frequencies be adhered to and that the transfer is conducted in accordance with national procedures. Compliance is also required for conditions of harmonised use where the frequency band is harmonised.

On sharing, the RSPG has published an opinion on LSA, but its implementation is not mandatory by Member States[28]. The CEPT also published a framework for LSA.[29] There have been a number of tests and trials of LSA conducted in Europe.[30] These include a demonstration between mobile services and PMSE video links at Mobile World Congress in Barcelona in March 2015, the pilot undertaken by the Italian Ministry for Economic Development in Rome together with the Joint Research Centre of the European Commission, an industry stakeholder trial undertaken in Paris, over the air LSA trials between PMSE and mobile in Finland and a pilot for on-line booking for PMSE in the Netherlands.

In the UK, there is no regulatory barrier to spectrum sub-leasing; according to the 2003 Communications Act, partial transfer of rights as well as transfers that result in rights and obligations being borne by both the transferrer and transferee are also allowed. This legislative construct therefore already allows sharing similar to LSA in the UK (although there has not been any use of it in this form so far for sharing with mobile services). In Germany, the TKG allows shared use such as spectrum pooling.

Stipulations exist on the provision of network access to third parties including for roaming and to virtual network operators, but there is nothing on the sort of wholesale business model describer earlier in this report[31]. Generally, it should be possible to run a wholesale network using assigned spectrum, if the spectrum assignment conditions are met. However, it should be noted that many conditions applied to current spectrum licenses are framed for network built at a national level and not local enterprise networks.

[23] Article 6, paragraph 8 of http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012D0243&from=EN
[24] http://www.legislation.gov.uk/ukpga/2003/21/part/2
[25] https://www.gesetze-im-internet.de/tkg_2004/ (under Flexibilisierung)
[26] https://www.comreg.ie/media/dlm_uploads/2017/06/ComReg-1747.pdf
[27] http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep169.pdf
[28] https://circabc.europa.eu/sd/d/.../RSPG13-538_RSPG-Opinion-on-LSA%20.pdf
[29] http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP205.PDF
[30] https://cept.org/ecc/topics/lsa-implementation
[31] EC Access Directive

6.3.2 USA

Spectrum trading and leasing are both possible in the USA[32]. The US secondary market for spectrum trading is one of the most active with thousands of trades conducted each year. There exists a marketplace and database of ownership data run by the FCC that support such trades. Leasing/subleasing is also possible, but the need for pre-notification renders this type of transfer less attractive.

CBRS in the 3.5GHz band allows for shared spectrum access. It is unclear whether this mechanism for shared use of spectrum will also be available in other frequency bands.

Presently, T-Mobile has a wholesale business for M2M devices and MVNOs[33], which suggest that a wholesale business model is possible. Therefore, it should be possible to operate a wholesale network, so long as the company has the right spectrum.

6.3.3 Canada

In Canada, the government published the Study of Market-based Exclusive Spectrum Rights and modified it in 2010[34]. This includes recommendations on spectrum transfer including trading, leasing and sub-leasing. In 2013, the finalised framework was published[35]. This spectrum transfer framework applies to all commercial mobile bands. Transfers of spectrum licences are commonplace, and their instances are documented on the IC's website. According to the framework, spectrum sharing is also allowed subject to a review of the request for a subordinate licence. Subordinate licensing allows the licensee to enter into an agreement with a third party to operate in the licensed area using the licensed spectrum or a part thereof, or to operate in a portion of the geographic area without completely transferring its licence[36].

Generally, licence conditions include wholesale access to the licensee's network for roaming, but there are no restrictions on the business model of the licence holders or subordinate licence holders.

6.3.4 Australia

Spectrum trading and leasing is allowed in Australia[37]. There are no restrictions on the type of entities that can take part in trading and leasing activities[38]. However, trading and leasing must be conducted in STUs or smallest trading units. These are units with a frequency dimension and geographic area dimension (which itself is represented in 2 dimensions). In addition, the trade should result in block sizes for the different entities that comply with the minimum contiguous bandwidth required.

[32] Cave and Webb. Spectrum Management. 2015
[33] https://www.forbes.com/sites/greatspeculations/2016/07/06/a-look-at-t-mobiles-wholesale-wireless-business/#63df2b2e7297
[34] https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09404.html
[35] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10653.html
[36] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01875.html#s5.6
[37] http://www.acma.gov.au/Industry/Spectrum/Radiocomms-licensing/Spectrum-licences/spectrum_23
[38] https://www.legislation.gov.au/Details/F2015C00469

In general, sharing of spectrum has so far been possible only between licensees of adjacent blocks[39]. According to the latest Five-Year Spectrum Outlook[40], in 2016 the ACMA adopted a dynamic sharing framework in the 3400–3600 MHz for shared use between terrestrial wireless broadband and defence radar system. This appears to be the only instance, but ACMA is closely monitoring developments in DSA.

Wholesale mobile service exists in Australia with multiple MVNOs. There appears to be no restriction on operation of a wholesale business, but the licence conditions on the spectrum will still need to be met.

6.3.5 Hong Kong

It is currently not possible to transfer licences in Hong Kong, so neither trading nor leasing is possible. Spectrum licences are either auctioned or directly assigned by the government[41].

Hong Kong has a vibrant MVNO market. Therefore, it should be possible to offer wholesale network capacity. Given the way which spectrum is assigned, it is, however, unlikely that an entity that is not an MNO is likely to be able to gain access to the spectrum to operate a wholesale network.

6.3.6 Singapore

In the wording of the licence to mobile operators, transfer including trading of spectrum may be allowed in Singapore subject to a written approval from IMDA (formerly IDA)[42]. Spectrum sharing is also mentioned in the document as a possibility; however, the form of sharing is not specified. According to the Telecommunications Act, under Telecommunications Regulations, the IMDA can require licensees to share their radio frequency resource subject to prior notice.

6.3.7 Bahrain

According to the TRA's National Spectrum Planning and Allocation Policy dated 2008, trading will be implemented as soon as it becomes possible to do so without violating the policy's objectives[43]. The TRA's responses to its 2013 consultation on the award of the licences in the 900, 1800, 1900, 2100 and 2600 MHz frequency bands state that trading is allowed. However, there are no conditions mentioned on what kind of trade is possible[44]. This means there is no information on whether it is possible for non-MNO to engage in a trade with a licence holder to acquire spectrum.

[39] http://www.acma.gov.au/Industry/Spectrum/Radiocomms-licensing/Spectrum-licences/spectrum_20#13
[40] http://www.acma.gov.au/theACMA/~/media/F7DA9B92820A4148980D28B395A88718.ashx
[41] https://hkt.com/staticfiles/.../Jan/20170118e%20Spectrum%20Trading%20Paper.pdf
[42] https://www.imda.gov.sg/~/media/imda/files/regulation%20licensing%20and%20consultations/frameworks%20and%20policies/spectrum% 20management%20and%20coordination/stmpcmts.pdf?la=end
[43] http://www.tra.org.bh/media/document/the%20National%20Spectrum%20Planning%20and%20Allocation%20Policy%20EN.pdf
[44] http://www.tra.org.bh/media/document/Consultation_Report_award2013.pdf

6.3.8 Qatar

The ictQATAR's General Guidelines for Radio Spectrum Licensing suggests that a licensee may be able to transfer a licence to a third party at the discretion of ictQATAR[45]. Again, the original conditions of the licence being transferred must be met by the transferee.

6.3.9 United Arab Emirates

The TRA's Regulations on Spectrum Allocation and Assignment dated 2008 states that licences are non-transferrable.

6.3.10 Chile

Spectrum licences have generally been awarded through beauty contest in Chile. Where there is a tie in the outcome – i.e. multiple applicants score the same – an auction may be used to break the tie. This was the case for the 700 MHz award in 2014.[46] The awarded licences generally carry many obligations.[47]

In 2015, Chile was in the process of undertaking legislative and regulatory measures to create secondary markets for spectrum. This was done through the country's Sub Secretariat of Telecommunications (Subsecretaría de Telecomunicaciones (Subtel)) to refocus spectrum policy. In Chile, the key policy objective of spectrum management has been on competition and at times at the expense of usage efficiency. There was an instance, in which the spectrum was awarded to a new entrant but has since become unused due to the operator switching to an MVNO business model.

According to a study by Subtel in 2013, the lack of mechanisms, chiefly for spectrum pricing and trading, is a key flaw Chilean spectrum management.[48] This makes it hard for transfer to take place, despite there being no legal barrier to transfer of licences. Transfer has only been possible of the entire licence including all attached obligations.

There is flexible spectrum use in Chile according to the ITU. This includes, amongst others, use of unlicensed spectrum and technology neutrality.

In Chile, licence holders (also called concessionaires) are not generally under obligation to provide wholesale access to others (MVNOs) by law. However, the assignees of 4G spectrum were under obligation to offer such access. Provision of wholesale access is also not prohibited under other circumstances and is therefore possible.

[45] http://www.cra.gov.qa/sites/default/files/documents/General%20Guidelines%20for%20Radio%20Spectrum%20Licenses.pdf
[46] http://www.5gamericas.org/files/8314/4051/7653/4G_Americas_700_MHz_Spectrum_Process_Lat_Am.pdf
[47] https://www.gsma.com/spectrum/wp-content/uploads/2016/11/spec_best_practice_ENG.pdf
[48] http://www.subtel.gob.cl/images/stories/apoyo_articulos/estudios/informe_final_uai_2013.pdf

6.3.11 Peru

Exchange of spectrum licences is not prohibited in Peru, but its request will be examined based on competition effects. The approval of the Ministerio de Transportes y Comunicaciones (MTC) is needed before any such transaction can take place. This is highlighted in the attempted sale by Movistar of 10 MHz of the spectrum it won in 2013 to its rival Claro in an auction. The MTC rejected the transaction on the basis of a recommendation by the regulator.[49]

There appears to be no regulatory framework for spectrum transfer, which hinders trade. There are, however, caps on spectrum. The limit set in 2012 means that operators cannot have more than 60 MHz in total in the 800 MHz, 900 MHz and 1900 MHz bands or more than 40 MHz of spectrum in the 1.7 / 2.1 GHz band. In addition, in the contract drawn up at the end of the 700 MHz award process in 2016 stipulates that transfer is not possible for the first 5 years.

There is flexible spectrum use in Peru according to the ITU. This includes, amongst others, use of unlicensed spectrum and technology neutrality.[50]

6.3.12 Country comparison

Figure 6-1 summarises and compares the key research findings for each country based on the information from Section 6.3.1 to Section 6.3.9.

Figure 6-1: Comparison of key country findings

Country	Trading allowed?	Leasing allowed?	Sharing allowed?	Wholesale allowed?
France	Yes	Yes	Yes (trials)	No prohibition
Germany	Yes	Yes	Yes	No prohibition
Ireland	Yes	Under consultation	Yes	No prohibition
UK	Yes	Yes	Yes	No prohibition
Canada	Yes	Yes	Yes	No prohibition
USA	Yes	Yes	CBRS in 3.5GHz	No prohibition
Australia	Yes	Yes	Yes (3.5GHz band)	No prohibition
Hong Kong	Being considered	Not yet	Not yet	No prohibition
Singapore	Yes	Yes	There are trials	No prohibition
Bahrain	Yes	Unknown	Unknown	Unknown
Qatar	Transfer is possible		Unknown	Unknown
UAE	No	No	Unknown	Unknwon
Chile	Yes	Under consideration	Unknown	No prohibition
Peru	Yes	Unknown	Unknown	No prohibition

Source: Plum research

[49] http://elcomercio.pe/economia/negocios/reventa-espectro-necesitara-pasar-congreso-210707
[50] https://www.itu.int/ITU-D/treg/Events/Seminars/GSR/GSR12/documents/Session_2_Horton_SpectrumPolicy.pdf

7 Conclusions and recommendations

The conclusions of the research activity undertaken for this report are as follows:

- There is ongoing scope for the development of private LTE network solutions for industrial automation. The move to cyber-physical systems and the convergence of platforms facilitated by LTE technology is a key enabler for this.
- The technology for private LTE will be available in the short term and it will access the scale and scope benefits of LTE, its ecosystem and its evolution to 5G.
- A range of implementation solutions is possible, ranging from stand alone to hosting on a public mobile network or a dedicated wholesale network, which will provide flexibility of options for implementation.
- Key to the success of private LTE solutions is the ability to access suitable harmonised mobile spectrum in required locations and on appropriate terms. This is likely to be challenging given the current approach to assignment of this spectrum, the lack of active secondary spectrum markets and the very limited use of spectrum sharing in these bands.

The last point is the key barrier we identified to the successful deployment of private LTE systems. Evidence so far suggests that:

- There is not a uniform picture for the operation of spectrum trading / leasing and spectrum sharing solutions in the countries considered in the report.
- Even where there is the ability to do trading / leasing and spectrum sharing (such as in the UK), there is a lack of clarity as to what can be done and how.

Recommendations

1. Governments and regulators should expand their view of the use of mobile systems to include provision of private network services and in particular private LTE. The private LTE concept is an enabler for industrial automation and it is realisable now.
2. The roll out of private LTE is constrained by an inability to access harmonised mobile spectrum. Authorisation of this spectrum is required on a localised basis and not the national / dedicated basis that has applied to date for mobile network operators providing services to the public. Governments and regulators should consider the following mechanisms for accessing mobile spectrum on a localised basis:
    a. Spectrum transfer through trading and leasing (the latter being likely to be more applicable to private LTE.
    b. Spectrum sharing concepts that deliver guaranteed quality of service such as licensed shared access.

Appendix A: Categorisation of applications

Each application falls under each of the two labels created for each dimension discussed in Section 4.2. For instance, remote navigation of outdoor drone in agriculture will need a high-QoS, high-speed, mobile and uplink-heavy connection. Therefore, this type of drone use falls in a category of service with the following requirements along the 4 dimensions: <u>High QoS</u> + <u>Reach/mobility required</u> + <u>Broadband</u> + <u>Asymmetric</u>

There are a total of 16 distinct categories based on the four dimensions. The categories are in effect all permutations of the 2 labels along the four dimensions. These are shown below (Cat. A to Cat P.).

Figure A-1: 16 categories of applications based on four technical dimensions

Appendix B: Examples of application for each category

We map these categories to the industrial applications envisaged for each industry scenario below. N/A appears where no expected future applications within an industry scenario fall under the category.

Indoor manufacturing – high-volume production line

Application category	Example application from industry scenario
Cat. A	Internet connection for workers along production line for reference purposes
Cat. B	Cameras for monitoring and tracking
Cat. C	Collection of data on production flow
Cat. D	
Cat. E	Internet connection for workers along production line for reference purposes
Cat. F	Cameras for monitoring and tracking
Cat. G	Collection of data on production flow
Cat. H	
Cat. I	Use of mobile robotics that require cloud computing access
Cat. J	Remote operation of mobile machinery on the production line
Cat. K	Sensors on mobile machinery for personnel safety in an environment where autonomous or remotely controlled machinery work in proximity to human workers.
Cat. L	
Cat. M	Use of stationary robotics that require cloud computing access
Cat. N	Remote operation of stationary machinery
Cat. O	Sensors on stationary machinery for personnel safety in an environment where autonomous or remotely controlled machinery work in proximity to human workers.
Cat. P	

Indoor manufacturing – Oil refinery

Application category	Example application from industry scenario
Cat. A	Internet connection for workers in the plant's outdoor areas for reference purposes
Cat. B	Pollution monitoring and management via sensors, e.g. water purification process
Cat. C	Collection of time-series data in processing plants
Cat. D	
Cat. E	Internet connection for workers in the plant's indoor areas for reference purposes

Cat. F	Cameras for monitoring and tracking
Cat. G	Collection of time-series data in processing plants
Cat. H	
Cat. I	Use of mobile robotics that require cloud computing access
Cat. J	Remote operation of mobile machinery in outdoor areas such as drone
Cat. K	Sensors on mobile machinery for personnel safety in an environment where autonomous or remotely controlled machinery work in proximity to human workers.
Cat. L	
Cat. M	Use of stationary robotics that require cloud computing access in processing plants
Cat. N	Remote operation of stationary machinery in processing plants
Cat. O	Safety alert: for maintenance and other staff e.g. relating to storage of hazard chemicals with risk of fire or spillage
Cat. P	

Logistics operation – Port

Application category	Example application from industry scenario
Cat. A	Internet connection for workers in the port's open areas for reference purposes
Cat. B	N/A
Cat. C	Collection of time-series data for asset management purposes
Cat. D	
Cat. E	Internet connection for workers in the port's offices for reference purposes
Cat. F	Cameras for monitoring and tracking of consignments for customs controls
Cat. G	Tracking of individual items that are part of containers or large consignments
Cat. H	
Cat. I	N/A
Cat. J	Remote operation of mobile machinery in outdoor areas such as surveillance drone
Cat. K	Logistics management for ships, vehicles and rail handling
Cat. L	
Cat. M	Use of stationary robotics that require cloud computing access
Cat. N	Remote operation of stationary machinery such as cranes
Cat. O	Sensors on stationary machinery for personnel safety in an environment where autonomous or remotely controlled machinery work in proximity to human workers.
Cat. P	

Agriculture – Large farm

Application category	Example application from industry scenario
Cat. A	N/A
Cat. B	N/A
Cat. C Cat. D	Collection of time-series data for farm asset management purposes
Cat. E	N/A
Cat. F	N/A
Cat. G Cat. H	Environmental monitoring and control (e.g. temperature, humidity, water level sensors) and sensing to determine solutions to optimise crop yield (e.g. soil support, seed placement density, infrared monitoring to prevent crop burning)
Cat. I	Cloud-based autonomous farm machines for use in fields
Cat. J	Remote operation of mobile farm machinery in outdoor areas such as harvesters
Cat. K Cat. L	Real-time collection of measurement data for yield optimisation of crops with a short life cycle
Cat. M Cat. N	Use of autonomous robotics that require cloud computing access such as soft fruit pickers in green houses
Cat. O Cat. P	Geofencing for livestock management in outdoors area

Storage facility – Compound of warehouses

Application category	Example application from industry scenario
Cat. A	Internet connection for workers in the compound's outdoors areas for reference
Cat. B	N/A
Cat. C Cat. D	Collection of time-series data for asset management purposes
Cat. E	Internet connection for workers in the compound's offices for reference purposes
Cat. F	N/A
Cat. G Cat. H	Environmental monitoring and control for condition-sensitive goods
Cat. I	Cloud-based autonomous transports for moving goods between warehouses
Cat. J	Remote operation of mobile robotics such as outdoor drones for safety surveillance
Cat. K	Real-time environmental monitoring for pest control

Cat. L	
Cat. M	Remote control and use of autonomous robotics that require cloud computing access such as forklifts used in warehouses for indoor transport of goods to different locations (cloud computing power needed for environmental sensing)
Cat. N	
Cat. O	Geofencing for access management of personnel across restricted areas
Cat. P	

Nomadic network – Outside broadcasting by PMSE user

Application category	Example application from industry scenario
Cat. A	Internet connection for personnel in the field
Cat. B	N/A
Cat. C	Collection of time-series data for asset management purposes (of field equipment in storage and in transit)
Cat. D	
Cat. E	N/A
Cat. F	N/A
Cat. G	N/A
Cat. H	
Cat. I	High-bandwidth transmission links for broadcasting and receiving HD footage for editing in mobile studios on location
Cat. J	
Cat. K	N/A
Cat. L	
Cat. M	High-speed, wireless local area networks for multiple OB vans on the remote transmission site
Cat. N	
Cat. O	N/A
Cat. P	