LTE for railways: one network for all communication needs

White Paper

How railway operators of all types can benefit from the most widely adopted mobile broadband technology of all time
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Executive Summary: LTE is ready for the railway industry

Long Term Evolution (LTE) wireless communications has been picked by the leading professional mobile radio standardization bodies as the technology of choice to support mission-critical voice and broadband services in the future. The ability of LTE to support advanced broadband applications is set to help public safety and railway organizations to operate more efficiently.

Railway operators of all types typically run a mix of narrowband and broadband communications technologies to support their safety-critical, safety-related and passenger services. Migrating to an LTE-based network has the potential to consolidate all their communications needs onto one single, highly flexible network. Furthermore, the high throughput low latency performance and stringent Quality of Service (QoS) management of LTE will enable the deployment of innovative services that will help the railways to deliver better services for passengers and reduce operational costs.

Depending on geography, some key issues still need to be resolved, for example the availability and suitability of spectrum and the delay facing European mainline railway operators as they await standardization of a technology to replace GSM-R. Yet, railway operators cannot afford to delay their investments because migrating to fully LTE-based operations will not happen overnight. The sooner the capabilities of LTE are brought into their operations, the sooner they will reap the rewards in terms of lower operational costs and new revenue opportunities from passenger services.

As a well-established technology that is supported by a solid and growing ecosystem, LTE has a long future ahead of it. Even when the much-vaunted 5G technologies start to be deployed, LTE will provide a long-term foundation for 5G networks.

Why railway communications must be transformed

The railway industry, including mainline, freight, metro and industrial rail, has been served well for many years by a range of digital radio access technologies that include TETRA, Digital Mobile Radio (DMR), GSM-R, WiMAX and Wi-Fi.

DMR, TETRA and GSM-R are narrowband technologies that provide reliable support for voice services but which have limited capabilities (mainly throughput) to support broadband data traffic. While GSM-R is widely used in many parts of the world for mainline operators, urban rail mainly relies on Wi-Fi, a very widely used enterprise Wireless LAN technology. Although Wi-Fi is easy to deploy, uses unlicensed spectrum and is a relatively low cost way to support some operational applications, it is not ideally suited for carrier-grade reliability, mobility or safety-critical data such as automatic train control (ETCS/CBTC).

The two dominant technologies, GSM-R and TETRA, are likely to be used for a number of years, but all the current technologies will ultimately be superseded by all-IP networks.

With the wider telecommunications sector having moved a long way towards fully IP-based mobile broadband communications, it is inevitable and desirable for the railway industry to adopt such technologies. The benefits will be many, including enhanced safety, improved operational efficiency and innovative passenger services.
LTE for all railway needs

The leading technology candidate for railway operators is LTE, which offers far more than just a TETRA and GSM-R substitute. LTE provides high speed, high security and high bandwidth capacity, making it well suited to support passenger connectivity needs, along with safety-critical operational applications such as train signaling, and safety-related applications like closed-circuit television (CCTV) and on-board communications.

Furthermore, all this can be achieved with a single, converged and flexible network, sweeping away the complexities and inefficiencies of managing a mixture of several network technologies, including GSM-R, TETRA, DMR, Wi-Fi and even analog technologies like VHF/UHF.

The all-IP architecture and superior broadband capacity performance of LTE open up the possibility of supporting new kinds of operational or infotainment services. Meanwhile, integration with IP-based applications is relatively simple and straightforward. LTE’s strong ecosystem of infrastructure suppliers, terminal suppliers and chipset makers delivers the highest performance-to-value ratio in the long term and ensures the technology has a long life.

Passenger experience
- Trip information: routes, timetables, delay notification
- Digital signage
- High-speed Intranet access
- Personal on-board multimedia entertainment

Business process support
- Network infrastructure for operational staff communications in stations and depots
- Electronic ticketing
- Remote diagnostics and fleet maintenance
- Location-based services

Operations support
- Remote driverless operation
- Real time traffic management
- Safety services including on-board CCTV, driver look-ahead video
- Automatic train control and signaling
- Legacy voice communications

Figure 1: LTE meets all railway communications needs from passenger information services to mission-critical broadband

Figure 2: Three groups of applications for future railway services that LTE will support
**Consolidating all communications onto one network**

IP-based LTE enables all communication networks to be rationalized into a single mobile LTE and fixed IP/Multiprotocol Label Switching (IP/MPLS) network. This leads to substantial savings on network design, management and maintenance.

With a user-plane latency as low as 10ms and a resilient architecture, LTE supports CBTC / ETCS, which is sensitive to delay, packet loss and jitter. Increased CBTC capabilities support automatic and driverless train operation and real-time voice applications. Sophisticated QoS built into LTE supports a mix of mission-critical CBTC traffic, real-time resource-intensive CCTV traffic and other best-effort traffic.

The LTE standard and products already provide off-the-shelf functionalities to match the stringent requirements for carrying mission critical services for railways. The solution will be enhanced with further railway specific functionalities as the ongoing 3GPP standardization proceeds.

With all these advantages in mind, LTE has become the technology-of-choice identified by several professional mobile radio standardization bodies (such as TETRA & Critical Communications Association (TCCA) and Association of Public-Safety Communications Officials (APCO)) to support mission-critical voice as well as broadband data. The first LTE networks for public safety are already being rolled out in the USA, while as far back as June 2009, the National Public Safety Telecommunications Council (NPSTC) endorsed LTE as the platform for a national public safety network in the USA.

As the leading mainstream mobile technology, LTE also offers a platform for future evolution and growth. For example, Nokia 4.9G will achieve gigabit throughout speeds and provide an essential seamless service experience with 5G.

The rail industry can look forward to 5G network speeds as high as 10 Gbps and extremely low latency that will enable new applications based on massive broadband capabilities. LTE will provide a foundation for 5G networks and will remain the long-term macro level technology standardized by the 3GPP even when 5G arrives. LTE will provide an anchor as 5G radio is introduced in phases, eventually becoming a complementary access technology.

**Several onboard technologies**

- **GSM-R for operational communication & ETCS**
- **WiFi for traffic offload in train stations**
- **Analog for shunting on low traffic lines & non-critical com.**
- **Public GSM & others for maintenance, electricity meters,...**
- **Separate ERTMS and CBTC radio**
- **Passenger BBoT via public 2G/3G/4G, SAT, Flash OFDM**

**Figure 3**: Traditionally, multiple communication applications have run on separate networks; LTE can carry all necessary communications data at high speed, with full security and sufficient capacity

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1. Source: urgentcomm.com article ‘700MHz LTE support’
The route to LTE adoption by railway operators

All mainline railway operators outside Europe can already opt for LTE today.

However, European mainline railway operators are restricted by a legal requirement that the next-generation railway telecommunication system must be standardized. There is joint activity within UIC, the European Union – Agency for Railway, ETSI and 3GPP to define a telecommunications system capable of replacing GSM-R from 2022 onwards. The migration phase is expected to last until 2030 depending on different projects.

LTE is seen as being the most suitable candidate under current standardization activities. The change to LTE will require extensive technical and regulatory standardization to achieve the necessary functionality, interoperability and smooth migration from GSM-R.

Urban metro line operators globally can already opt for LTE as their train control technology. As demand for mass rapid transit rises with growing urban populations, metro railway operators can gain substantial benefits by moving to a single LTE network for all their communications needs from CBTC to video protection. Currently, such applications are typically carried by separate radio access networks, generally based on proprietary or standard Wi-Fi. In addition, voice communications between the driver and control center or emergency call points for passengers are delivered over terrestrial trunked radio (TETRA), DMR technology, or another private mobile radio network.

Moving from managing seven or eight separate networks to one LTE-based network that supports multiple applications has clear cost and efficiency advantages for metro and other railway operators. The network could even be built as a private LTE network by a service provider focusing on the needs of mission-critical organizations.

Korea builds one of the world’s first LTE networks for rail

Nokia is supplying an LTE-based mobile broadband network for mainline railway operations and employee services in Korea. The network will be deployed on the 250km/h Wonju - Gangneung line as part of preparations for the major international sporting event being hosted by Korea in 2018. The LTE network will provide secure, reliable, high-speed connectivity between trains, stations and other railway facilities to support operational and maintenance services on the high-speed line.

Nokia is supplying radio access network (RAN) base stations along with NetAct™ virtualized network management for mobile networks. Nokia systems integration and deployment services will help to establish the new LTE network.

The network will be interoperable with other LTE networks supporting public safety and maritime operations as well as legacy VHF and trunked radio system networks.

The deployment is using the same dedicated 700 MHz spectrum as the national public safety network in the country, showing how LTE helps different critical communications agencies benefit from economies of scale with a common technology infrastructure. This shared spectrum model is a practical option for use in many other countries and regions.
Wide availability of spectrum for LTE

The availability of spectrum is a persistent concern for many commercial mobile broadband operators as they seek to implement the capacity needed to satisfy the continuing strong growth in demand from their customers. Likewise, spectrum availability is one of most important considerations for the railway industry. LTE helps to address these concerns through its flexibility that enables deployment in various frequency bands (all existing 2G, 3G and 4G bands as well as the 400 and 450 MHz bands. LTE can use different channel bandwidths (1.4, 3, 5, 10, 15 or 20 MHz) in accordance with the available amount of spectrum.

LTE, therefore, gives railway operators the choice of deploying their future communication systems in the frequency bands currently allocated for railways, or migrating to different ones.

The most likely bands for LTE network deployments include:

- Current GSM-R and extended GSM-R bands. Assessments are ongoing to determine if currently allocated spectrum can be re-used for LTE in the railway environment and whether the available frequency bands can offer sufficient bandwidth. Public operators are likely to deploy LTE in the 900 MHz band due to its good propagation conditions. Therefore any potential LTE interference with railway radio mobile systems in the current GSM-R band is currently being evaluated.

- 700 MHz to 800 MHz. These “digital dividend” bands released by the conversion from analog to digital television are scheduled for LTE deployment in Europe. The 700 MHz band is typically used in North America and Korea for public safety users. The 800 MHz band is usually deployed in Europe and Asia for LTE.

- The 2.6 GHz band has a smaller cell size but offers better spectral efficiency and higher throughput to meet high capacity requirements, especially in mass transit deployments where high capacity is accompanied by high train density.

- The 900 MHz / 1800 MHz / 2100 MHz bands are currently deployed for 2G/3G systems in Europe and Asia, and will be refarmed for LTE.

- 450 MHz. This frequency band has gained attention, not only in railway environments, but also in public safety and utility installations, since it delivers wider coverage and is well suited to carry mission-critical traffic. The main issue is the availability of bandwidth since these frequencies are currently used for TETRA trunked radio communications. To overcome this limitation and still be consistent with LTE, narrower bandwidths such as 1.4 MHz, 3 MHz and 5 MHz have been proposed.

- Railway operators may also have the option of working with existing commercial mobile operators to use their licensed spectrum in a virtual network operator arrangement.
LTE applications and their QoS demands

As well as train control and other safety-critical applications, LTE can support safety-related communications in trains and stations, as well as provide mobile broadband coverage to run a variety of services for passengers.

Mission-critical applications

Mission-critical class reliability is primarily driven by CBTC / ETCS systems, although operational voice services also demand extreme network prioritization as they help to ensure security and provide an essential means of manually sustaining train operation should the CBTC system fail. A CBTC application will typically tolerate a communications loss of no more than a few seconds, while a mission-critical voice service will usually have higher tolerance of communications loss.

End-to-end security, high reliability and quality of service

Figure 4: LTE provides broadband connectivity for safe and efficient train control and enabling the operation of automated and driverless trains
Operational security

The availability of high capacity and low latency connectivity will also enable applications to help improve passenger safety and security. These will include driver video for advance views of platforms and level crossings, as well as remote supervision of passengers through on-board closed circuit television (CCTV).

On-board CCTV and operational voice services can help secure train operations. Such CCTV systems will contain innovative features such as video analytics software to automatically detect intrusions, strange behavior or unattended baggage.

On-board CCTV services require high uplink throughput, while the platform CCTV service requires high downlink throughput. Due to the intrinsic nature of a mobile network, the uplink spectral efficiency is typically lower than the downlink spectral efficiency. Of all types of application traffic relating to train operations, CCTV traffic is probably the most dominant in a capacity budget. Yet the loss of platform CCTV service could prompt a fallback to manual inspection of door closure procedures. This, in turn, could cause departure delays.

End-to-end security, high reliability and quality of service

Figure 5: Broadband in stations is provided by LTE macro networks and small cells
Enhanced passenger experience

Passenger information and multimedia entertainment applications are common examples of applications that could enhance the passenger experience. For instance, passenger information applications can provide route information, weather forecasts or the time of day. Entertainment applications can provide video streaming with buffering.

This type of “Infotainment” traffic is typically low priority and may consume only a low to moderate amount of network capacity. It also tolerates relatively high network latency. However, passenger Internet services could eventually become the single highest consumer of network capacity.

Reducing operational costs

Lower maintenance and operational costs will be achieved through the efficient operation of rolling stock based on real-time information and improved communication between moving trains, maintenance staff and track-side systems.

Operational costs will also be reduced by introducing new applications (for example remote diagnostics) and services to simplify and automate operational processes as well as by consolidating fragmented legacy networks with a unified LTE network capable of running multiple services.

Deployment considerations for LTE

By deploying an LTE overlay network, existing GSM-R or other network site locations can be re-used by mainline operators for a cost-effective roll out when comparable frequencies are being used. This will enable the LTE overlay network to support broadband services, while the existing network is retained for voice and narrowband services.

LTE radio access uses a so-called flat architecture in which the base stations, or eNodeBs, are connected directly to the core network without the need for an intermediate radio network controller. The eNodeB comprises radio frequency (RF) modules and a baseband processing module that has control and modem units. These can all be integrated into a single cabinet. Alternatively, the baseband unit and RF units, or remote radio heads (RRHs), can be deployed separately and linked by a cable. The RRH contains the RF power amplifier and RF filter. For railway environments the RRHs are located in the outdoor track area and the baseband units are located in station telecom rooms, which enables more flexible deployment options.

Next generation radio access, now coming on stream, offers further architecture flexibility by being able to take advantage of cloud technologies that offer flexibility, enhanced reliability and easy scalability of capacity to meet actual demand. Radio functions can be run in large centralized data centers or smaller distributed sites, or a combination of both with all components treated as a single cloud for easy and efficient management.

In recent years, the mobile industry has adopted the distributed base station architecture because of its low deployment costs, easier site acquisition and reduced site rentals.

A distributed architecture also has the advantage of a better uplink (UL) budget because of lower RF cable losses, which means fewer sites would be needed compared to the integrated cabinet option. This is a particularly strong advantage for operators deploying LTE on the 2.6 GHz band, which has limited coverage compared to lower frequency deployments and would require a higher number of sites.

While all railway operators can enjoy these advantages, the compact size of distributed deployments is particularly beneficial for metro operators facing the challenge of deploying equipment in restricted tunnel spaces that may not easily accommodate conventional integrated deployments.
Small cells running LTE technology also provide advantages for metro railways because they are generally easier to install in underground and other limited-space stations.

Introducing LTE for railway operators

The speed with which LTE can be introduced depends on multiple factors like spectrum availability, regulatory environment and life-cycle status of legacy systems.

Some operators with access to additional spectrum might want to start deploying LTE as an overlay network for broadband service while moving their GSM-R network towards LTE in a second phase.

Other operators might start to migrate their legacy train control and voice communication system immediately to LTE and add broadband service at a later phase. This approach is especially beneficial when only limited spectrum is available and all spectrum is needed during the first migration phase.

Migrating from existing network technologies to LTE is likely to be a lengthy process with different radio technologies coexisting. LTE needs to be carefully integrated with existing railway solutions to leverage the investments railway operators have already made.

Migration options for European rail operators

As part of any network modernization strategy, the limited availability of dedicated spectrum for European railway operators needs to be taken into consideration.

Nokia advocates a three-step approach to the deployment of LTE by European mainline railway operators.

In step 1, the existing GSM-R network would support mission-critical voice and European Train Control System (ETCS) layer 2 operations, while the LTE network would support non-critical high speed data access. In this first step toward migration, the GSM-R system transmission network architecture would also evolve to an IP/MPLS architecture to simplify the migration process.

Figure 6: Deploying an overlay LTE network enables existing connectivity, such as GSM-R, to be re-used
Step 2 consists of using the LTE network to support multimedia railway services such as CCTV safety-related applications, maintenance applications, high speed data transmission and voice services for regular operations. Interoperability tests would need to be performed between LTE and GSM-R to implement this migration.

Step 3 would fully implement LTE as the only radio communication system being used. At that point, all railway services would be fully supported by LTE technology, which in turn will lead to the evolution of current GSM-R network entities into LTE entities. For example, the serving GPRS support node (SGSN) would become an LTE mobility management entity (MME) and the gateway GPRS support node (GGSN) would become a packet gateway (PGW) in the LTE core network.

Migration options for urban rail operators and mainline rail operators outside Europe

As they are not obliged to follow the European standardization of the final definition of next generation technology for railway communications, urban rail and mainline operators outside Europe can directly migrate from any existing legacy access technology to a mission critical LTE railway network. The first non-standard LTE systems for railways are already deployed in the Asian region.

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**LTE proves single network viability on Paris metro**

LTE for multi-service and broadband urban rail ground-to-train networks was tested on the Paris metro, operated by the Régie Autonome des Transports Parisiens (RATP). The trial was conducted as part of an initiative to demonstrate the feasibility of using a single radio communication technology to deliver safety-critical and non-safety-critical services on a metro network simultaneously.

Working with several partners, Nokia managed the project, supplied the LTE technology, and was responsible for testing at its Transportation Solution Labs. Its R&D subsidiary, Nokia Bell Labs, assisted with advanced development of LTE small cells.

The trial demonstrated the capacity of LTE to simultaneously transport several applications, such as CBTC, CCTV, voice, network maintenance applications and passenger information on a single radio link. It also showed that LTE can offer service prioritization and excellent QoS levels.

The most critical applications, such as CBTC and NTP clock synchronization, were able to operate with no packet loss and lower latencies than conventional Wi-Fi technologies, even in metro tunnels, and when operating in proximity with other trains.

The trial proved valuable in showing how LTE can be the foundation of future-proof, unified network architecture.
Nokia offers a comprehensive LTE portfolio

Radio access network

At the heart of the Nokia LTE family is the Flexi Base Station portfolio that offers more network capacity, more efficiency and more flexibility, with lower costs. Nokia Flexi Multiradio 10 Base Station is the world's smallest high-capacity, software-defined, multi-technology base station.

Nokia small cells provide easily scalable, cost-effective capacity. Nokia Flexi Zone suite is a 3G/LTE/Wi-Fi-capable small cell solution for offloading traffic from a macro network. Flexi Zone Base Stations can be deployed stand-alone or to create a zone covered by a cluster of low-power access points connected to a local controller.

Building on the success of the Flexi Base Station portfolio, the next generation Nokia AirScale Radio Access solution is able to use any architecture topology to deliver services with unlimited capacity scaling and market-leading latency and connectivity. The solution can meet very high capacity demand and paves the way to 5G.

Standard 3GPP mission critical core

The Nokia mission critical core scales to suit a variety of network requirements - compact units to serve deployable and small networks, mid-sized core for full network deployments, and data center solutions for nationwide networks. Further flexibility comes from Nokia virtualization and cloud technology.

Depending on the railway operator’s strategy, the core solution is constructed from various components: Compact Core, IMS, VoLTE/open TAS core, and HSS. Further enhancements are achieved by application servers that provide railway-specific functionalities together with the mission critical application server used in the public safety domain. The Nokia product portfolio includes a Group Communication Server that is fully aligned with 3GPP and ready for Release 13 mission-critical specifications that has future synergies with the rail segment.

Backhaul network

The Nokia IP/MPLS backhaul solution with integrated packet microwave and optical transport is a shared services network infrastructure that can be deployed flexibly with no performance degradation. This helps meet diverse connectivity requirements and allows for future growth. Ready for software defined networks (SDN), it allows for future network evolution.

In hybrid and commercial network deployments, Nokia supports QoS with prioritization of mission-critical voice and data and emergency calls over non-mission critical and commercial voice and data. The solution supports policy management, QoS-capable backhaul and radio networks, traffic engineering, user differentiation based on 3GPP standard QCIs, load balancing and admission control.

With regards to railway specific devices like cab-radios and dispatchers, Nokia works with best-in-class device suppliers based on full 3GPP compliance and defined railway specific standardization as part of its end-to-end service integration capability.

The Nokia product portfolio is complemented by comprehensive services to simplify the evolution to high speed mission critical networks while assuring mission critical reliability and performance. Services include transformation consulting, network design and build, systems integration, managed services and care.

Nokia can provide local delivery and operations center capabilities in key regions across the world to serve railway customers. Our global scope and reach is built on six Global Delivery Centers, four Delivery Hubs, 13 Local Delivery Centers and four special scope Delivery Centers supporting an established service presence in 150+ countries.
Figure 7: Nokia offers a comprehensive product portfolio encompassing radio access, backhaul solutions and 3GPP mission critical core.
Conclusion

As existing communications technologies that have supported railway operations for several years approach their end of life, the industry has a golden opportunity to migrate to a proven system that can support new broadband services and reduce costs. LTE mobile communications technology has been adopted rapidly worldwide for its unparalleled performance and off-the-shelf convenience backed by a well-developed and still growing ecosystem.

By implementing LTE, mainline, metro and other railway operators can consolidate multiple legacy systems, while supporting all their diverse applications, including the ultra-high availability requirements of CBTC/ETCS. LTE also provides an environment that enables easy introduction of new applications by leveraging its all-IP based mechanism.

While mainline operators outside Europe and all metro operators globally can already adopt LTE today, European mainline operators must wait for the standardization of the next communications system to be finalized. With LTE looking to be a near-certainty for this standardization, Nokia advises all railway operators to begin investing in LTE without delay to gain the benefits of valuable applications that require higher bandwidth than GSM-R offers, whether on-board trains, track-side or in stations.

Figure 8: Nokia offers a complete range of innovative services with delivery excellence
## Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>3GPP</td>
<td>3rd Generation Project Partnership</td>
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<td>APCO</td>
<td>Association of Public-Safety Communications Officials</td>
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<td>CBTC</td>
<td>Communications-Based Train Control</td>
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<td>CCTV</td>
<td>Closed Circuit Television</td>
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<td>DMR</td>
<td>Digital Mobile Radio</td>
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<td>ETCS</td>
<td>European Train Control System</td>
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<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
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<td>GGSN</td>
<td>Gateway GPRS Support Node</td>
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<td>GSM-R</td>
<td>GSM Railway</td>
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<tr>
<td>HSS</td>
<td>Home Subscriber Server</td>
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<td>IP/MPLS</td>
<td>IP/Multiprotocol Label Switching</td>
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<td>LTE</td>
<td>Long Term Evolution</td>
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<td>MME</td>
<td>Mobility Management Entity</td>
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<td>NPSTC</td>
<td>National Public Safety Telecommunications Council</td>
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<td>PGW</td>
<td>Packet Gateway</td>
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<td>QCI</td>
<td>QoS Class Indicator</td>
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<td>QoS</td>
<td>Quality of Service</td>
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<td>RAN</td>
<td>Radio Access Network</td>
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<td>RRH</td>
<td>Remote Radio Head</td>
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<td>SDN</td>
<td>Software Defined Networks</td>
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<td>SGSN</td>
<td>Serving GPRS Support Node</td>
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<tr>
<td>TAS</td>
<td>Telecom Application Server</td>
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<tr>
<td>TCCA</td>
<td>TETRA &amp; Critical Communications Association</td>
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<tr>
<td>TETRA</td>
<td>Terrestrial Trunked Radio</td>
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<td>UHF</td>
<td>Ultra-High Frequency</td>
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<td>UIC</td>
<td>European Union – Agency for Railway</td>
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<td>VHF</td>
<td>Very High Frequency</td>
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<td>VoLTE</td>
<td>Voice over LTE</td>
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