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WHITE PAPER

Private LTE Networks

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PRIVATE LTE NETWORKS: A NEW ENTERPRISE ENABLER

Today's progressive enterprises, in virtually all industrial sectors, are pursuing software-driven operating models using analytics, automation and machine communications to improve productivity. These processes are underpinned by new-wave wireless networking solutions that offer scalable control and extreme reliability in very dense, machine-oriented environments. From Industry 4.0 factory-floor automation, to control of autonomous trucks in open cast mines, to electricity distribution grids, to logistics and warehousing, to venue services, and many more use cases, wireless networks are essential to real-time process automation and can unleash phenomenal productivity benefits.

This white paper will discuss why LTE is now a highly attractive technology for private wireless networks across a wide range of enterprise verticals. It addresses the performance attributes of the LTE radio and system architecture and how the global LTE ecosystem makes it possible for private organizations to deploy and operate high-performance networks without dependency on licensed mobile operators. It argues that LTE is now the preferred wireless platform for enterprises with production-critical automation and mobility needs.

Organizations that control their own networking environment can more easily modify the technology and optimize it for their own purposes – for example, for fast recovery from failure, extended range coverage, or specific prioritization and reliability schemes. The availability of open access spectrum, notably the shared access 3.5 GHz band in the U.S. and the 5 GHz unlicensed band globally, in combination with built-for-purpose equipment, now make it possible for almost any organization to deploy and operate a private LTE network.

However, the ongoing contribution of licensed mobile operators to private wireless networks should not be overlooked. There remain many opportunities to deploy private networks in licensed spectrum, to offer private LTE as a managed service, or to extend private local-area networks across the wide-area public network to create enterprise-specific VPNs.

Who Needs Private Wireless Networks?

Organizations that can generate the greatest benefit from private LTE have use cases that are not readily supported on public networks. Once the use case is established, and performance requirements are known, the primary reasons to deploy a private network are:

- **Coverage:** Organizations can guarantee coverage at their facility or location by installing their own network. This is most necessary where public networks do not exist or are not robust (in remote areas, e.g., mines or agricultural lands), but can often also apply to indoor and campus locations (e.g., factories, warehouses, power plants, etc.)
- **Capacity:** Without contention with other network users, enterprises can make full and exclusive use of available capacity. They can configure uplink and downlink, set usage policy and engineer the RAN according to their specific capacity demands – for example, to support HD video streaming and analysis for, say, a security application.
- **Control:** Private operators can determine which users connect, how resources are utilized and how traffic is prioritized. If needed, parameters in the LTE radio can be customized to optimize reliability and latency in challenging physical environments (e.g., warehouse or oil/gas facility with lots of metal). This is unthinkable on the public network. Companies can also control their own **security** to ensure that sensitive information doesn't leave the premises – essential to many types of high-tech businesses.

In general, private LTE networks are designed with machine communications as the primary user in mind. Nevertheless, one of the strengths of LTE is a multiservice capability that supports, for example, low-bit-rate Internet of Things (IoT), critical control signaling (e.g., for programmable logic controllers) and human smartphone users on a common infrastructure. Examples of use cases where reliability and performance are critical are shown in **Figure 1**.

Figure 1: Example Use Cases for Private 4G Networks

Use Case Type	Description
Automation & Industry 4.0	• Factory-floor robotics – e.g., wireless robots introduce much greater flexibility to reconfigure production lines • Logistics and warehousing – e.g., pick-and-pack machines; often considered under the banner of "Industry 4.0" • Typically focused very dense deployments with low latency requirements
Mission-Critical Services	• To monitor and control critical infrastructure – e.g., electricity distribution grids, power plants, etc. • Public safety agencies often need to create closed user group *ad hoc* networks at the scene of emergency • Government & military agencies want dedicated, highly available networks at their facilities – e.g., the Finnish government has pioneered this model
Primary Industries	• Locations often not covered by public wireless infrastructure • Very diverse sector from mining to agriculture, making increasing use of automated machinery • Often requires hardened equipment with good link budget for low-density long-range coverage
Venue Services	• Public venues such as airports, stadiums, hospitals, ports • These venues have many users (internal, contractor, public), some of which have requirements for fast, highly secure access • Private network can be "sliced" (configured) for different user groups

Source: Heavy Reading

Advantages of LTE for Private Wireless Networks

Most private wireless networks today use WiFi. This is fast and easy to deploy, there is a competitive market for equipment, and a feature-rich roadmap. In many cases, WiFi will remain a good solution. Private LTE is based on technologies developed for wide-area mobility and scaled down to be deployable by private organizations. This background gives LTE some advantages over WiFi, particularly as relates to radio performance and mobility, that can help meet more demanding use cases. These advantages include:

- **Range/Link Budget:** LTE systems are generally developed and deployed using RF equipment with higher specification, which extends the link budget considerably. As LTE is a cellular technology, it has been designed to operate well under fading channel conditions, providing good cell edge performance. As a very approximate rule of thumb, one LTE small cell will cover about the same area as two to three WiFi access points at more or less equivalent power output. If CBRS 3.5 GHz spectrum and Category-B small cells are used, range can be significantly greater still.
- **Spectral Efficiency/Capacity:** Many of the concepts that improve range and reliability also increase spectral efficiency. LTE is more spectrally efficient than WiFi (more

than double, according to some analyses) because of higher efficiencies at both link and MAC level from concepts such as hybrid automatic repeat request (ARQ) with channel state information, more granular modulation and coding schemes and more adaptable schedulers (compared to WiFi). LTE is designed for mobility and outdoor operation, and with concepts such as long cyclic prefix, it can handle larger delay spreads, which also contributes to overall spectral efficiency.

- **Configurable QoS:** The LTE QoS model allows for multiple layers of prioritization. It is well standardized and can be adapted to the needs of the application – for example, priority bearers can be engineered to provide low and predictable latencies, while default bearers can be configured for best-effort throughput. This is why LTE is proposed for mission-critical lifeline and production-critical automation use cases. There are many opportunities to take advantage of QoS in private networks.
- **Mobility:** The undoubted strength of LTE. This includes intra-network mobility using standard cellular mechanisms and inter-network mobility – for example, "roaming" from private LTE to the public RAN. Where needed, LTE also supports high-speed mobility, which can be useful for vehicles and robots, for example.
- **Ecosystem & Interoperability:** The 3GPP ecosystem is well developed with very good interoperability testing and certification processes, allowing organizations to deploy networks using a mix of suppliers and devices. Over-the-air interoperability applies especially to devices, but organizations can also expect RAN and core products to interoperate, and for compatibility to be maintained over multiple upgrade cycles.
- **High to Low Rate Scaling:** LTE supports a wide range of devices and applications, from gigabit services such as 4K/augmented reality to NB-IoT devices for low-power, low-data-rate services. These services can be supported on the same network. Many organizations have a mix of machine-type and human employees as users.
- **Spectrum Options:** WiFi is only deployable in unlicensed spectrum, whereas private LTE systems can soon also be deployed in CBRS 3.5 GHz shared spectrum in the U.S., as well as in unlicensed spectrum using MulteFire. This gives private organizations the right to use multiple 10 MHz or 20 MHz channels on an exclusive primary or secondary basis. Private networks can also be deployed in licensed spectrum with the agreement of the mobile network operator or regulator.
- **Security:** LTE-based private networks benefit from proven security technology deployed in cellular networks worldwide. Classic SIM-based security can be used, as well as emerging non-SIM options. There is significant deployment flexibility, allowing for local credential management or centralized/remote credential management using roaming-based solutions.
- **Roadmap to 5G:** LTE is feature-rich with an ongoing roadmap and is important to the development and evolution of 5G, in terms of both features/technology and business/use case. 5G itself has many advanced capabilities that are well suited to private networks, such as ultra-low latency (1 ms on the air link), mission-critical functionality, low-power operation, flow-based QoS and native support for shared spectrum. Industry expectations are that LTE-Advanced and 5G will coexist for many years.

The above capabilities are generic advantages of LTE that also apply in large-scale public networks. When deployed as private networks, organizations can take advantage of the full LTE feature set to configure and optimize the network for their specific use cases. For example, in ultra-reliable automation scenarios, the operator may implement fast recovery from cell failure, which is an LTE feature not typically used in public networks.

PRIVATE LTE USE CASES & DEPLOYMENT EXAMPLES

Private LTE can support many use cases and deployments across different vertical sectors. This includes industrial facilities, primary industries, utilities, airports, venues, general enterprise, etc., and diverse services from low-bit-rate IoT through high-speed broadband, on a common network.

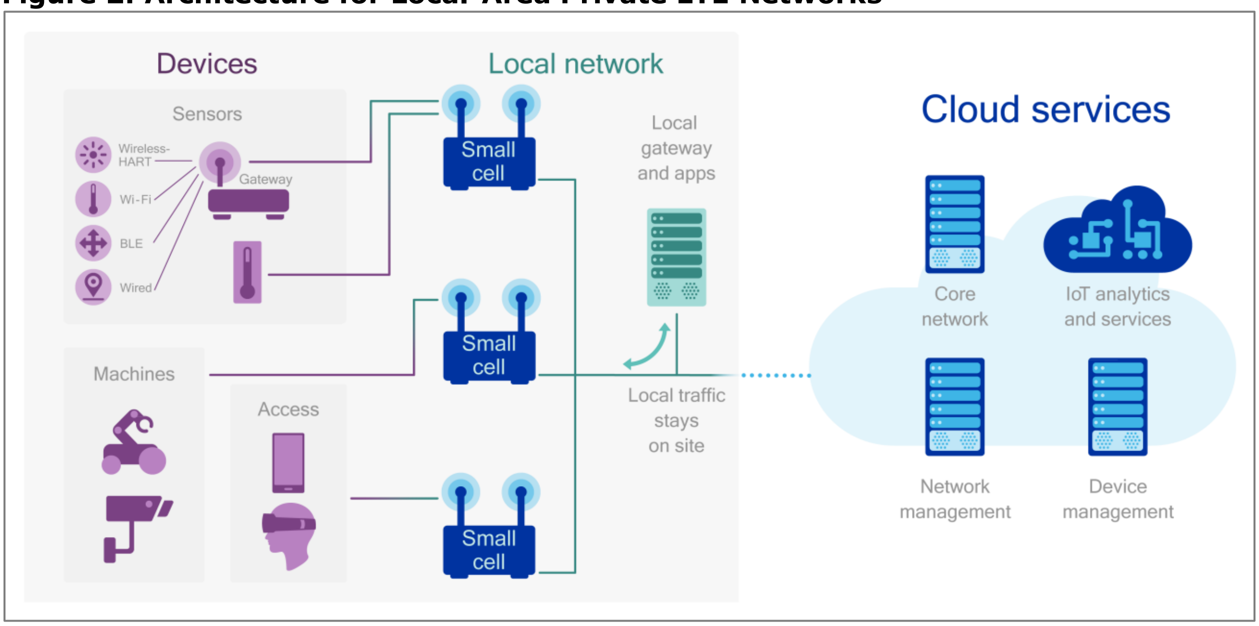
Ease of Deployment

To take advantage of LTE technology, enterprises need equipment that is cost-effective, fast to deploy and simple to operate and maintain. WiFi provides the benchmark with widely available equipment and a large, sophisticated professional services market. LTE is now close to replicating this. Many vendors offer solutions for private LTE networks. The major RAN vendors – Nokia, Huawei and Ericsson – have integrated solutions, and many smaller companies – e.g., SpiderCloud, Airspan, Athonet, Ruckus, etc. – also provide competitive product portfolios and associated services.

There is also an emerging, powerful base of industrial system integrators that provide industry-specific systems and support. Integrators add considerable value to private networks because the use cases often require special domain knowledge. In this scenario, the wireless network is but one part – an enabler – of a wider enterprise process. Note also, however, that private LTE will help system integrators develop new lines of business as they address use cases not easily supported by other technologies.

A baseline architecture for private LTE is shown in **Figure 2**. It includes radio access, devices and core network.

Figure 2: Architecture for Local-Area Private LTE Networks



Source: Qualcomm

The core-network-in-a-box is typically virtualized and is deployed on premises to ensure that traffic stays local to the site. Deploying the core on premises is important for performance (minimal delay), for privacy/security (sensitive data does not leave the site), and for service continuity (not at risk of disruption if a WAN link fails). Additional application logic can be deployed on-site on a local server, or off-site in the cloud, depending on the deployment preference.

MulteFire technology is designed for standalone LTE operation, such as shown above, and is ideal for private networks. The first MulteFire specifications were released in 2017 and cover system architecture and radio performance. The initial focus is on 5 GHz, with the intent to provide "LTE performance with WiFi-like simplicity." In the U.S., 3.5 GHz CBRS spectrum will also be available and is similarly an excellent option for self-contained private networks.

Specialist system integrators can use this baseline architecture, using MulteFire at 5 GHz and LTE-TDD in CBRS spectrum, to support a wide variety of vertical applications. For example, many industries use the Supervisory Control and Data Acquisition (SCADA) system to connect machines and controllers and can benefit from wireless networks optimized to these requirements.

Private LTE Network Case Studies

This section presents case studies of companies that have deployed private LTE networks that are critical to their day-to-day business operations. These are pioneer deployments that provide useful guidance for system developers on features and capabilities required, and for enterprises considering deployment of their own networks.

Rio Tinto

Rio Tinto

Country: Australia
Industry: Mining

Mining conglomerate Rio Tinto was one of the first large enterprises to use a private LTE network to support commercial operations at scale. The company developed a solution to cover 15 mines and other related facilities, including transport hubs, railways, ports, offices, etc., in Australia.

The system was designed to support a variety of safety and production critical systems, including in-pit CCTV monitoring, intelligent earthmoving, telemetry, high-precision GPS and various other monitoring services. It was developed with a view to preparing the company for the industry-wide drive toward autonomous mining platforms, including autonomous drilling systems and autonomous haulage (huge trucks).

The solution uses 1800 MHz spectrum under special arrangement from the local regulator. At the time (2013), unlicensed LTE was not available and, in this use case, extended range was very useful. In the initial deployment, Rio Tinto was able to replace 30 WiFi access points with just four LTE base stations (it has since added more LTE). The network includes an LTE core and related applications, for example to support VoLTE, push-to-talk and unified communications. The network is managed from a single NOC. According to Rio Tinto, the key benefits of LTE technology for large production-critical private mobile networks are:

- Improved reliability and resiliency for production and safety-critical services
    - The LTE network operates on a licensed frequency – no interference
    - Complete wireless coverage of all operational areas

- Ability to prioritize traffic (QoS)
    - Safety and production critical traffic given priority over corporate traffic
- Consolidated network platform to support all in-pit systems concurrently
    - The network can concurrently support all current in-pit systems, which are typically supported by multiple wireless networks/technologies
- Reduced infrastructure requirement
    - Four LTE communications trailers compared to 30+ WiFi communications trailers
    - All LTE infrastructure located outside of blast zones – no need to move trailers

Ocado Technology

Country: U.K.
Industry: Online Groceries; Warehouse Logistics

U.K.-based Ocado claims to be the largest online-only grocery retailer. It has developed its own e-commerce fulfillment and logistics cloud platform, called OSP. It uses the platform in its warehouses to pick and pack customer orders using robots and control software. It now also markets OSP to other retailers and to the logistics and warehouse sectors.

To connect the pick-and-pack machines (robots), Ocado needed a wireless solution. Due to its requirement for mobility, connection density, reliability, and low latency, it decided to use LTE in the unlicensed 5 GHz band. This was the first deployment anywhere in the world to use unlicensed 4G for warehouse automation. The solution was designed-for-purpose by Cambridge Consultants and uses a redesigned MAC and resource scheduler on top of the LTE physical layer to meet strict performance requirements.

The result is what the company calls a breakthrough in radio design to serve "the most densely packed mobile network in the world." The system enables Ocado to control 1,000 fast-moving robots from a single base station, communicating with them 10 times a second within an area the size of an Olympic swimming pool. It can scale to handle 20 times the number of movements, and to support multiple base stations.

Ocado has plans to deploy the solution in even larger warehouses and to develop the solution further for use in other industries (e.g., construction). From an R&D perspective, it plans to analyze how alternate MAC layers could help improve warehouse efficiency, and to design a custom roaming algorithm optimized for this specific application.

Enel Group

Country: Italy
Industry: Power Generation & Distribution

Enel is a major power generator and electricity distributor in Italy. In this project the company worked with the operator H3G, part of the Three Group, and startup vendor Athonet to create a private LTE network solution that a) covered a major power plant and b) integrated with virtual private network on the wide-area RAN.

The power station in Brindisi (Italy) is one of Europe's largest. The company uses LTE-TDD to cover the entire power station, including indoor/outdoor area, underground rooms and a coal storage dome construction site. The objective was to support services such as predictive diagnostics, workforce management, machine automation and safety of all plant operations.

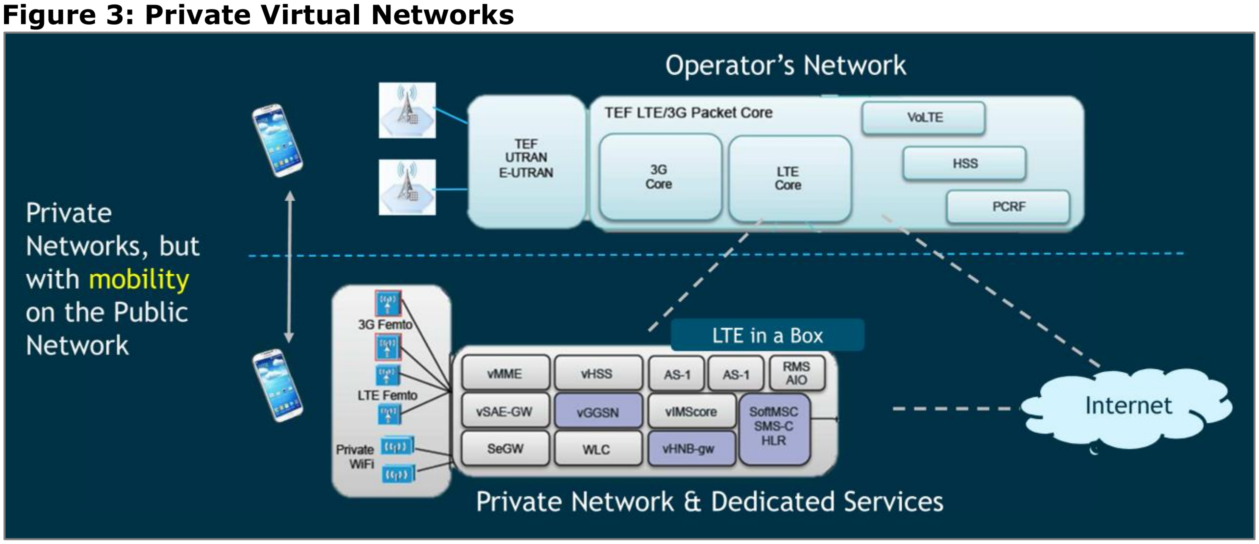
The network uses a dedicated, on-premises core network to offer integrated communications between personnel, sensors, machines and applications. Services include voice-over-LTE services, very-low-latency control systems, monitoring of moving vehicles, live audio-video communication among plant personnel, sending and receiving alarms from fixed or mobile body-worn sensors, and service continuity during critical emergency situations.

Integration With Wide-Area LTE

Private networks are generally designed for local-area coverage. Many enterprises, however, have multiple sites, and have equipment and users that move between sites, or employees that are "on the road" visiting customers, etc. They therefore also have a requirement for virtual private networks on the public operator network. Virtualization and "slicing" mechanisms such as Dedicated Core Networks (DECOR) make this more attractive than in the past, and this is now a market segment that Heavy Reading expects to grow rapidly. For technology-led companies in many sectors (e.g., pharmaceuticals, aerospace manufacturing, etc.) it is of critical importance that employees be able to access sensitive information (e.g., designs, customer data, etc.) securely.

Using virtualization and DECOR, there is potential to map local private networks and virtual networks running in the mobile operator's public network to create a single unified private 4G network for the enterprise customer. **Figure 3** shows one example service being developed by Telefónica to deliver local-area private LTE and wide-area LTE to a major automotive company with many factories, distribution points and offices across Europe.

Figure 3: Private Virtual Networks



Source: Telefónica

Telefónica's private-LTE-in-a-box solution is deployed on premises at the factory – as in the examples above – while mobility is provided by the operator's public networks and roaming partners worldwide. This model is enabled by the transition to cloud-based mobile core networks.

PRIVATE LTE IN 3.5 GHZ CBRS & 5 GHZ UNLICENSED

Spectrum is important for any wireless network deployment. Frequency, channel bandwidth, power limits, etc., are critical determinants of network design. Similarly, harmonized spectrum, backed by detailed standards, such as 3GPP specifications, is important to ensure over-the-air interoperability between devices and networks, and to ecosystem scale.

Private LTE networks can be built using licensed spectrum, with the permission of the mobile operator or regulator. This is often appropriate in remote areas where the spectrum would otherwise go unused, or at specific locations such as power plants, where public network coverage is insufficiently robust. This model can work well, particularly for large customers with "special case" requirements; however, it also often meets resistance from the license holder and may involve spectrum leasing costs or other compensation. Not just anyone can deploy LTE in licensed bands.

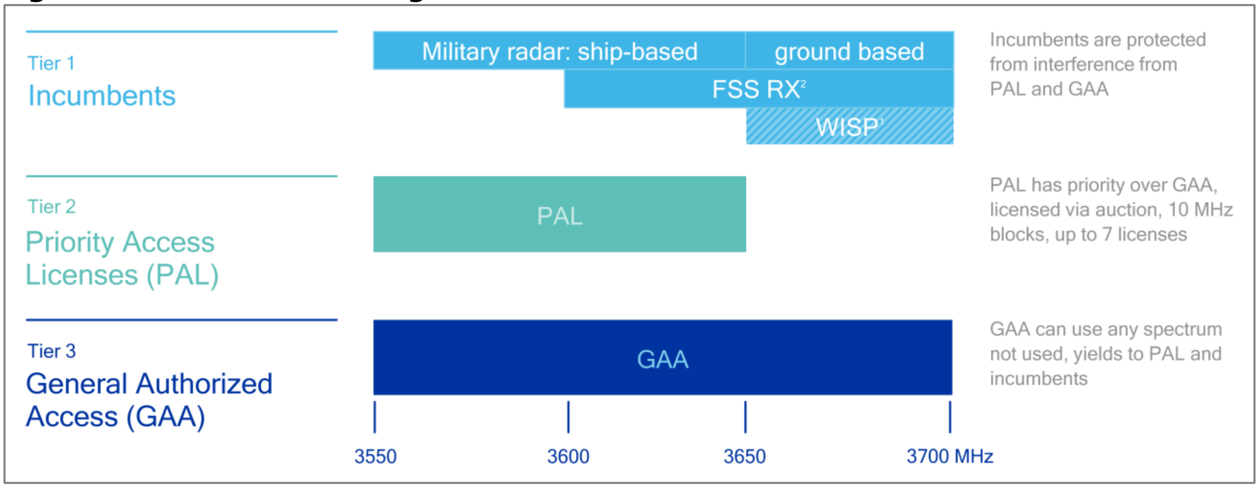
New LTE systems that operate in shared and unlicensed spectrum enable any organization to deploy networks without dependencies on mobile operators. Because the organization controls both end of the link (base station and device) there is an opportunity for rapid innovation, customization and optimization of private network solutions.

The two key bands that have emerged for private LTE are the 3.5 GHz shared access band, known as Citizens Broadband Radio Service (CBRS), soon to be available in the U.S.; and the global unlicensed 5 GHz band. These are both non-licensed spectrum and are well suited to private LTE networks. In the short term, the focus for the CBRS band is on commercializing standard LTE-TDD technology. In the 5 GHz band, MulteFire and License Assisted Access technology introduce listen-before-talk mechanisms to LTE to enable it to coexist with WiFi.

Citizens Broadband Radio Service at 3.5 GHz

CBRS is one of the most exciting developments in private LTE networks. The U.S. government is making 150 MHz of spectrum available on a lightly-licensed, shared-access basis using a three-tiered model, as shown in **Figure 4**. This protects Tier 1 incumbent users from interference and allows for Tier 2 priority access and Tier 3 general access users.

Figure 4: Three-Tier Sharing Model for CBRS



Source: Qualcomm

The appeal of this model is that any organization, from large mobile network operators to small enterprises, can get access to spectrum and deploy an LTE network, and in so doing, can gain access to the advantages of LTE technology and ecosystem quickly and affordably.

Where the enterprise is granted a Tier 2 "priority access license," they have priority over GAA (Tier 3) users. This is particularly appealing to production-critical networks of the type discussed in this paper. Below that, a general access tier is available, on a dynamically shared basis, to any user with appropriate, certified equipment.

There are many trials underway in the CBRS bands for many different types of service, from fixed wireless residential access, to general enterprise, to specialized industrial applications. The first live deployments are expected toward the end of 2017 and into 2018.

The CBRS Alliance is an industry-wide initiative that aims to evangelize and develop CBRS technology. One of its goals is to establish an effective product certification program for LTE equipment in the U.S. 3.5 GHz band to ensure multi-vendor interoperability. One big advantage of this frequency is that commercial equipment, devices and chipsets are already available, and can be made CBRS-compatible relatively quickly. Japanese carriers Docomo and SoftBank, for example, have deployed 3.5 GHz in their urban macro networks with commercial smartphones.

MulteFire at 5 GHz

MulteFire is a version of LTE being developed specifically for unlicensed and shared spectrum, initially in the 5 GHz band, which is available globally. There is 500 MHz of available spectrum in the U.S., and European regulators are in the process of expanding their allocations to a similar level. Over time, MulteFire will also be specified for use in CBRS bands.

The MulteFire Alliance has been set up to develop specifications and drive certification of LTE in unlicensed spectrum. Because unlicensed operation is already specified by the 3GPP in the form of License Assisted Access (LTE-LAA), which uses listen-before-talk to coexist with WiFi and other users of the band, there isn't an enormous amount of work to be done on the underlying technology. MulteFire is LTE and benefits from the same ecosystem and performance advantages.

The essential difference is the development of a standalone architecture that allows non-mobile network operators to deploy networks without a licensed cellular anchor (as is required for LTE-LAA). The architecture includes a core network to handle session management, mobility, authentication, policy, etc. Crucially, it makes provision for SIM-free authentication using certificates. This is particularly important for IoT modules, but extends to any non-carrier device, such as tablets, vehicles, etc.

The first MulteFire specifications were completed in January 2017, and the Alliance aims to have a certification program in place by the end of 2017, to allow for trials in early 2018. Networks deployed for IoT services, where the network owner controls the entire end-to-end environment, are likely to be the first to go live commercially, in part because compatible devices will be available sooner.

MulteFire targets cable companies, wireline operators, wireless ISPs, general enterprise, specialist verticals, and mobile operators themselves.

ABOUT QUALCOMM

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At Mobile World Congress in February 2017, Qualcomm unveiled the first private LTE-based trial network customized for industrial IoT. The demonstration utilized LTE-TDD in the U.S. 3.5 GHz shared spectrum band, known as Citizens Broadband Radio Service (CBRS).