Private wireless communications for underground mines

White paper

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Abstract

The automation of critical processes is vital for mining companies seeking to increase operational efficiency and productivity while improving worker safety. To enable the automation applications that will deliver these results, mining companies need pervasive and dependable wireless connectivity above ground and underground. Reliable critical communications is the foundation for mine digitalization, automation and autonomous operation.

Industrial-grade private wireless networks based on 4.9G/LTE and 5G technology provide a single infrastructure for fast, reliable and secure voice, data and video communications in mine settings characterized by highly challenging deployment conditions. They offer an ideal solution for the unique communication and connectivity challenges presented by underground mining environments.

Introduction

The case for innovation in the mining industry has never been more compelling. Driven by the need to reinvent operations, increase safety, and optimize productivity and efficiency, mining companies have invested strongly in Industry 4.0 solutions in recent years.

The rewards of digital transformation and automation can be substantial. Advances in technologies such as the industrial internet of things (IIoT), artificial intelligence (AI), machine learning (ML), augmented reality (AR), virtual reality (VR) and extended reality (XR) will enable mining companies to optimize decision making, automate manual processes and eventually replace all manual operations with fully autonomous systems. These advances will also give them the ability to see and effectively track assets and monitor people's locations and working conditions, all of which are essential for keeping workers safe.

To get the best out of these technologies and the digital applications they enable, mining companies need high-performing wireless connectivity in the mining areas. But many mines still rely on legacy networks that weren't created to address the demands of ultra-broadband and mission-critical use cases.

Fortunately, there is a proven network technology that can address these demands. Trusted by mobile operators worldwide, 4G/LTE cellular technology has all the features and characteristics required to enable the vast majority of business-critical and mission-critical mining applications.

Over the past few years, Nokia has led the way in making critical wireless network technologies available to enterprises through industrial-grade private wireless solutions that are fully compliant with 3GPP standards. Nokia 4.9G solutions provide a single infrastructure for fast, reliable and secure data transfer, mission-critical push-to-talk (PTT) and push-to-video (PTV) communications, and real-time video transmission in mining settings that are characterized by highly challenging deployment conditions.

In the meantime, operators are rolling out 5G networks and industries have started following. This next-generation cellular technology will support even more extreme applications and use cases from pit to port, as the same network technologies will be used for rail and seaport operations.

The mining industry is a complex space and conversations about underground mines often feature unique jargon. Even coal miners and silver miners tend to use different vocabularies. To keep this document readable for a broad audience, we have limited the use of specialized mining terminology.

Why the network matters

Important developments in communication technologies are providing an extra push towards digitalization and automation by reducing the cost, delivering lower latency for mission-critical applications and increasing the options for licensed spectrum.

Mine sites need pervasive and dependable wireless voice and data connectivity to get the results they want from digitalization and automation. But today's Wi-Fi networks can't provide the highly robust, predictable, and secure wireless connectivity that automated mining operations demand. TETRA and P25-based radio networks were never built for broadband data and video communications. And proprietary network technologies don't offer the future-safe roadmap that standards-based solutions do.

4.9G/LTE provides all the capabilities of Ethernet in a mobile wireless format. It also has a mature ecosystem of connected industrial devices and has proven its capabilities for a decade in the most demanding public networks in the world.

Table 1. Comparison of mine communication network technologies

	Wi-Fi	UHF/VHF	TETRA / P25	LoRaWAN / sigfox	Bluetooth	LTE / 5G
High data rates, low latency	✓	✗	✗	✗	✗	✓
Mission-critical	✗	✓	✓	✗	✗	✓
Cyber-secure	✗	✓	✓	✗	✗	✓
Predictable performance	✗	✗	✗	✗	✗	✓
Coverage	✗	✓	✓	✓	✗	✓
Mobility	✗	✓	✓	✗	✗	✓
LP-WAN (IoT)	✗	✗	✗	✓	✓	✓
Voice	✗	✓	✓	✗	✗	✓
Multi-service	✗	✗	✗	✗	✗	✓

Private wireless networks based on 4G/LTE standards can support all mining applications on a single industrial-grade infrastructure. In addition, they can provide seamless handovers and mobility at high speeds with predictable quality of service (QoS) and support a massive number of active device connections per access point with far greater reliability and security than legacy network technologies. They can also support a smooth evolution to 5G.

With a Nokia 4.9G private wireless network, mine operators will benefit from applications such as mission-critical PTT and PTV services, high-definition video, low-latency edge computing for remote and automated operations and camera surveillance, low-power sensor networks, telemetry and IoT in above ground and underground environments. They will also benefit from having a technology that smoothly evolves to 5G.

Nokia industrial-grade private wireless solutions meet the connectivity challenges of underground mines by providing better coverage than Wi-Fi and supporting all voice, data and video services with one network. This network can connect thousands of devices for handheld, vehicle and machine use with greater predictability and performance than Wi-Fi under high load.

Communication challenges in underground mines

Underground mines that use a variety of mining methods in confined spaces and extensive networks of drifts and galleries present tougher connectivity challenges than those presented by open-air outdoor sites.

Extracting or from open pits requires no tunneling and is utilized for metals and minerals that are fairly close to the surface. As such, open-pit mines have a relatively large space available for network infrastructure deployment and radio antennas have a large coverage angle. Compared to Wi-Fi, private wireless technology dramatically reduces the number of access points and nearly eliminates the need for in-pit antennas mounted on trailers, which often need to be moved or reconfigured because of nearby blasting activity. One Nokia mining customer saved more than 10 million euros by replacing 150 Wi-Fi trailers with six LTE eNodeBs.

When a surface mine becomes exhausted or it is no longer possible to access the desired resources from a pit, mining activities move underground. This is where the extra complexity comes in, with factors such as underground ventilation, ground support, sophisticated excavation equipment and transportation systems, intensive machine movement and new safety requirements for workers.

Mining companies may operate in different areas of an underground mine at the same time to address different geological or geotechnical considerations or adhere to extraction sequence optimization restrictions and requirements. This means that equipment and people can be working in one area of the mine this week, move to another area next week, and come back to the original area at the end of the month.

The planning, design and deployment of a communication network is also more complex in an underground mine. To connect miners and machines, the network needs to deliver reliable wireless voice and data communication across a variety of harsh production areas, including spiral ramps, vertical shafts, horizontal adits, steep declines, narrow drifts and galleries, and wide rooms with massive rock walls. The physical incapacity to see and effectively track the people and equipment deployed in the mine is a significant difference between underground and surface mining. Because of this “blind” environment, people and systems are extremely dependant on fast and reliable data transfer.

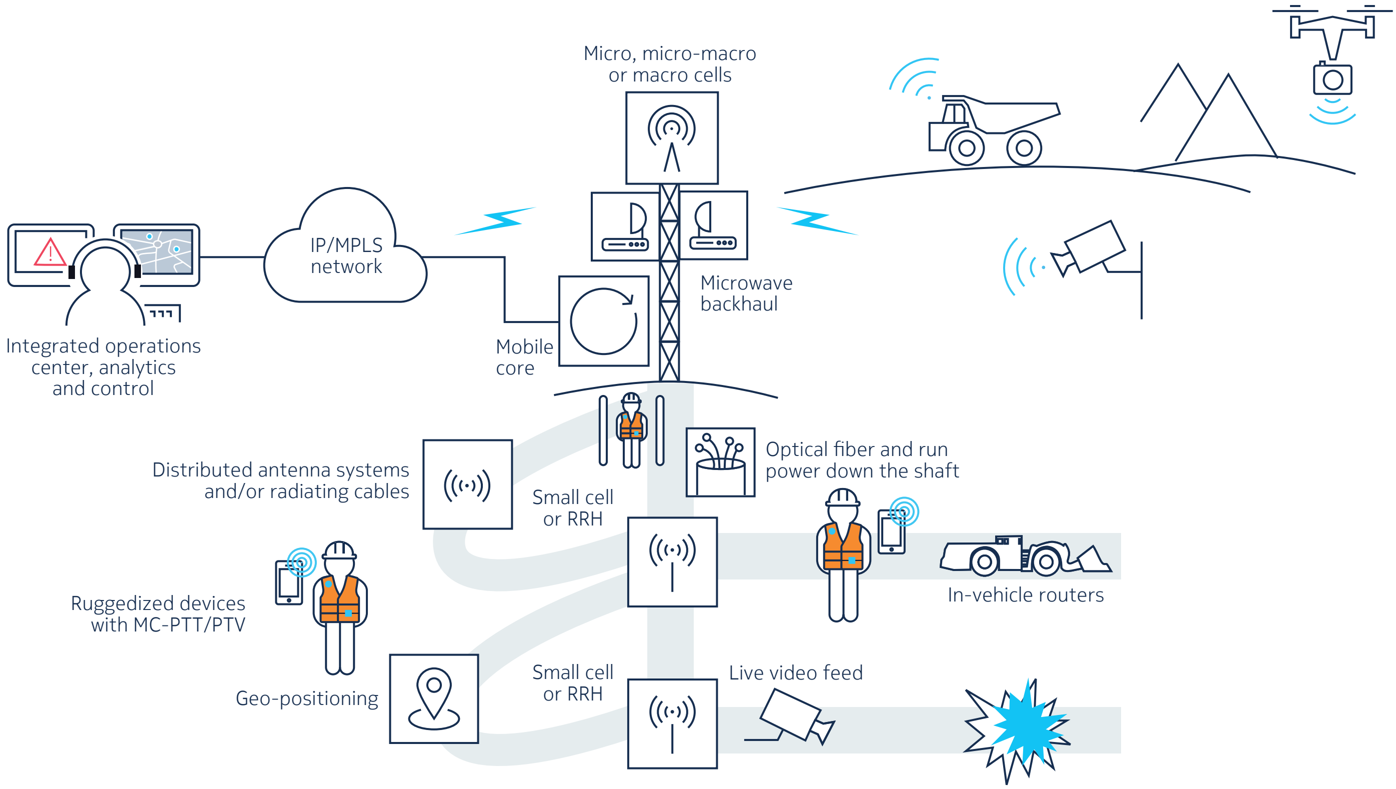
Network requirements for underground mines

Underground mining operators have expressed the need for wireless connectivity to support a wide variety of use cases, including simple and basic connectivity for personnel, remote drilling and blasting control over autonomous and tele-remote-controlled vehicles, and person-to-person voice and video communications. To support these mission-critical, business-critical and safety-critical applications, the underlying connectivity system needs to:

- Be highly reliable and industrial grade
- Support a variety of services, including broadband data, low-latency control, Internet of Things (IoT) and mission critical PTT and PTV
- Perform in a predictable manner with respect to latency, jitter and throughput when loads are high or mobility is required
- Prioritize traffic classes and guarantee end-to-end QoS for industry-specific traffic patterns
- Meet mining industry safety and security standards

Because of its reliability, low latency and high-speed data transfer capacity, private 4.9G/LTE wireless is the most suitable communications technology for supporting all automation applications in underground mines. Although coverage of a single antenna is often limited to a section or a gallery, the power of the 4.9G/LTE signal to penetrate long, straight distances makes it a convenient solution for supporting regular mining methods such as caving, room and pillar, and long wall. This power also makes it ideally suited for in-mine mission-critical and emergency voice and video communications.

Figure 1. High-level underground network architecture



To ensure flexible coverage, the network may need a combination of radio technologies such as small cells, micro remote radio heads (RRHs), radiating cables (also known as leaky feeders) and distributed antenna systems (DASs), all of which need to be integrated with existing UHF/VHF systems. Table 2 shows a comparison of radio access network (RAN) architecture options that use different combinations of radio technologies.

Table 2. Comparison of different RAN architectures

	Macro eNB (CRAN) + radiating cable	Small cells + radiating cable	Small cells + antennas
High data rates, low latency	Medium to large sites with intensive development	Small sites without complex development	Driven by mining method, mine design and operational practices
Coverage	Uniform coverage	Uniform coverage	Coverage depends on operational practices and infrastructure
Amount of fiber required	High	Low	Low
Infrastructure required in tunnels	High passive, low active	High passive, low active	Low passive, high active

It must be noted that there is a significant dependency on frequency and band availability for each of these options. These dependencies may affect coverage, throughput and device availability. As a result, network architecture design and radio planning play a key role in a successful network implementation.

If wireless spectrum is available, the same network infrastructure, including the eNodeBs (access points), packet core, management system and applications, can be deployed above ground and underground. This deployment could, for example, provide fleet connectivity and person-to-person or group communications across the entire mine.

All of these requirements make it necessary and appropriate to deploy a dedicated private wireless network infrastructure that keeps traffic within the enterprise. Private wireless networks feature purpose-built network elements that match the mining environment with respect to footprint, scalability, flexibility and reliability. Network serviceability is optimized to meet the needs and capabilities of mining personnel so the network can be deployed and managed easily by them or by a service partner.

The harsh conditions in which miners operate also create specific network hardware and end-user device requirements. Workpads and handhelds used for person-to-person communication must be ruggedized with hardened enclosures and industrial-grade components. They also need to be user friendly. Dongles and field routers must have high IP protection (IP67 or IP68) to remain functional in moist or wet environments that may be filled with dust and other airborne particles. ATEX-certified devices are tested for use in continuously or occasionally explosive environments.

Use cases for industrial-grade private wireless

Mining operations teams usually consider the merits of different communication network technologies based on specific use cases. The broad range of private wireless-enabled use cases alone would justify the adoption of an LTE-based industrial wireless solution (for location services, in combination with Bluetooth beacons) for underground mining. These use cases include:

- Connecting thousands of devices for handheld, vehicle and machine use with greater predictability and performance under high load
- Massive-scale sensing of critical parameters such as structural integrity, temperature humidity, water leaks, gas levels, dust, noise and vibration to provide near-real time visibility into mine safety
- Enhanced collaboration, improved productivity and worker safety through mission-critical PTT/PTV, video monitoring, digital PPE and industrial location tracking
- Tracking and protecting people, equipment and structural integrity through geo-location, geo-tracking and geo-fencing
- Getting real-time alerts when humans enter forbidden areas or vehicles perform unusual maneuvers, either intentionally or unintentionally
- Emergency alerting, evacuation notifications and worker mustering
- Utilizing low-latency communications for blasting control and tele-remote-controlled and autonomous load, haul and dump (LHD) vehicles, robots and drones.
- Digitalizing and automating business-critical processes through the use of data collection, AI and analytics
- Health monitoring, predictive maintenance and remote repair assistance for mining equipment
- Creating energy efficiencies and cost savings through close monitoring and control of underground mine ventilation, which ensures safety when workers are present and extends the lifetime of ventilation systems
- Enhancing worker efficiency and training with AR/VR applications

The adoption of LTE as general support for digital transformation can also provide some important mine-wide benefits. For example, virtually any application that requires wireless connectivity, and even some that could be supported with a cabled connection, can be served by 4.9G/LTE and (soon) 5G. This is because LTE and 5G have the capability to handle the bandwidth needs of any application, including HDTV camera feeds. They also support low-power sensor and IoT networks, and are adaptable to older network protocols used in legacy applications.

Both LTE and 5G achieve a level of reliability that can only be matched with a dedicated wired network. They also support mobility and are more flexible than wired networks. Through the use of network slicing, a single LTE or 5G network can provide multiple applications with dedicated resources and QoS that are programmed with specific parameters for each use case.

Figure 2. One single network for creating the connected digital mine

Near-real-time broadband data			Mission-critical communications	Massive IoT and analytics	Worker health and safety	Optimized mine-to-port
On-demand adaptive bit rate video from vehicles and machines with potential for tele-operations	Video monitoring and analytics on CCTV and drone camera stream for surveillance, inspections and repair	Augmented reality (e.g., overlay of obstacle detection) on topographical maps, digital twin creation and sychroni-zation	Mission-critical push-to-talk (PTT) and push-to-video (PTV) services for worker safety and team communi-cation applications (out-phasing TETRA/P25)	Communications from sensors for asset health and diagnostics, position reporting, environmental monitoring, ventilation on demand, and process control	Worker health and safety monitoring with digital personal protective equipment (PPE) and wearables, and geofencing for unauthorized or unsafe areas	Leveraging extreme autonomy and near-real-time equipment, load and people tracking for improved safety, productivity and efficiency
High bit rate	High bit rate	Medium bit rate				
Low to moderate latency			Low bit rate, low latency, high priority	Low bit rate, moderate to high priority	Low to moderate bit rate and latency	Low to high bit rate, low to moderate latency

In practice, the use of LTE or 5G private wireless brings a substantial reduction in operating costs and a huge increase in possible operational gains from a wide range of use cases. For future digital transformation projects, it eliminates the question of which connectivity technology to use. Essentially all applications that require connectivity will be able to ride on the existing LTE or 5G system, which will act as a unified communications infrastructure that operates above ground and underground.

For mining companies, one of the principal benefits of digital transformation is the ability to create data synergies between applications. Increased sensing capability is the first step. It provides additional sources of data that can describe the operations in the mine. If operators can join more data lakes, they will improve the possibility of finding correlations through on-premises cloud-based analytics and AI/ML algorithms that can identify opportunities to create system-wide efficiencies. Traditionally, specific applications on a mine site have not been connected because the costs outweighed the perceived benefits. But once many applications are using the same communications infrastructure, linking data between applications is a relatively trivial task.

By connecting data from different applications, mines can use big data techniques to carry out end-to-end workflow optimization and predictive maintenance and perform forensic analytics on incidents. It is also possible to extract data from sensors all over the mine, including environmental monitors, sensors integrated in PPE and sensors embedded on equipment. This can give new meaning to situational awareness, providing a much more thorough and detailed understanding of the safety of workers and the mine environment, including non-pit areas such as tailing dams and ponds, waste piles, crushers and mills, processing plants, power stations and microgrids.

The road from 4G to 5G

The industrial journey to 5G has just begun, so most Nokia mining customers are still opting for 4.9G solutions. They know that the 5G era is around the corner, and that the upgrade will be straightforward. More than 85 percent of digital mining applications can already run on 4.9G. 5G will add even more capabilities, such as more bandwidth for ultra-high-definition video services and ultra-low latency for real-time tele-remote-controlled robots and drones.

Once the 5G network is fully implemented, it will allow mining operators to benefit from a new arsenal of game-changing capabilities, along with the ability to run several different applications over the network. With 5G, they will be able to reserve capacity for specific applications, resulting in predictable performance and improved reliability.

In the meantime, there is still some work to be done in 5G standardization. 5G Release 16 was finalized in July 2020, and Release 17 is planned for 2022. Together, these releases will enable critical machine connectivity features such as ultra-low latency and time-sensitive networking.

These next two 5G releases are critical steps for Industry 4.0 applications. They will bring significant benefits for private wireless and enable the bulk of the 15 percent (or even less) of applications that cannot be supported on private 4.9G networks. The Release 18 standard, which is due in 2023, should provide the final piece of the puzzle with massive IoT connectivity – the successor to LTE-M and NB-IoT.

The availability of 5G spectrum may be a temporary hurdle for some countries. While a few markets have started releasing vertical spectrum for 5G, they are small in number compared to those that have released LTE/4.9G vertical spectrum.

Another important success factor is the presence of an industrial chipset and device ecosystem that can support the 5G standard. Consumers can now buy high-end 5G smartphones, and ruggedized 5G handsets and IoT devices built to operate in harsh mining environments are hitting the market. The fact that private wireless technology will be used across a broad range of industries and verticals will create a strong ecosystem that the mining sector can leverage.

Mining equipment vendors such as Sandvik and Komatsu are now collaborating with Nokia to evolve their applications for the 5G era. The concept of collision awareness through vehicle-to-everything (V2X) communication is one example of what could be a benefit of using 5G. Time-sensitive communications, high bandwidth, low latency and ultra reliability will support GNSS corrections, messaging for emergency stops, and proximity warnings.

Automation capabilities beyond the network

A dedicated private wireless network infrastructure provides greater flexibility to supply unconstrained communications services while enhancing the transparency and accountability of operational performance. The goal of substantial productivity gains will drive mining companies to move to next-generation mining through remote operations and autonomous equipment. LTE will meet the need for reliable, scalable and highly secure wireless connectivity and provide a stable, future-proof wireless foundation for digital mines.

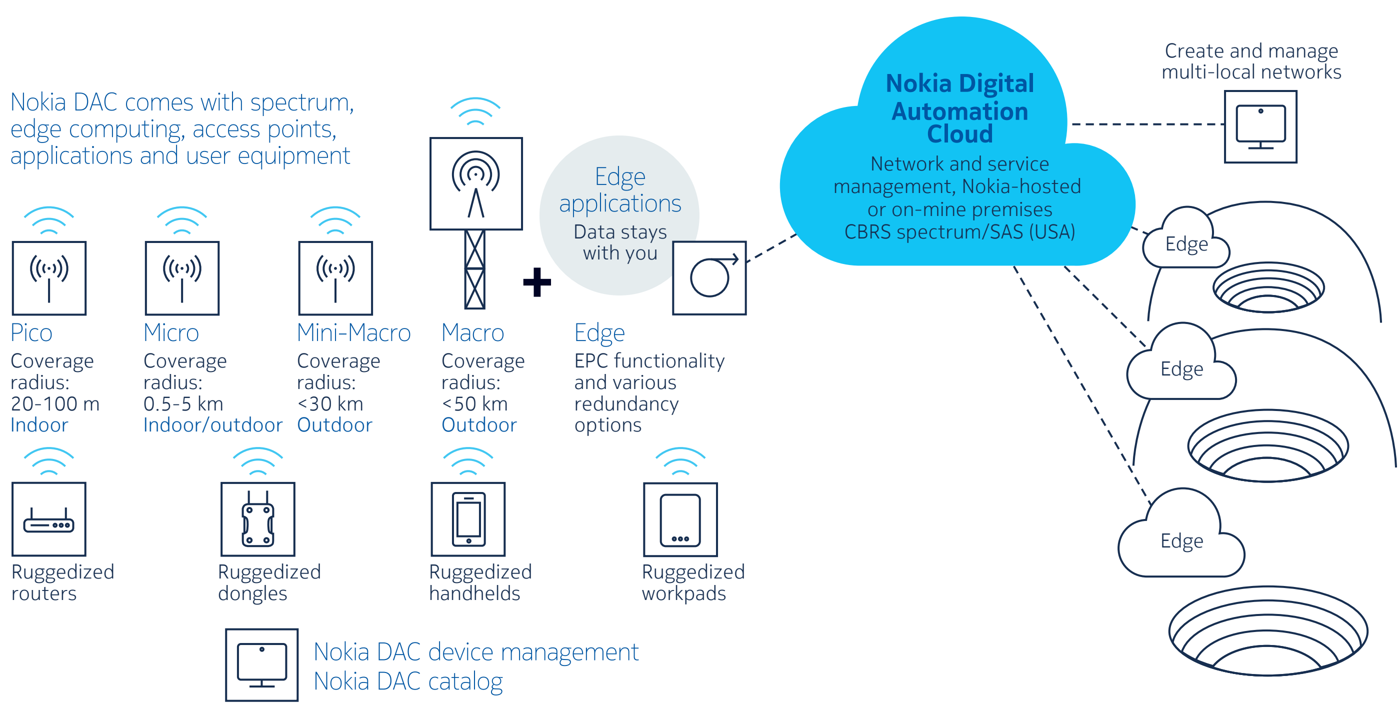
Nokia private wireless solutions are designed to meet the high security demands of enterprises and industries. With private wireless, a mining operator has complete control of its data. This data stays local and does not leave the premises until the operator authorizes its export through a secured channel. The data security capabilities are built on an independent and isolated network architecture that uses dedicated equipment and SIM-based authentication.

Nokia Digital Automation Cloud (DAC) is a network-as-a-service solution that introduces and integrates advanced technologies such as edge computing and a micro-services framework to meet the strict performance, scalability and latency demands. The built-in micro-services framework can be used to optimize the service level for each application. These virtual connections use the same underlying network infrastructure but are dedicated to the precise performance needs of each application, which can include ultra-reliability, high bandwidth, low latency, extreme capacity or any other requirement.

A Nokia DAC deployment can support applications such as underground positioning and real-time video analytics. It can run and manage several applications in real time, which enables mining companies to improve operational efficiency. An ultra-scalable edge computing platform provides efficiency, security, local data analytics and a runtime environment to host applications and IoT stacks that require high speed and low latency, as is the case for AR and VR applications.

In challenging mine environments, Nokia DAC provides the seamless network coverage needed to support PTT and PTV devices and services that connect people in real-time and ensure worker safety. It can also provide pervasive connectivity for drones equipped with cameras and sensors, which can be used to inspect pits, conveyor belts, stockpiles or underground corridors.

Figure 3. Nokia Digital Automation Cloud



The Nokia DAC platform also provides integrated device management and supports seamless plug-and-play device onboarding. It offers the scalability to manage thousands of devices.

The Nokia device portfolio includes ruggedized dongles, field routers, workpads and handhelds. These devices are manufactured and certified to address various markets and frequency bands, and cover the needs of customers for 4G and 5G applications.

Nokia application partners provide independent software applications that complement the private wireless solution with capabilities such as AR/VR and video and image recognition. Similarly, device partners can bring in sensors, camera solutions and other hardware to develop complete IoT solutions. Data collection partners transform the vast data streams generated by sensors and other devices into rich, real-time insights that can help mining companies improve productivity, make critical decisions and create connected products.

Conclusion

Reliable critical communications is a foundation for mine digitalization and automation. Nokia private wireless networks provide the pervasive, industrial-grade connectivity that enables mining operators to accelerate the digitalization of their operations and support automation applications that will power a new wave of business transformation, also known as Mining 4.0.

Nokia private wireless solutions also address use cases and digital applications beyond drilling, loading, hauling and dumping, including mission-critical person-to-person and group communications, underground location tracking, video surveillance, drone inspection, fleet management and predictive asset analytics.

Nokia has deployed private wireless networks for more than 340 customers in the transport, energy, manufacturing, logistics, and public sector segments. These deployments include networks in 60 mines for more than 35 mining companies around the world.

Visit our mining industry page to learn move about how our solutions, expertise and experience can help you deploy industrial-grade networks that make the connected digital mine a reality – above ground and underground.

Abbreviations

AI	artificial intelligence
AR	augmented reality
DAC	Digital Automation Cloud
DAS	distributed antenna system
GNSS	Global Navigation Satellite System
HDTV	high-definition television
IoT	Internet of Things
IIoT	Industrial Internet of Things
IP	Ingress Protection
LHD	load, haul and dump
LTE-M	Long Term Evolution for Machines

ML	machine learning
NB-IoT	Narrowband IoT
PPE	personal protective equipment
PTT	push to talk
PTV	push to video
RAN	radio access network
RRH	remote radio head
SIM	subscriber identity module
UHF	ultra high frequency
VHF	very high frequency
VR	virtual reality
XR	extended reality
V2X	vehicle to everything

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As a trusted partner for critical networks, we are committed to innovation and technology leadership across mobile, fixed and cloud networks. We create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

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Nokia OYJ
Karakaari 7
02610 Espoo
Finland
Tel. +358 (0) 10 44 88 000

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