DELL Technologies

Whitepaper

Navigating Private Mobility

Abstract

Digital transformation across many verticals drives new private mobility use cases and requirements. This whitepaper looks at the business trends, explores technology options, and provides an overview of Dell Technologies private mobility solutions.

February 2023

Revisions

Date	Description
May 2021	Initial release.
February 2023	Updated section 6 Dell Technologies private mobility solutions.

Acknowledgements

This paper was produced by the following:

Authors:

Jade Zhu, Telecom Solutions Architect, Jade_Zhu@Dell.com

Kohei Yasuda, Solution Campaign Manager, Kohei_Yasuda@Dell.com

Rodrigo De Faria Custodio, Solution Campaign Manager, Rodrigo_Custodio@Dell.com

Alexis Debreu, Telecom Solutions Architect, alexis_debreu@dell.com

Support:

Arnaud Bouchoucha, Project Manager, Arnaud.Bouchoucha@Dell.com

Limor MorYosef, Project Manager, limor.moryosef@dell.com

Table of contents

1 Executive summary

Private cellular wireless networks have recently been a hot topic, owing to the emergence of 5G, the maturity of IoT (Internet of Things) ecosystems and the increased availability of radio spectrum. Carriers, vendors, and enterprises have been deploying various types of private wireless connectivity since the onset of the cellular era to address coverage, capacity, and security needs. Yet no vendor has addressed those customer needs in a comprehensive and cost-effective way.

The market for private cellular wireless networks is expected to grow at a high compound annual growth rate (CAGR) of 60% between 2021 and 2026, and many analysts assume that the industrial sectors (manufacturing, energy, and logistics) will experience the highest spend. Enterprises expect private cellular wireless networks to bring a series of benefits: increased security and control of the data generated within the enterprise, more flexibility to deploy and configure the network, better performance than other technologies (public cellular, fixed or Wi-Fi) and seamless connectivity.

The latest generation of Wi-Fi allows more throughput and supports more simultaneous users. However, unlike cellular technologies, deployment of Wi-Fi for coverage of large areas remains complex and latency is unpredictable. Wi-Fi may also suffer from security issues related to backward compatibility with older generations.

Policymakers and regulatory authorities understand that digitization, spectrum availability and high-quality mobile broadband are key determinants of economic development. In that sense, some countries have already allocated dedicated spectrum bands for the deployment of private cellular wireless networks.

5G, the latest mobile cellular generation, enables game-changing services in the enterprise domain. This includes use cases that increase coverage and capacity or address mission-critical and low latency applications. We have analyzed several verticals and assessed the use cases that will require private cellular wireless network LTE (4G) / 5G or Wi-Fi.

Dell Technologies has created private cellular wireless networks solutions that deliver at cloud speed, and can be consumed by the enterprise as a service to accelerate the adoption of private networks, edge computing and end-to-end industrial solutions. Together with our partners, we have already launched several solutions, and are working on expanding portfolio of private cellular wireless network solutions. As the market and the industry evolve, we will keep adding relevant solutions that will benefit our enterprise and telco customers.

2 What is private mobility?

Private mobility is a dedicated, end-to-end infrastructure used exclusively by an enterprise, supporting the connection of enterprise-authorized end-user devices using LTE (4G, Long Term Evolution) or 5G technology. Private mobility uses licensed, unlicensed or shared spectrum, providing the user with increased security, quality of service and full control over the network and the data generated within.

Cellular technology and Wi-Fi both provide wireless connectivity. Private mobility solutions overcome the limitations of Wi-Fi and the challenges faced by cellular devices such as:

- Poor coverage because of limited availability of cell sites or sub-optimal RF (Radio Frequency) design.
- Users in large private or public venues (stadiums, train stations, etc.) voice or data connection issues due to the high density of users trying to connect simultaneously.
- RF penetration issues, due to their inherent construction or in order to achieve high energy efficiency, complicating indoor use of mobile phones.

Mobile operators, vendors, building and venue owners have collaborated to address some of those issues. Initiatives include using indoor access points, distributed antenna systems, temporary mobile cell sites, and more.

More recently, the maturity of IoT ecosystems and the emergence of 5G led the way to the development of industrial use cases enabled by private mobility. Global trends such as disaggregation(1), virtualization and edge computing, together with some regulators' initiatives to expand the spectrum of frequencies directly available to enterprises, have paved the way to cost effective ways of using private networks.

Some types of private cellular connectivity for voice and data users have been around for a long time. However, legacy vendors' proprietary solutions have never fully addressed all the above challenges. Collaborating with our partners, Dell Technologies has created solutions to speed up the adoption of private networks, edge computing and end-to-end industrial solutions, delivered with the speed of the cloud, and consumed by the enterprise as-a-service.

Note (1): *In our context, the disaggregation breaks up a monolithic design, which is in most cases is proprietary, into smaller standardized entities. This allows more flexibility for creating new designs matching the targeted models of deployment. The disaggregated components are for the most part software based, allowing cloud deployment or onboarding on a hardware appliance.*

2.1 Drivers for private mobility

Some of the drivers for private mobility are the requirements for industrial use cases and business processes which are not supported by public mobile networks, such as:

Security

The security of intellectual property is a key factor, as retaining sensitive operational data is crucial to high tech industrial companies, who do not want to risk information leaks.

Flexible configuration

Private mobility can be configured to an entity's specific needs, in a way that may not be possible on a public network. Configurations can vary by site, depending on the type of deployment in each venue.

High performance

Performance, low latency and high throughput, requirements for demanding applications are another key driver. 5G has a clear performance advantage over LTE and Wi-Fi in industrial systems. 5G's enhanced capabilities support many locations and uses which were previously unfeasible.

Dedicated coverage

A private network also allows companies to determine the network's coverage quality, which is important in locations with harsh radio frequency or operating conditions, or in remote areas where public network coverage is limited. The private network can run on a dedicated spectrum, reducing the risk of varying service levels due to usage by third parties.

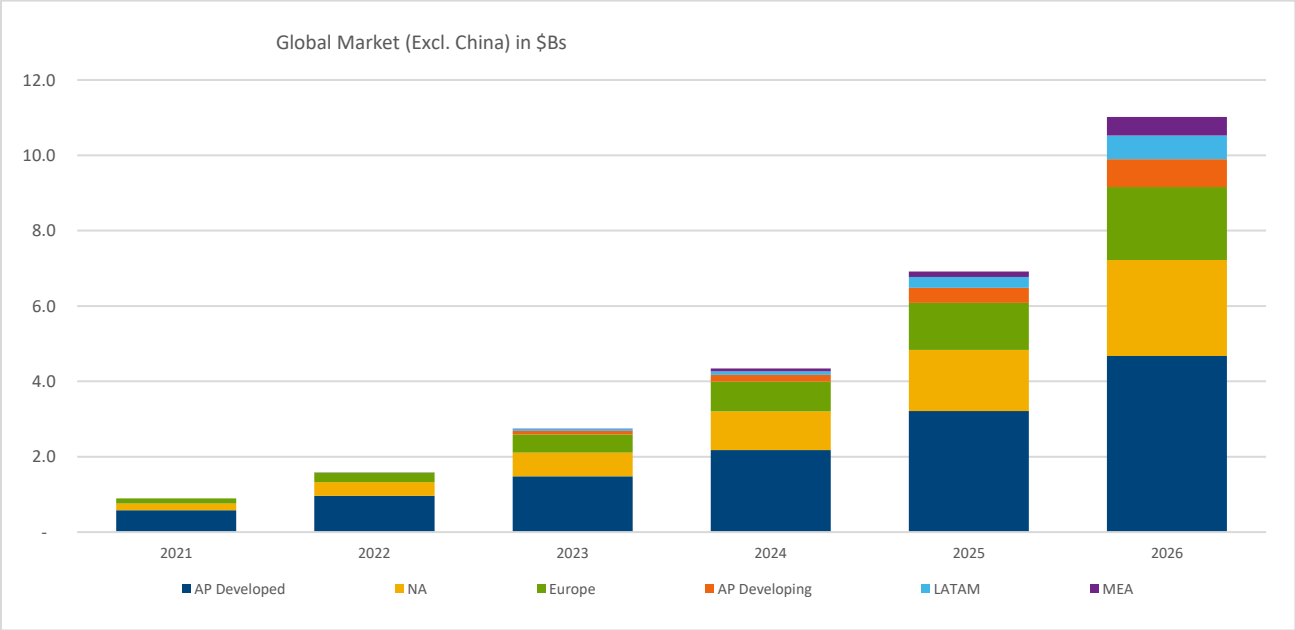
Seamless connectivity

A private network offers companies sseamless connectivity, which can be important for devices such as sensors in automated guided vehicles (AGVs) moving around their sites.

The 3rd Generation Partnership Project (3GPP) is the industry consortium setting standards for 5G. The first phase of 3GPP 5G specifications in Release-15 was completed in 2019. Since the second phase in 3GPP Release, 16 standards were issued in 2020, with an expansion in 2021, when diverse industrial applications accelerated to adopt various 5G mobile networking technologies. Examples include robotic production lines, sensor networks and industrial plant equipment. In some of these cases, the performance requirements for the link between the control system and physical actuator are extremely demanding and cannot be met by LTE and Wi-Fi.

2.2 Private mobility market opportunities

The global private mobility market size is expected to reach $11 billion in 2026 and is estimated to register a compound annual growth rate (CAGR) of 60% between 2021 and 2026. The evolving next-generation network services are expected to address the need for critical wireless communication serving industrial operations, public safety, and critical infrastructure connectivity. Moreover, the global market is primarily driven by the growing need for ultra-reliable low latency connectivity for Industrial Internet of Things (IIoT) applications, including collaborative robots, industrial cameras, and industrial sensors.



Source: Dell Analysis based on ABI Research, Q3 2020 [2]

3 Overview - wireless technologies

Two main technologies support the deployment of wireless IP networks in enterprises: Wi-Fi and cellular LTE/5G. This paper will provide a high-level overview of both technologies, followed by a comparison of the latest generation Wi-Fi 6 and 5G.

The deployment of a wireless network is a tradeoff between the size of the area to be covered, and the expected performance vs the number of users. The capacity of each antenna is shared between the users in the area it covers.

If the average performance per user equipment (UE) is too low, the radio cell must be subdivided into smaller cells, adding antennas with smaller area coverage. Subdividing a cell or managing many access points enables increasing UE density, but also introduces complexity. Moving a UE from one antenna to another frequently generates extra traffic and latency, and adds zones of cell overlap, causing interferences.

In another scenario, the user density is low, and we need to extend the coverage area. This could be the case for complex indoor coverage or a mix of indoor and outdoor, such as airports. The distributed antenna system (DAS) enables extension of the coverage by deporting antennas. A DAS system is suitable for cellular networks. The DAS works at the radio interface level and comprises expensive analog devices and passive antennas.

Selecting 5G is the right approach to protect the enterprise investments over time. However, in some cases mobile devices are not yet available with the latest technology when the networks must be deployed. This could be the case for specific equipment like wireless tools, connected screwdrivers with real time torque adjustment, Industrial IoT gateways, rugged handheld mobile device... In this context, starting with an evolutive platform supporting both 4G and 5G is a factor to be considered.

Lastly, the technology of choice is the one providing the right level of performance at the right cost.

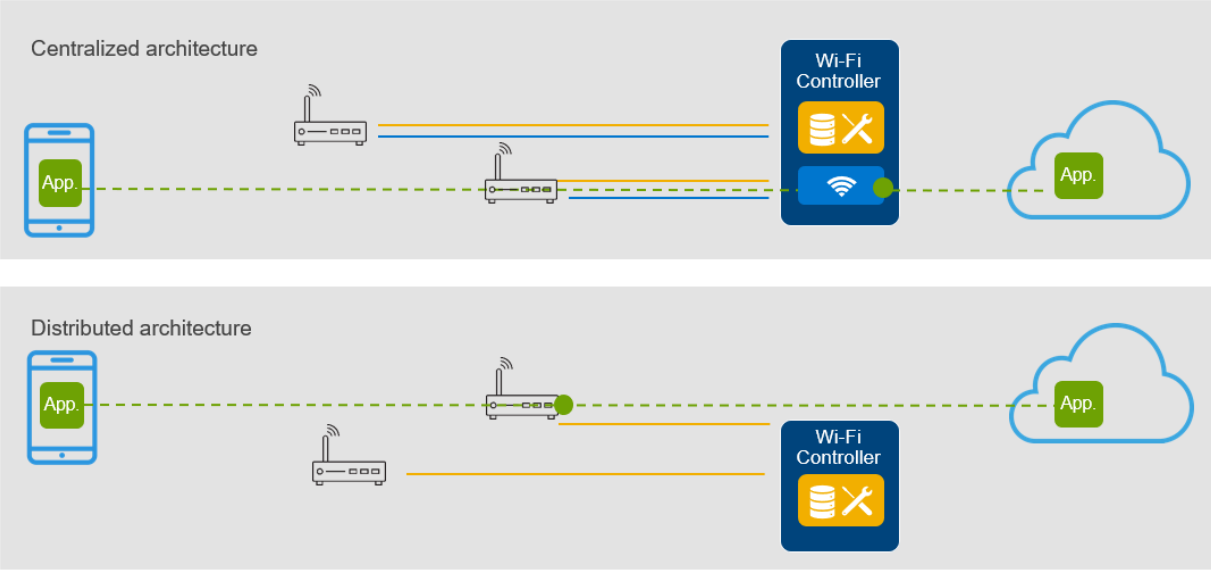
3.1 Wi-Fi and Wi-Fi 6 in a nutshell

Wi-Fi is the most commonly used wireless communication technology. An enterprise-grade Wi-Fi solution is composed of multiple access points. A controller allows the configuration and supervision of access points. Some controllers with advanced features provide additional tools to monitor the efficiency of the radio coverage. The controller is also the entity managing the provisioning and authentication of the devices.

A Wi-Fi solution can be distributed, with each access point managing all the protocol stacks, or centralized, in which case the radio stack and upper layer are centralized in the Wi-Fi controller.

The centralized architecture allows better management of interferences between access points, with seamless mobility of devices across the covered area. The traffic of each access point is forwarded to the controller. With a distributed architecture, the connections with the wire network are established directly from each access point allowing a higher scalability.

In a consumer Wi-Fi access point, the controller is onboarded to the access point.



Wi-Fi 6 (or 802.1ax) is the 6th generation of Wi-Fi. Each generation of Wi-Fi offers users higher speed and device density, additional frequency bands, and faster throughput enabling users to integrate Wi-Fi into everything they do at home, at work and on the go. Wi-Fi 6 introduces new capabilities to effectively handle current traffic demands, increasing capacity, coverage, and network intelligence. Enterprise Wi-Fi solution vendors offer proprietary solutions to enable mobility across Wi-Fi access points.

Key features of Wi-Fi 6 include:

- Uplink and downlink orthogonal frequency division multiple access (OFDMA) increases efficiency and lowers latency for high-demand environments
- Downlink multiple user multiple input, multiple output (multi-user MIMO), provides performance improvements for networks with many users

- 160 MHz channel capability increases bandwidth to deliver greater performance with low latency, even for clients without multiple antennae
- New modulation mode enables peak gigabit speeds for emerging, bandwidth-intensive use cases
- Increased symbol duration makes outdoor network operations more robust
- Improved media access control (MAC) signaling increases throughput and capacity while reducing latency

* *Source: Wi-Fi Alliance*

Wi-Fi 6 can provide up to 1.2 Gbps per spatial stream with a 160MHz bandwidth, and a maximum of 8 spatial streams uplink and down link.

Wi-Fi 6E

Wi-Fi works in the two unlicensed bands 2.4GHz and 5GHz. With Wi-Fi 6E, the Wi-Fi alliance introduced a 3rd band in the 6GHz frequency range. While this band is available in the US, it is not available in all regions and countries. When available, Wi-Fi 6E will provide extended capacity for more connected devices and supporting better throughput.

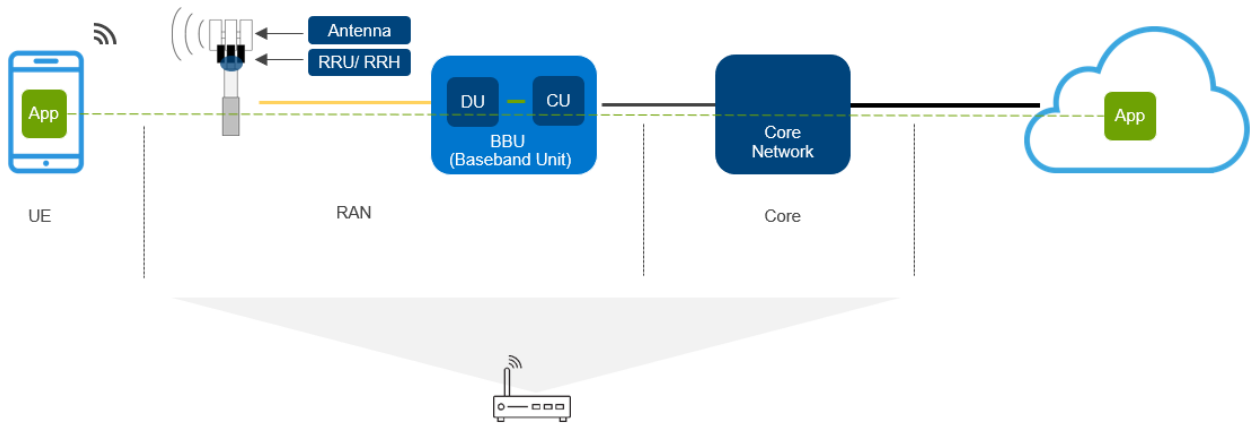
Wi-Fi operates on a band of frequencies that can be used simultaneously by other technologies like Bluetooth. Consequentially, a Wi-Fi device must listen before transmitting data. Because of this mechanism, Wi-Fi performance becomes unpredictable when the number of devices increases.

3.2 Cellular and 5G in a nutshell

A mobile cellular network comprises two main parts. The Radio Access Network (RAN) and the Core Network. The RAN provides the radio attachment level (right to access the media), and the core network manages the network connection for the UE (typically a phone) and its mobility in the network. The cellular network architecture allows country-wide deployment.

The RAN comprises the antennas, the remote radio unit, and the baseband unit. In 5G, the baseband unit may be split into the distributed unit and centralized unit, respectively DU and CU.

The data session established by the UE to reach an application is established across the RAN and the Core.



Unlike Wi-Fi, all cellular network functional blocks are integrated into a consumer Wi-Fi access point

Mobile cellular networks have evolved from analog to full digital solutions. Each generation - 2G, 3G, 4G and now 5G - brought a new set of applications. 2G was voice and text. 3G introduced data. 4G, also named long term evolution (LTE), was the first full IP mobile network, with services based on the IP protocol.

Unlike Wi-Fi, cellular technologies' (LTE, 5G) architecture allows seamless connectivity and mobility across the cells countrywide. The roaming agreements extend mobility beyond country borders.

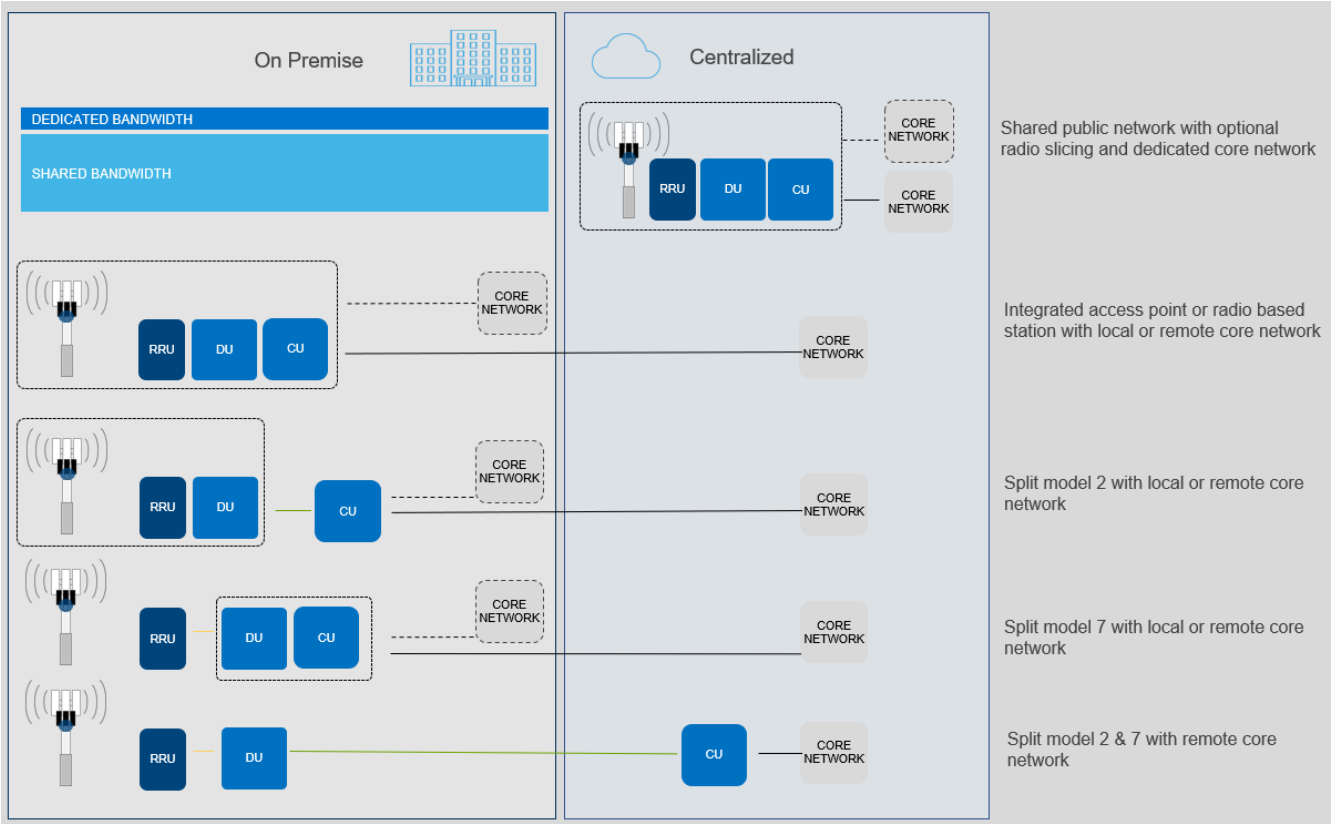
5G enables:

- More data and faster, Enhanced Mobile Broadband (eMBB). User experience: 100 Mbps; Peak data rate: 20 Gbps; Area traffic capacity: 10 Mbps/m2
- More devices, Massive Machine Type Communications (mMTC). Connection density: 10^6 devices/km2
- Instant response, Ultra-Reliable and Low Latency Communications (URLLC). Latency: 1ms; Mobility: 500 km/h

5G introduces the concept of network slicing, which means splitting the network capacity into several classes of services, from the radio to the application, through the core network. Network slicing is a 5G feature that enables agile delivery of "smart pipes". Logical network slices can be created to support customer services or vertical needs with its associated SLA (Service Level Agreement). It is now possible to have an end-to-end private network using the public infrastructure.

Cellular technology for private mobility

Several architectures support private mobility solution with 5G:



- Shared public radio with a dedicated core network, with optional network slicing into different classes of service. In this case, there is no deployment of on-premises equipment.
- Integrated access point, with shared or dedicated core network. This is a typical case for small cell indoor
- Disaggregated RAN, split model 2, with shared or dedicated core network. This model is well suited for covering an area with multiple small cells.
- Disaggregated RAN, split model 7, with shared or dedicated core network. Compared to the previous case, the server where the Centralized Unit (CU) and Distributed Unit (DU) are deployed needs a hardware acceleration card. This model is the most flexible as it allows management of any type of deployment, indoor, outdoor, small cell and macro cell.
- Disaggregated RAN, with shared or dedicated and centralized core network. This model allows optimization of the hardware infrastructure for deployment of a large area with a very high user density. A typical example of deployment is the smart city.

3.3 Wi-Fi or cellular technology?

As 5G and Wi-Fi 6 aim to address the same pain points - bandwidth, security, user density and cost efficiency - they use the same root technologies: modulation, MIMO for spatial diversity. In the following pages we will compare the technical criteria of 5G and Wi-Fi 6

Cellular technology will be the choice in the following cases:

- Demanding coverage requirement
- Resilience and stability
- Continuity of service with public cellular network
- Inefficient control of Wi-Fi devices in an area where mission-critical applications are running

	Cellular Technology LTE-5G	Wi-Fi
Radio Coverage Range	LTE/5G cell can provide a radius of a few kms for macro cell, up to 2km for micro cell and up to 200m for Pico/small cell	Up to 300m outdoor and 30m indoor (can often be much less)
Bandwidth & user density	Peak data rate of 20Gbps for an average user experience of 100 Mbps Up to 64x64. MIMO	68 Mbps to 10.5 Gbps up to 8x8 MIMO
Latency	A few ms guarantee during handover when user moves across cells	A few ms without guarantee when user moves between access points and when the number of connected devices increases. Proprietary implementation.
Security	5G implements the 128 bits Advanced Encryption Standard.	WPA3 Enterprise 192 bits provides a cryptographic strength of 192 bits from authentication to air interface encryption. A major weakness is backward compatibility with a less secured mechanism for preserving investments in older generation devices
Technical architecture	Ethernet with optional PoE (Power over Ethernet) for the small cell Access points. Usage of Ethernet to deploy cellular macro cell will become the standard, however, legacy equipment still uses non-Ethernet interfaces requiring dedicated optics fibers. Macro cell radio equipment may need an external -48V DC (Direct current) power supply. Radio equipment must be synchronized. Radio controllers and core networks run on regular x86, bare metal or virtualized. The equipment running the real time part of the radio (DU) needs hardware accelerator.	Ethernet with optional PoE (Power over Ethernet) to connect the access points. The controllers run on regular x86. Bare metal or virtualized

Radio planning & site survey

As in any radio solution deployment, to reach the expected performance, a site survey is required to select and place the radio components, including antennas. Radio Frequency planning tools are available for analysis prior to on-site spectrum measurement.

4 Spectrum & regulation

4.1 Why do frequencies matter?

Wireless connectivity is ruled by the physics of radio transmission. A signal over the air is transmitted on a frequency and consumes a given bandwidth. The larger the bandwidth, the more information is carried. With the same radio parameters, the resulting user throughput is proportional to the radio bandwidth. The higher the frequency, the higher the performance (throughput), but the reach and indoor penetration are poorer. Low frequencies, however, offer good coverage and indoor penetration, but lower throughput performance. The indoor penetration is considered good for frequencies below 2.6GHz, and focused attention is required for frequencies higher than 2.6GHz.

Low frequencies under 1GHz are considered Low band, frequencies between 1 GHz and 6GHz are Mid band and frequencies from 24GHz are High band, also named millimeter Wave (mmWave). Mid band is a compromise between coverage and performance.

Frequencies available for deploying a new radio technology are scarce. The emission of a radio signal is not allowed without licenses, except for unlicensed bands. Unlicensed bands used by Wi-Fi are 2.4GHz, and 5GHz. A third unlicensed band, 6GHz, is available in some countries and is under study in others. These bands are not reserved for a given service and can be used by anyone if the permitted transmission power limit is not exceeded. Wi-Fi and Bluetooth share the same band, which generates interferences and may result in degraded performance. The main advantage of an unlicensed band is that no authorization is required to deploy a Wi-Fi network.

The licensed bands used by cellular are cleaner as they are dedicated to one service. In most cases, a band is allocated to a nationwide single operator. The operator can authorize the usage of frequencies by a third party under its control.

Of course, the network and terminals must operate on the same band. For generic purpose devices (UE), this is not an issue; problems may arise for specific devices only available in a few bands. The table below summarizes the bands for LTE/4G, 5G and Wi-Fi.

LTE/4G	**5G**		**Wi-Fi**
Licensed			**Unlicensed**
410 MHz – 5900 MHz	FR1	410 MHz – 7125 MHz	2.4 GHz
	FR2 (mm Wave)	24250 MHz – 52600 MHz	5 GHz *6 GHz*

4.2 Shared spectrum concept

In the US, in 2015, the Federal Communications Commission (FCC) adopted rules for shared commercial use of the 3550-3700 MHz band (3.5 GHz band). The Commission established the Citizens Broadband Radio Service (CBRS) and created a three-tiered access and authorization framework to accommodate shared federal and non-federal use of the band. This is a new concept of shared spectrum. Indeed, some frequencies are reserved for the radar of the US Navy. In non-coastal regions, the frequencies are not used, and thus can be reused for private cellular applications. A company who wants to use one or several channels must be granted permission by the SAS (Spectrum Access System).

There are 3 levels of priority: The highest priority remains reserved for federal government, the second is the Priority Access Level (PAL) and is chargeable, while the lowest, General Authorized Access (GAA), is free of charge. PAL guarantees the bandwidth that is purchased through an auction. This process allows a very flexible and optimized usage of the spectrum. Some countries are examining the possibility of replicating this concept of shared spectrum.

4.3 Availability of spectrum for private cellular

In some countries, one or several licensed bands are reserved for private cellular. The table below lists the countries where spectrum is available or under study for private cellular – a list that will include more countries in upcoming years. In countries with no dedicated band for private cellular, there is generally an incumbent telco operator owning a licensed band. In some countries the spectrum allocated to the deployment of private networks is directly accessible by the enterprises, while in other countries, they are reserved for the local telecom operators. Also, some restrictions may take place, depending on the services deployed on the private network, data, voice, neutral hosting, etc.

Country	Local Regulator	Low Band (<1GHz)	Mid Band (1GHz - 6GHz)	High Band (24GHz - 40 GHz)
Europe				
UK	Ofcom (https://www.ofcom.org.uk/home)		✓	✓
France	Arcep (https://www.arcep.fr/)		✓	
Germany	Bundes Netz Agentur (https://www.bundesnetzagentur.de/)		✓	✓
Netherlands	Agentschap Telecom (https://www.agentschaptelecom.nl/)		✓	✓
Sweeden	PTS (https://www.pts.se/en/)		✓	✓
Finland	Traficom (https://www.traficom.fi/en/)		✓	✓
Belgium	BIPT (https://www.bipt.be/consumers)		✓	
Croatia	Hakom (https://www.hakom.hr/)		✓	
Norway	Nkom (https://www.nkom.no/english/frequency-licences)		✓	✓
Russia	GRFC (http://rfs-rf.ru/grfc/eng/main/)	✓		✓
Slovenia	AKOS (https://www.akos-rs.si/en/tv-radio-and-vod/explore/radio)		✓	
APAC				
Japan	MIC (https://www.tele.soumu.go.jp/e/index.htm)		✓	✓
Hong Kong S-A-R	OFCA (https://www.ofca.gov.hk/en/home/index.html)	✓		✓
Australia	ACMA (https://www.acma.gov.au/)			✓
Malaysia	MCMC (https://www.mcmc.gov.my/en/spectrum/spectrum-management)		✓	

Country	Local Regulator	Low Band (<1GHz)	Mid Band (1GHz - 6GHz)	High Band (24GHz - 40 GHz)
New Zealand	RSM (https://www.rsm.govt.nz/)		✓	
Singapore	CMS (https://cms.law/en/int/)			✓
Americas				
US	FCC (https://www.fcc.gov/)		✓	
Brazil	Anatel (https://www.gov.br/anatel/pt-br/)		✓	✓
Chile	Subtel (https://www.subtel.gob.cl/)		✓	

5 Use cases

Use cases for private mobility solutions are widespread, spanning all verticals undergoing digitalization. Identifying use cases is critical when deciding which private mobility solutions to adopt, whether based on Wi-Fi or Cellular (LTE, 5G). To do so, articulating the real value of the use cases to an enterprise is important, to avoid pushing technology for technology's sake.

Existing connectivity solutions, such as Wi-Fi, industrial ethernet, public cellular etc., may serve current needs based on the nature of relevant operating sites and technical needs of various use cases. Future upgrades, to Wi-Fi 6 & 6E for example, may be even better suited if an entity expects its connectivity requirements to increase for higher capacity and data rates, for example, supporting use cases such as AR/VR (Augmented Reality / Virtual Reality) for maintenance and repair.

A private 5G or LTE network may not be required now, but has potential for exploration as a means of innovation. As an industry player starts adopting more advanced, mission-critical, or business-critical use cases that demand higher bandwidth, increased reliability and lower latency, current networks such as Wi-Fi may be more of a hindrance than an enabler. When the existing network is unable to support all the new use cases, it is a good time to invest in private 5G or LTE network. This applies particularly to enterprises with requirements such as indoor-outdoor coverage, lower latency for mission-critical operations, higher security and reliability, regulatory compliance, or extra-fast implementation. In addition, given the large investment required for a private network, it may be more challenging to justify the business case if you cannot secure alignment within the organization for consolidating multiple applications onto one unified private network. This is where 5G or LTE outcompetes Wi-Fi/Wi-Fi 6, thanks to their capability of supporting all the old and new use cases in one 5G or LTE network.

The table below offers a snapshot view of use cases from various industries which have adopted all sorts of traditional technologies including Wi-Fi and are currently deploying private LTE and 5G as part of their digital transformation journey, to support more advanced use cases.

Vertical	Use Cases	Key Features	Preferred Technology
Healthcare	Security and surveillance, CCTV (Closed-circuit television) cameras at hospitals, to be monitored & stored at backend office	Low user density, low bandwidth	Wi-Fi
	1. Asset tracking performs real time monitoring of beds, rooms and equipment will provide better service and more comfortable environments for patients. 2. Building automation, hospital surgeons use control interfaces outside their operating rooms to create pressurized spaces. Empowers hospital staff to use mobile tablet devices and	Good coverage	Cellular LTE/5G

Vertical	Use Cases	Key Features	Preferred Technology
	management apps to view air, humidity, pressure and temperature data.		
	1. Video-driven in-hospital patient monitoring with AI (Artificial Intelligence) complements legacy sensors. 2. Video-driven emergency rescue in scenarios where every second counts, for real-time streaming from HD (High definition) cameras, enabling emergency responders to understand and visualize the scene prior to arrival, and provide ongoing information throughout the event.	High bandwidth, low latency, high security	Cellular 5G
Retail	1. Security and surveillance 2. Digital Marketing, sending promotions and ads when visitors connect to Wi-Fi hotspots	Low bandwidth, low user density	Wi-Fi
	1. Mobile point of sale, mobile cashier 2. Real-time flow analysis and visitor-specific content pushing	1.Good coverage 2.High bandwidth, low latency	Cellular LTE/5G
	1. AR (Augmented Reality) /VR (Virtual Reality) shopping from anywhere, lets consumers try before they buy during customer visits 2. Interactive fitting rooms, enabling customers to try on outfits before purchasing	Low latency, high bandwidth	Cellular 5G
Manufacturing -Unmanned factories, remote operation	1. Critical remote controlling of systems, at second level, through massive sensors, and edge computing -based quality inspection and assurance algorithms	Good coverage, high bandwidth, low latency, High security	Cellular LTE/5G
	2. Real-time-visualization-based supply chain optimization	Good coverage, high bandwidth, low latency, high security	
	3. Predictive quality improvement, derived from optimizing machine settings, and AR/VR driven remote assistance	Good coverage, high bandwidth, high security	

Vertical	Use Cases	Key Features	Preferred Technology
	4. Real time video analytics-based asset performance monitoring, combined with machine learning or AI, improve processes, asset use, supply chain and product design	Good coverage, high bandwidth, low latency, high security	Cellular 5G
Ports, Cargo Train stations	1. Basic connectivity, Ad-hoc Internet connectivity	Average bandwidth	Wi-Fi
	2. Real-time asset tracking	Good coverage, high security	Cellular LTE/5G
	3. Remote and automated operation of cargo loading/offloading through Unmanned Guided Vehicles (UGVs)	Good coverage, low latency, high bandwidth, high security	Cellular 5G
	4. AI/ high-quality-video driven supply chain management with end to end control	High bandwidth, low latency, high security	Cellular 5G
Stadiums and Events	1. Internet service	Basic bandwidth	Wi-Fi
	2. AR- and VR-based immersive content consumption for remote consumers	High user density, high bandwidth, low latency	Cellular 5G
	3. Immersive content production for media outlets, circumventing Outside broadcasting units (OBs)	High user density, high bandwidth, low latency	
Energy – unmanned production field, digital oilfield	1. Real-time personnel and critical asset location	Good coverage, high security	Cellular LTE/5G
	2. Real-time high-quality video surveillance of critical assets 3. Remote operation 4. Automating mission-critical applications (e.g emergency shutdown) 5. Intelligent and automated production management	Good coverage, Low Latency, high bandwidth, high security	Cellular 5G

Vertical	Use Cases	Key Features	Preferred Technology
Agriculture	1. Massive wireless sensor network for condition monitoring of crops and livestock 2. Automated irrigation, as well as use of pesticides and fertilizers to reduce consumption and wastage	Very high user density, good coverage	Cellular LTE/5G
Banks	1. Real-time high-quality video chat and consultations between bankers and consumers	high bandwidth, good coverage, high security	Cellular LTE/5G
	2. Flexible ATM (automated teller machine) placement	Good coverage, high security	
	3. Enhanced personalization experiences for consumer visits, powered by real-time information gathering for AI-based personalized banking services.	Good coverage, high bandwidth, high security	

6 Dell Technologies private mobility solutions

6.1 Dell Technologies Telco Strategy

The telecom industry is moving towards a software-defined infrastructure in both the RAN and core network. Rapid market changes require levels of flexibility which are currently impossible with today's architectures, long testing, and validation cycles.

Dell Technologies intends to become the largest provider of open, software-defined, industry-standard infrastructure. Dell Technologies is an active member of the O-RAN alliance, which plays a major role in accelerating the adoption of modern disaggregated RAN solutions.

Our strategy is based on delivering a modern ecosystem platform and partnering with service providers, system integrators, ISVs and IHVs, in order to capture the emerging opportunities of 5G, AI, AR/VR, IoT and edge computing. We will help service providers modernize their network, leverage innovation, and capture B2B revenue by focusing on three critical areas:

- Helping service providers rapidly roll out their 5G network, so they can enable ultra-low latency applications and connect billions of devices.
- Supporting service providers in building, deploying, and monetizing Multi-Access Edge Computing (MEC), so they can capture enterprise edge workloads.
- Assisting service providers in building and deploying a variety of over-the-top, as-a-service offerings, including analytics, data management, network slices, messaging services and a broad array of Industry 4.0 applications, enabling them to serve a variety of verticals.

Over the past decade, Dell Technologies has helped enterprises digitally transform their businesses. We have modernized information technology (IT) services through a robust hybrid cloud approach, established agile-based processes and leveraged an application programming interface (API) driven infrastructure foundation. We will extend those principles into building and managing a modern telecom infrastructure. In this regard, we have invested in creating an enhanced services portfolio, enabling Dell Technologies to design, integrate, deploy, operate and support telecom networks, providing a single interface to service providers.

With Dell expert service delivery, we allow enterprises to securely adopt edge services, and to achieve business outcomes through tailored adoption of validated solutions. Being the Single point of contact for streamlined access to the engagement, we:

- Architect multivendor solutions
- Remove the worry from your operations
- Accelerate solution implementation and adoption
- Maximize uptime and reduce risk

Finally, with a well-managed and modern cloud native platform in place, the business can focus its development efforts on delivering differentiated services. Dell Technologies has a dedicated co-creation services team whose sole job is to partner with Communication or Cloud Service Providers (CSPs), to design, build, market and sell Telecom software as a service (SaaS), MEC and Private Mobility services to the enterprise and accelerate joint go-to-market.

6.2 Private Mobility Solutions

Dell Technologies' role in defining the functions and services that build 5G will significantly increase in the future, as we have been instrumental for years in driving the evolution of various workload execution environments. Accordingly, many Dell Technologies teams have been working to analyze the potential of private mobility, creating market-relevant products and solutions.

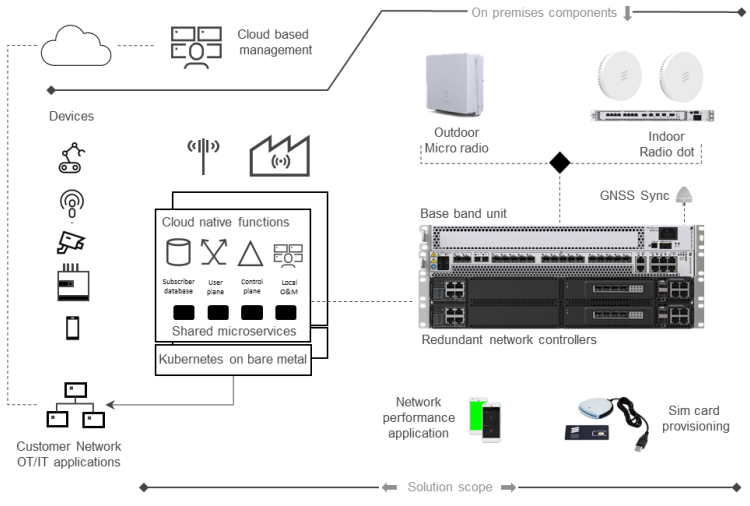
We have been developing validated designs and solutions in this domain since 2020. The following solutions have already been launched:

- Ericsson Private 5G, with Dell Technologies
- Dell Private Wireless with Airspan and Expeto
- Private Mobility with JMA Wireless and Dell Technologies
- Dell Small business solution with Athonet

Referring to the models of architecture described in section "Cellular technology for private mobility" page 12, Ericsson Private 5G is a "Split model 7 with local core network" while Service Edge Vx 1.0 is an "Integrated access point with dedicated core network." Private Mobility with JMA Wireless is a "Disaggregated RAN with shared or dedicated core network".

Complementing these solutions, we partner with Telcos as well. Dish Spectrum (for US only) Dell Technologies is a reseller (for US only) of the CBRS PAL Dish spectrum. This enables enterprises to design their own private cellular solution, independently of any public mobile network, with a spectrum reserved and dedicated for a given enterprise. Dish spectrum can be associated and bundled with all CBRS Private Mobility solutions. AT&T MEC + APEX (for US only), powered by Dell Technologies, enables the enterprise to keep selected cellular data within the local area network.

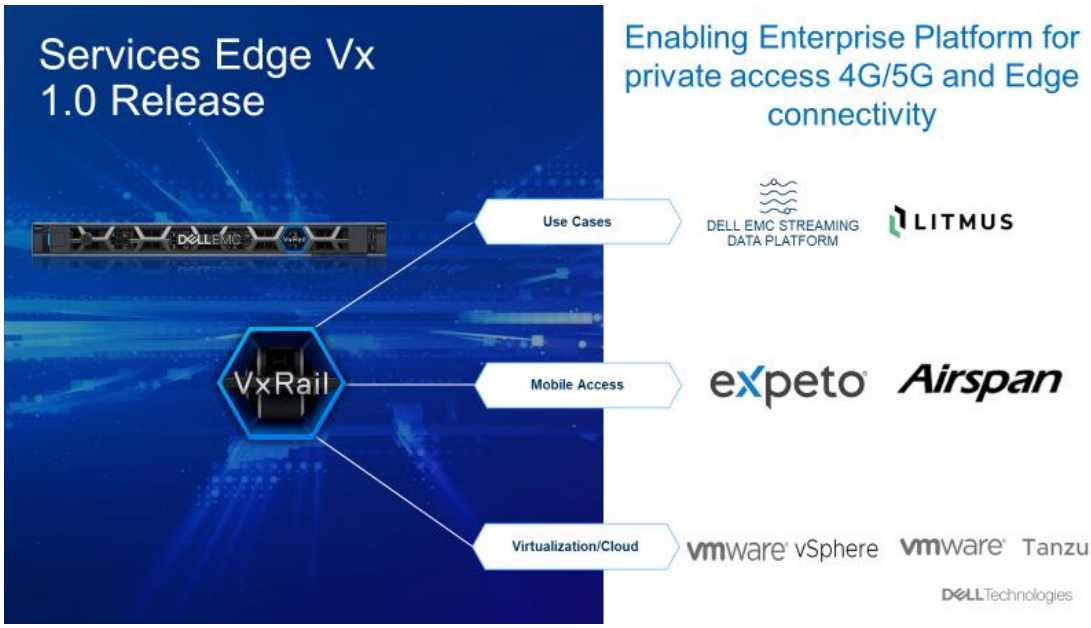
6.2.1 Ericsson Private 5G, with Dell Technologies



Ericsson Private 5G establishes a 4G or 5G private cellular network on the end customer's premises. The network hardware, together with the software, have all the functionality required for a complete solution. Ericsson Private 5G allows isolated deployment, which is independent of any public mobile network. Isolated deployments are very reliable, as there is no risk of network outage with the centralized component. Ericsson Private 5G is a product designed by Ericsson with Dell Technologies servers. Dell Technologies is also a reseller of Ericsson Private 5G for the United States market on the CBRS band.

6.2.2 Dell Private Wireless with Airspan and Expeto

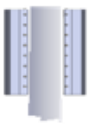
Dell Private Wireless with Airspan and Expeto is an enterprise-ready platform, allowing deployment of private 4G/5G. The solution is based on VxRail allowing easy edge deployment and dynamic scale for throughput expansion. Version 1.0 comprises Airspan radio access point and Expeto core network, with roaming from the private to public network.



6.2.3 Private mobility with JMA Wireless and Dell Technologies

Private mobility with JMA Wireless is a private LTE/4G / 5G RAN solution suitable for larger private cellular deployments or for telco VRAN, in single or multi-tenancy scenarios.

JMA / Dell Private Mobility Building Blocks

XRAN	CellHub (Radio)	Antennas
		
LTE/4G & 5G RAN	Designed for outdoor & indoor	indoor & outdoor versions
Built using 100% SW (no HW accelerators)	Can enable all CBRS 150MHz	Multiple beam options for max coverage
Uses standard Dell server technology	Single & multi-brand variants	Can enable all CBRS 150MHz
Supports 10,000s of connected users/homes	Use different antennas for coverage	Matched with JMA Jumpers for best RF

The JMA Wireless XRAN® software platform delivers a virtualized RAN running on advanced Dell EMC PowerEdge servers. With its digital interface to RF distribution platforms, XRAN eliminates the need for

intermediary radio equipment. The software-based architecture offers scalability to ensure cellular service coverage across a range of venues.

The solution is compatible with any core network, centralized and on premises, dedicated or shared. Using the same infrastructure, XRAN can also support carrier networks, so it can be used to simultaneously provide a full private mobility solution and an extension to public mobile network. The largest configuration running on one PowerEdge R740 covers areas over one million square feet and over 15,000 connected users.

6.2.4 Dell Private Wireless with Athonet

Athonet Private Mobility core solution is a standard compliant 4G/5G stand-alone private mobility core that, when paired with a Communication Service Providers (CSP) frequency spectrum and RAN solution, forms a complete end-to-end private mobility solution. It can be used with radio solutions from Tier 1 vendors or radios from affordable or other innovative radio vendors. It fills a gap where CSPs face the challenge of scaling down their core to meet small business needs. Its core is modular and flexible and can be deployed in the CSP's data center or on the end-customer premises.

Its core solution operates and has been tested on Dell Technologies Virtual Edge Platform (VEP) and PowerEdge server families.

7 Conclusion

"5G is the most transformative change in our generation," Michael Dell told an online audience at an Incompas Show. "It's not about talking faster on the phone; it's about connecting things and making an intelligent world with enormous amounts of data."

Spectrum availability is key in this evolution. The more available spectrum, the more use cases there will be. Some countries already dedicate some spectrums for private cellular solution. In this context, private mobility is an accelerator, as it allows service provisioning even before availability of the public network. Private mobility also enables tailoring an optimized wireless solution to match the target application requirements. Governments and politics understand the benefits that full 5G deployment can bring to industries and public services. They recommend accelerating the provision of dedicating spectrum for the deployment of private wireless cellular networks.

Investing in an open, flexible private mobility solution is a future-proof decision. Coexistence of private cellular technology with Wi-Fi will remain and will fade out to the benefit of 5G, which will become the main consolidated wireless media. This trend toward a single technology will run simultaneously with the growth of 5G enabled devices. The number of Dell laptops equipped with a 4G/5G modem is growing as they become increasingly popular.

In the industry domain, industry 4.0, digitalization with real time features offers new capabilities, allowing optimization of the production processes is a big driver for 5G.

Critical communications systems which are nearing end-of-life or are limited in features, but are required to support more video, can be consolidated into private 5G networks, providing workforces with an enhanced, more reliable service at a low additional cost.

As the market and competitive environment evolve, so does Dell’s strategy in addressing these changes. Therefore, we will be creating new solutions with our partners to match the business requirements of our customers.

A Glossary

2/5/4/5G: 2nd, 3rd, 4th and 5th generation of cellular network

3GPP: 3rd Generation Partnership Project. partnership project bringing together national Standards Development Organizations (SDOs) from around the globe initially to develop technical specifications for the 3rd generation of mobile, cellular telecommunications. (https://www.etsi.org/committee/3gpp)

AGV: Automated Guided Vehicle

APN: Access Point Names. This is a parameter sets in the smartphone to indicate the core network to connect to.

AI : Artificial Intelligence

AR: Augmented reality

ATM: Automated Teller Machine

CAGR: Compound Annual Growth Rate

CBRS: Citizens Broadband Radio Service

CoSP: Communication Service Providers

CPRI: Common Public Radio Interface. This is the interface between the eNode B, the cellulare base station, and the RRU (radio remote unit). This interface is evolving to eCPRI. eCPRI is Ethernet based.

DAS: Distributed Antenna System

DU/CU: Distributed Unit, Centralized unit. Functional split of base station allowing desegregation and a more efficient deployment.

eMBB: Enhanced Mobile Broadband

EPC: Evolved Packet Core. LTE packet core

GAL: In the context of US CBRS, General Authorized Access

IIoT : Industrial Internet of Things

IoT : Internet of Things

LTE: Long Term Evolution. In the context of this paper, can be considered the same as 4G.

MAC: medium access control

MEC: Multi Access Edge Computing (https://www.etsi.org/technologies/multi-access-edge-computing)

MIMO: Multiple-Input Multiple-Output

mMTC : Massive Machine Type Communications

mmWave: Millimeter wave

MNO: Mobile Network Operator

NEP: Network Equipment Provider

NFVI: Network Functions Virtualization Infrastructure. NFV (Network Functions Virtualization) is a network architecture concept that uses the technologies of IT virtualization to virtualize entire classes of network node functions.

OB: Outside Broadcasting units

OEE: Overall Equipment Effectiveness

O-RAN: Open RAN, (https://www.o-ran.org/)

OFDMA: Orthogonal Frequency Division Multiple Access. Digital modulation scheme

PAL: In the context of US CBRS, Priority Access License

PoE: Power over Ethernet

PMR: Private Mobile Radio. Radio solution for mission critical communication. E.g. Push to Talk, walkie talkie

RAN: Radio Access Network

RF Radio Frequency

RRU: Remote radio Unit, also called Remote Radio Head. Remote RF part of the base station with Analog to digital convertor and vice versa.

TIP: Telecom Infrastructure Project (https://telecominfraproject.com/)

RTG: Rubber Tyred Gantry cranes / transtainers

SAS: In the context of US CBRS, Spectrum Access System

SI: System Integrator

UE: User Equipment. Device connecting to a cellular network

URLLC: Ultra-reliable and low latency Communications

VNF: Virtual Network Function. One or more virtual machines or containers running different software and processes instead of a physical appliance.

VR: Virtual reality

Wi-Fi: Wireless Fidelity

WPA: Wi-Fi Protected Access

B References

[1]: https://www.smartcitiesworld.net/news/news/global-smart-hospitals-market-to-surpass-103bn-by-2027-5830

[2]: https://www.abiresearch.com/press/private-cellular-networks-generate-over-us64-billion-equipment-revenues-2030/)