Laying the tracks for digital railways

With a mission-critical IP/MPLS backbone communications network

Application note

Abstract

Rapid urbanization, increasing highway congestion and climate change present challenges to our society—but also unique opportunities for railways to grow and be an integral part of the solutions. To realize the opportunities, operators need to embark on a digital transformation journey. This application note explains how the Nokia Mission-critical IP/MPLS Network for Railways solution can become the communications foundation of digital transformation and enable operators to meet the needs of today and tomorrow.

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Embark on a digital transformation journey

Railways were first used in the early 19th century to carry coal and iron, powering the first Industrial Revolution. Two hundred years later, railways have become one of the most important modes of travel. They are widely recognized as an efficient, clean and climate-friendly type of transportation to move people and freight across countries and continents, contributing to a thriving society. According to statistics from the International Transport Forum of the OECD, by 2050 the demand for non-urban passenger transport will increase by 225% from 2015[1] This presents an immense opportunity for the railway industry to grow.

To realize this opportunity amid robust competition from other modes of transport such as low-cost airlines, long-haul buses and automated driving, railway operators need to stay competitive by enhancing their services, improving the customer experience and attaining higher efficiency. They need to strive to accomplish the following.

Offer faster, more frequent train service with efficient, reliable, on-time operations

A 2018 UIC report on high speed rail comments that passengers are likely to favor rail travel over air if the rail travel time is under 3.5 hours. Many railway operators are considering investing or have already invested in high speed[2] railway infrastructure because they recognize that shortening travel time is pivotal to gain market share of the travel business. They are also introducing automatic train operation (ATO) to assist engineers/train drivers and optimize both track utilization and energy usage. Furthermore, to constantly provide reliable service, operators also need to continually monitor rail asset health as preventive maintenance to avoid unexpected breakdowns.

Ensure round-the-clock safety and security

Safety and security are always operators' paramount concerns because any incident could put lives at risk and also incur high recovery cost, including compensation to users and even lawsuits. It is imperative to continually provide safe passenger transport while increasing train speed. ATO is pivotal to improve train safety, particularly for high speed trains. Furthermore, whether it is inside a station, on a platform or inside a railway car, operators also need to constantly ensure physical security for passenger and staff everywhere across the railway infrastructure. In addition, the wide adoption of IP-based OT and IT systems significantly expands the cyberattack surface, making the cybersecurity a prime concern.

## Enhance the journey experience

Passengers in a digital society expect to be online anywhere they go. Riding on a train is no exception. Connecting them to entertainment and information throughout the journey immensely improves their quality of experience while greatly differentiating railway service from other modes of transport.

To meet these challenges, railway operators are embracing digital transformation by introducing new railway applications (see Figure 1). These include safety-critical control and signaling systems (ETCS/PTC) and mobile radio systems (GSM-R and FRMCS). Operational applications include CCTV and intrusion and access control systems as well as passenger applications such as passenger information display systems (PIDS). To enhance the journey experience, operators also often provide on-board infotainment and Wi-Fi services.

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1   ITF Transport Outlook 2019, International Transport Forum, May 2019.

2   According to a UIC definition, above 200 km/hr (124 mph) is considered high speed.

Figure 1. Digital applications used by railway operators
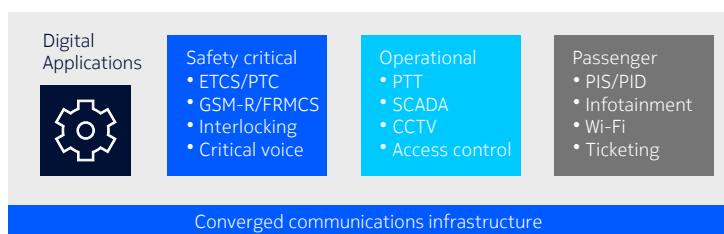
As shown in Figure 1, digital transformation requires a converged communications infrastructure as the foundation to support all railway applications. As railway operators operate a vast railway network encompassing multitudes of kilometers of tracks, a plethora of rolling stocks and many train stations, they need to flexibly harness various access technologies. These technologies, ranging from wireless to cable, are required to transport data from applications to operations centers, data centers or wherever required.

Adopt a backbone network for converged communications infrastructure

Central to the communications is the backbone network that interconnects all the different access network domains with the operations and data centers (see Figure 2). In addition to connecting to devices via fiber- or copper-based Ethernet access, the backbone network acts as a backhaul network for various wireless domains.

Figure 2. Architectural overview of railway converged communications infrastructure
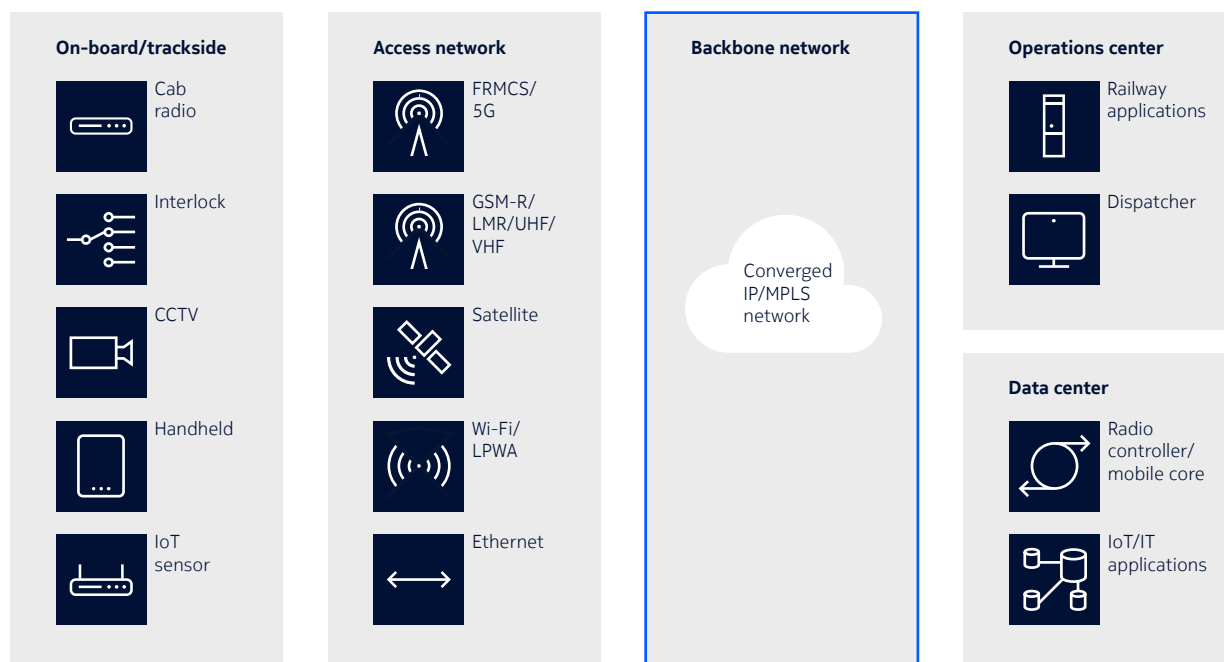
To effectively provide resilient, reliable and secure backbone connections across the railway infrastructure, the backbone network needs to meet the challenges that follow.

Full service convergence

In the past, railway operators have deployed purpose-built networks to support specific applications. As a result, they need to operate multiple networks with different generations of technology. With extensive adoption of applications, this old paradigm of an application-specific, purpose-built communications network is no longer feasible. Operators need a converged network architecture that can support multiservice applications with VPN technology.

Furthermore, because new applications and systems such as ETCS/PTC, FRMCS, CCTV and PID are IP-based, scalable IP VPN capabilities in the converged network are imperative to be prepared for a multitude of applications today and tomorrow.

Deterministic QoS

There is a diverse set of applications across the railway infrastructure, and each has a different network quality of service (QoS) requirement (see Table 1). Real-time, safety-critical applications such as control and signaling running atop ETCS/PTC have strict delay requirements. Other applications, such as CCTV and PIDS, have less demanding network performance requirements. It is imperative that the network can be engineered to constantly meet the required QoS level. With deterministic QoS capability, the network can consistently meet different application-specific requirements, ensuring that all application performance levels are met constantly.

Table 1. Sample railway applications and associated network QoS requirements

Applications	Latency	Bandwidth	Reliability	Criticality
Signaling	Low	Low	High	High
Switching/interlocking	Low	Low	High	High
CCTV	Medium	High	Medium	Medium
PIDS	High	Low	Medium	Low
Passenger Wi-Fi	High	High	Low	Low

Versatile use of transport medium

Railway tracks span dense urban centers, sparse rural areas, wilderness and even uninhabited mountainous terrain. Therefore, when deploying the backbone network, it is important that operators can select the best-suited media (microwave, fiber, copper or carrier VPN services) to flexibly build out the network.

High network availability

With most of the network deployed outdoors in uncontrolled environments, railway backbone networks are more vulnerable to failure than urban transit networks. Connectivity outages disrupt mission-critical applications such as signaling, forcing operators to halt train services; this causes significant passenger delays as well as incurring economic loss and tarnishing the railway company's reputation. As a result, it is imperative that railway operators strive to design the network with the highest network availability, fully harnessing available redundancy protection schemes and path diversity in the railway network topology.

Rigorous security

Digital transformation ushers in wide use of information and communication technologies (ICT) in railway operations, increasing the attack surface and introducing new vulnerabilities. Consequently, cyber security has become a top concern. Operators need to strengthen their security perimeter to safeguard the railway infrastructure from malicious attacks.

Accurate network synchronization

Accurate network synchronization is crucial for maintaining operations and applications integrity. Older TDM-based applications such as emergency voice and SCADA require accurate frequency synchronization in the network to attain high integrity and performance. All mobile communications systems also require frequency synchronization to ensure alignment of their on-air transmissions. Newer wireless radio technology such as LTE and 5G require phase and time synchronization to allow for advanced mobile capabilities such as carrier aggregation and to minimize time alignment errors.

Simplified network management

Managing a reliable network carrying numerous applications is a monumental task. Operators need a network management platform that can help them to provision, operate, maintain and troubleshoot the network proficiently.

To optimize efficiency and maximize network availability, a service-centric management platform can:

- Enable unified, end-to-end management, with fast and proficient provisioning
- Support proactive service assurance and intelligent alarm correlations
- Simplify other aspects of network operation, including configuration backup and upgrade.

Using a mix use of microwave and optical transport technologies, a unified management platform can provide cross-domain management over the network and transport layers, significantly boosting network operations efficiency.

Bridging the past to the future

Railway operators have used applications to attain operations efficiency and safety for a very long time. One example is the use of TDM-based SCADA systems to supervise and manage train operations and railway assets.

Once in use, these applications typically have a long life and are seldom replaced. Therefore, it is crucial that the converged network can seamlessly interoperate with these systems installed decades ago with no performance degradation or disruption of operations.

The network also needs to enable railway operators to fully adopt emerging and future ICT technology so they can capitalize on technologies such as cloud computing and the Internet of things (IoT) to optimize train operations and provide the best services.

The rest of this paper discusses how the Nokia Mission-critical IP/MPLS Network for Railways solution can help railway operators to tackle these challenges.

Nokia Mission-critical IP/MPLS Network for Railways solution

The Nokia Mission-Critical IP/MPLS Network for Railways solution is based on a converged, service-oriented architecture to support all applications. It provides strong resiliency, assured QoS and robust agility. As a converged backbone network, it can support all railway applications regardless of their criticality over a common network infrastructure, with no compromise in performance and security.

Solution blueprint

The Nokia IP/MPLS solution blueprint forms a multi-ring topology built with optical fiber systems buried in trenches, microwave links or both, along railway tracks in different lines, supplemented by carrier service where necessary (see Figure 3).

Figure 3. Nokia mission-critical IP/MPLS network blueprint topology
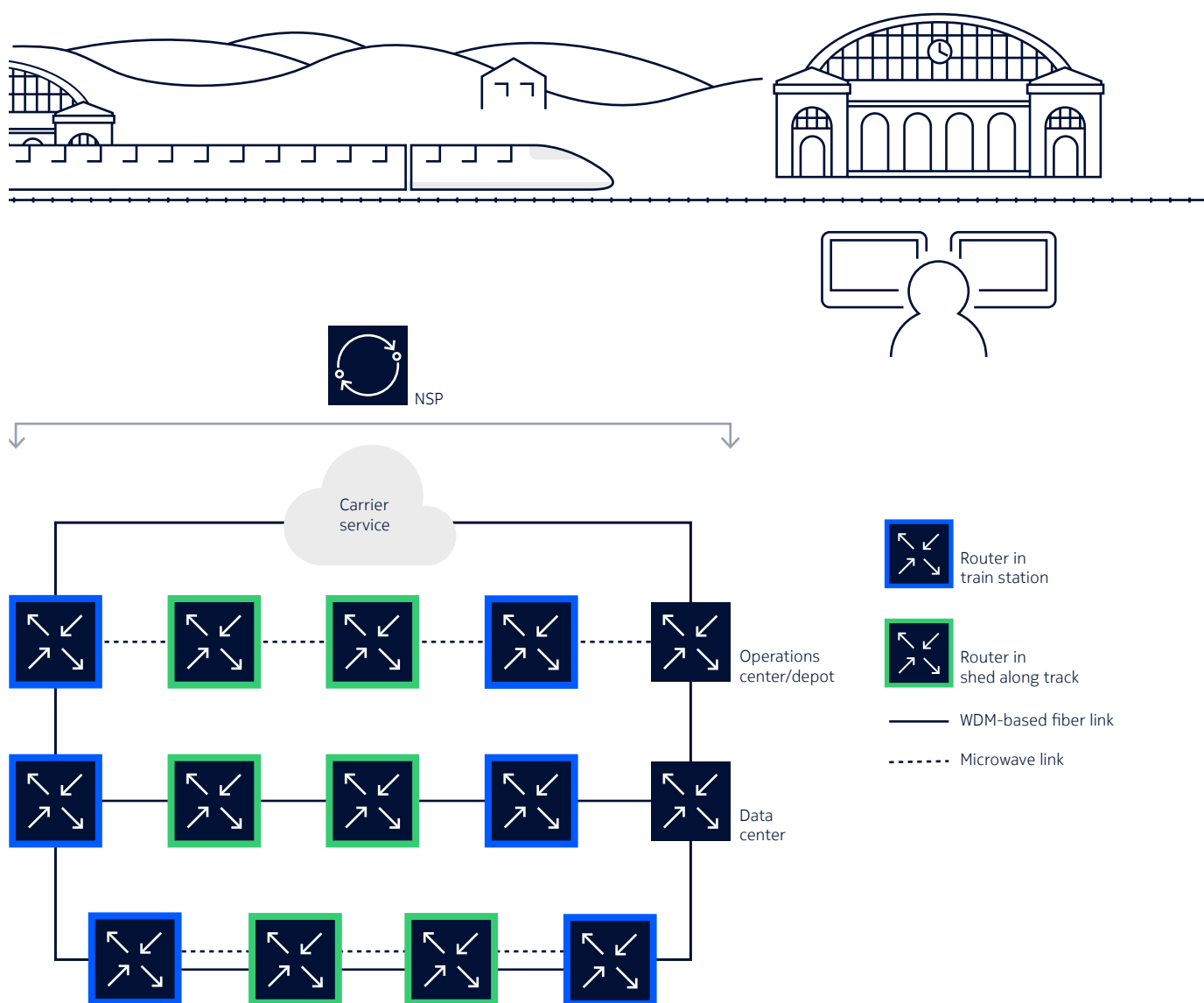
Solution components

The network solution extends IP/MPLS and service capabilities from the core to distribution to access, across the railway infrastructure. It includes the following main components:

- Nokia 7705 Service Aggregation Router (SAR)
- Nokia 7250 Interconnect Router (IXR)
- Nokia 7750 Service Router (SR)
- Nokia 7210 Service Access Switch (SAS)
- Nokia Network Services Platform (NSP)

The Nokia IP/MPLS products provide routing, switching and multiservice capabilities, enabling railway operators to carry safety-critical applications such as ETCS/PTC and interlock as well as best-effort applications such as passenger Wi-Fi service in the same network, without compromise.

Nokia solution benefits

The Nokia IP/MPLS network solution can help operators to overcome the previously described challenges. The solution capitalizes on full IP/MPLS capabilities to offer railway operators a wide variety of benefits.

High communications network efficiency with service convergence

Railway operators can achieve high network operations efficiency with a Nokia IP/MPLS network, which provides full service convergence by supporting a multitude of diverse applications. The network's flexible IP/MPLS VPN service capability supports IP, Ethernet and TDM communications in both point-to-point and multipoint manner to meet the communications requirements of different applications. Each application is carried over a dedicated VPN, segregated from all other VPNs (see Figure 4).

The network's native IP, Ethernet and TDM capabilities eliminate the need for external routers, switches and TDM multiplexers, achieving equipment efficiency while minimizing management efforts, power consumption, sparing and footprint. As a result, a converged network can greatly improve operations efficiency when compared to legacy purpose-built networks.

Figure 4. A converged IP/MPLS railway network
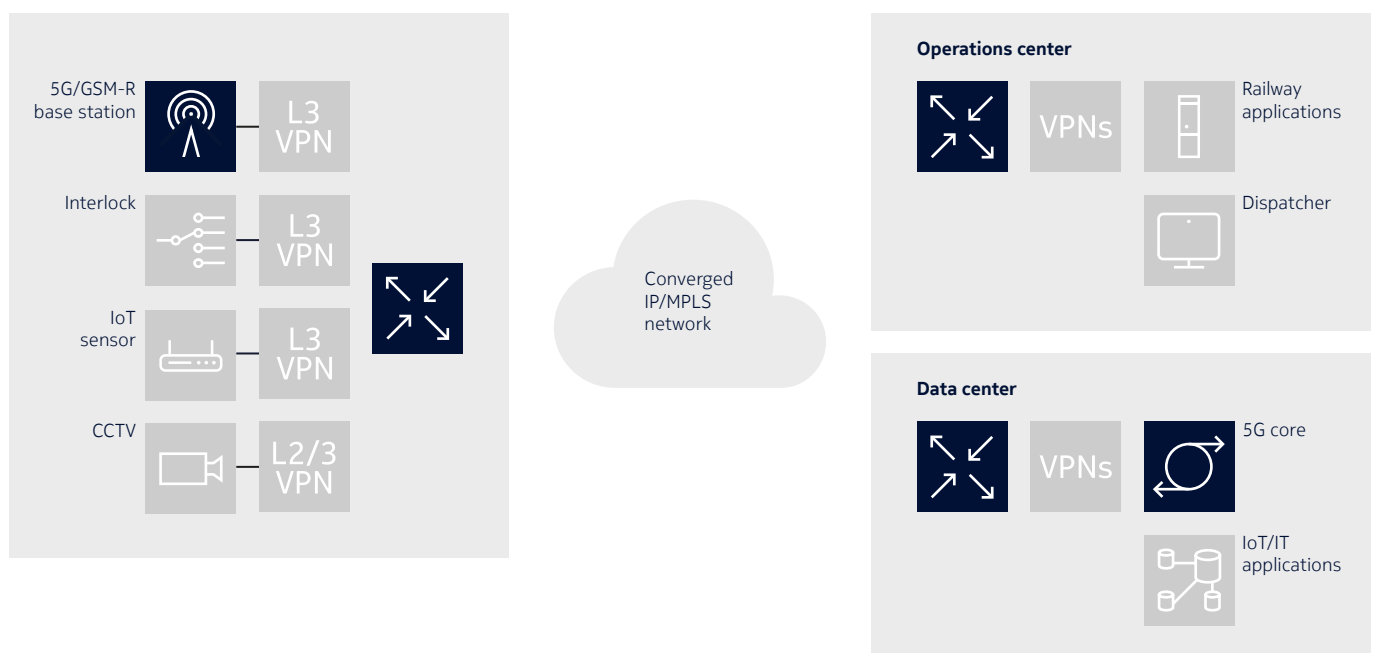
Assured application performance with deterministic QoS

With a proper network QoS policy, railway operators can be assured of network performance for their mission-critical applications. Based on a rich set of classification attributes at layers 1, 2 and 3, the QoS policy can classify all traffic and prioritize traffic transmission accordingly, with extensive advanced queuing and scheduling, in a hierarchical manner. With multiple levels and instances of shaping, queuing and priority scheduling, performance parameters (such as bandwidth, delay and jitter) for different applications can be met constantly (Figure 5).

Figure 5. Deterministic IP/MPLS QoS brings assured performance
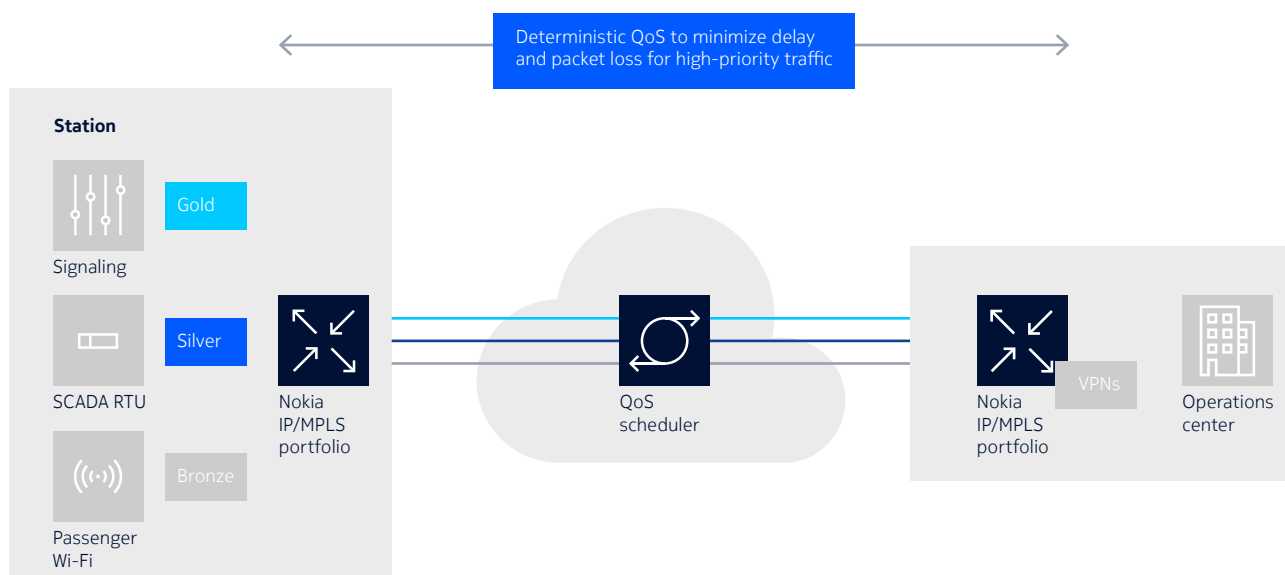
## Optimized network design with transport technology integration

By its very nature, IP/MPLS technology rides seamlessly atop any transport technology (e.g., microwave or optical) and any access technology (e.g., cellular, satellite or Wi-Fi) technology as well as carrier leased line service (see Figure 6). Harnessing this versatility, railway operators can extend connectivity to everywhere with one common model. This attains high network operations efficiency.

Figure 6. IP/MPLS supports multi-transport/access to outreach everywhere
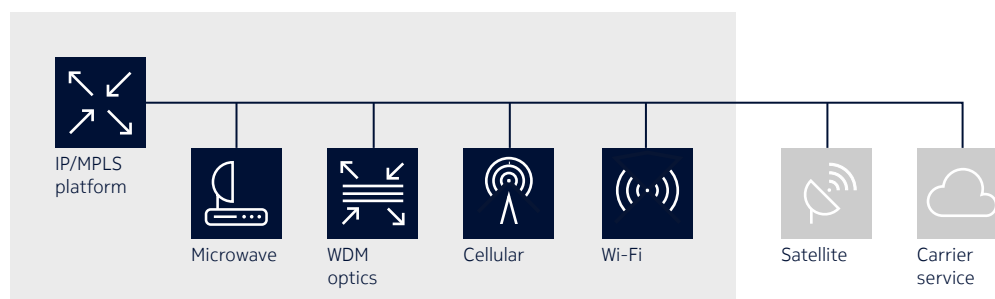
In addition, the Nokia IP/MPLS platform fully integrates different transport and access technologies, eliminating the need for a separate transport or access node (see Figure 7). Reducing the number of network elements optimizes network design and deployment, and further improves operations efficiency and management simplicity.

Figure 7 Nokia IP/MPLS platform integrated with transport and access technologies
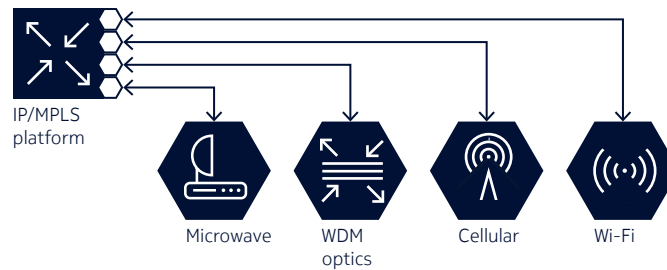

Uninterrupted operations with the ultra-high network availability

The Nokia IP/MPLS network can provide ultra-high network availability, which is imperative for railway operators to monitor track and rolling stock conditions even under extremely inclement weather. Most network technology recovery mechanisms, such as Ethernet Protection Ring as specified in ITU-T G.8032, can restore network connectivity proficiently when one fault occurs. However, this does not offer protection during a multi-fault scenario, which is common during severe weather events. A multi-fault scenario isolates rail segments and leaves operators blind, causing service to stop and stranding passengers.

Figure 8 shows how an IP/MPLS network with multi-ring topology can restore traffic despite multiple faults occurring in the network:

1. Under normal circumstances, data flows along the primary communication tunnel, called the label switched path (LSP). When the first fault occurs, traffic is rerouted to Backup LSP #1. Backup LSP#1 could be a fast reroute (FRR) tunnel or a provisioned secondary LSP.

2. When the second fault occurs, impacting Backup LSP#1, data is rerouted to Backup LSP #2.

3. When the third fault occurs, affecting Backup LSP#2, data is rerouted to Backup LSP #3. In this example, LSP #3 traverses over a carrier leased line used by railway operators, restoring data flow. This enables applications to continue running, which is crucial to train operations.

Figure 8. A multi-ring IP/MPLS network to provide utmost resiliency
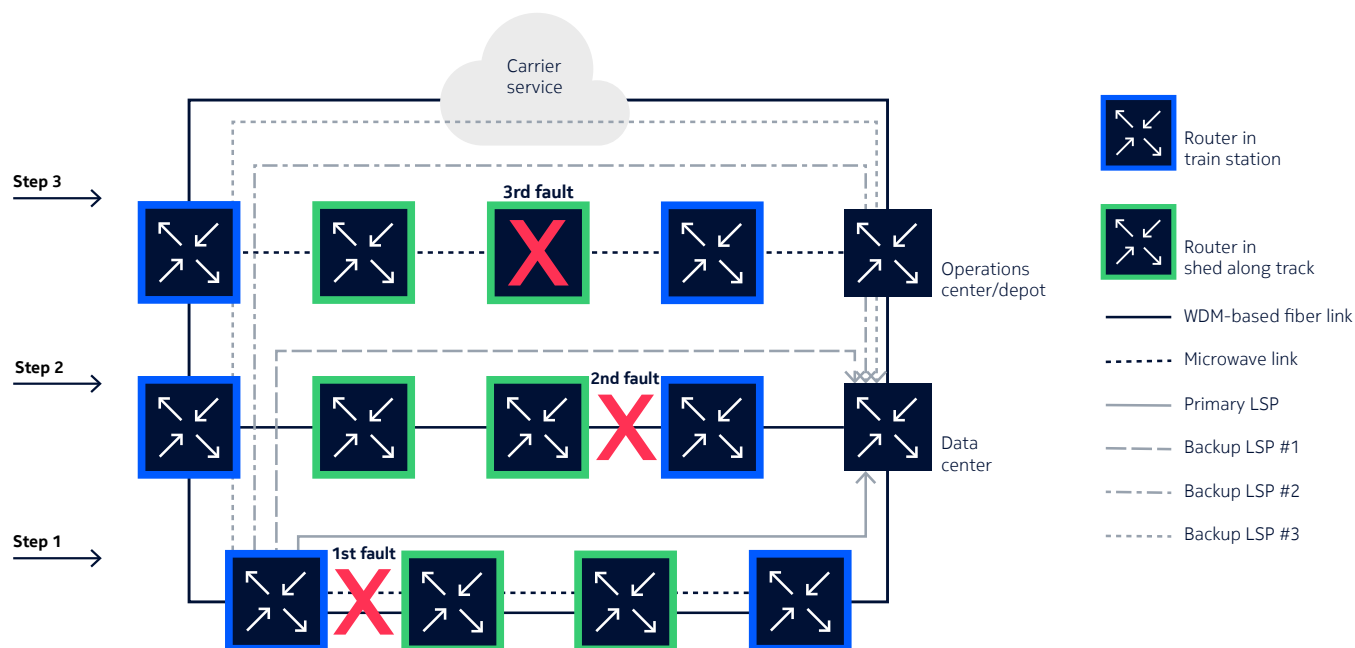
Because the operations center and data center are the nexus of the railway infrastructure, it is also mandatory to have geo-redundancy protection with standby facilities so that the railway system is still up and running even when the operations center is closed due to fire or flooding. Utilizing the restoration capability of pseudowire redundancy, the network can reroute data away from the active operations center to the standby facility, allowing the railway staff to continue operate the network (see Figure 9).

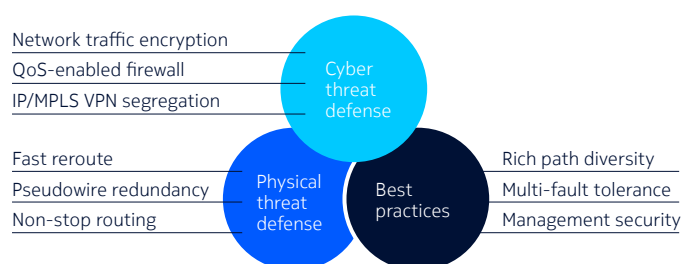Figure 9. IP/MPLS providing geo-redundancy to help to keep the rail system running
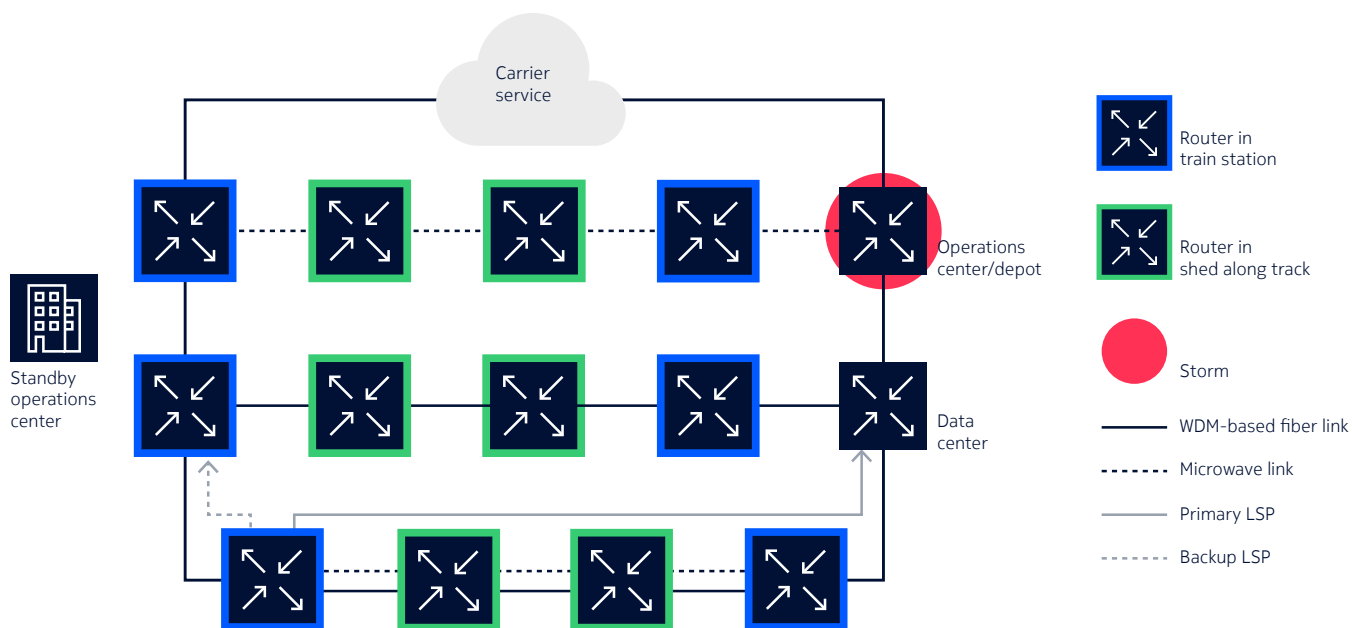
Secured operations protected by strong cyber defense[3]

As railway infrastructure becomes interconnected and its operations depend heavily on ICT, its attack surface expands significantly. The attacks range from cyberattacks trying to eavesdrop, interrupt and infiltrate to physical attacks to sabotage communication facilities and sever cables.

A Nokia IP/MPLS network is an integral part of an in-depth defense framework to protect railway infrastructure from both cyber threats and physical threats (see Figure 10). The network offers a wide range of security capabilities, including encryption and a firewall. Its resiliency is a bulwark against physical threats. Coupled with security best practices, the Nokia IP/MPLS network can effectively deter attacks, enabling the infrastructure to operate without compromise.

Figure 10. Comprehensive network security with a Nokia IP/MPLS network

Network traffic encryption
QoS-enabled firewall
IP/MPLS VPN segregation

Cyber threat defense

Fast reroute
Pseudowire redundancy
Non-stop routing

Physical threat defense

Best practices

Rich path diversity
Multi-fault tolerance
Management security

Flexible end-to-end network synchronization for frequency, phase and time-of-day

Because a railway backbone network covers multitudes of kilometers of tracks, the Nokia IP/MPLS network must support versatile synchronization options and robust clock recovery algorithms to distribute and attain accurate synchronization everywhere. The Nokia IP/MPLS platform supports many options, including integrated GPS receiver, line timing (SDH/SONET, E1/T1, synchronous Ethernet and packet microwave) and IEEE 1588v2 Precision Timing Protocol (PTP) in master, boundary clock and slave mode. PTP supports frequency, phase and time-of-day synchronization, preparing operators to adopt new technologies such as 5G.

Unified management for increased operations speed

The Nokia NSP takes railway operators beyond the traditional boundaries of network management. Unifying service, network and element management layers across IP/MPLS and transport domains, the NSP greatly simplifies management tasks. It supports:

• Fast and easy provisioning with great flexibility

• Proactive service assurance, helping to resolve problems early on

• Intelligent alarm correlation capabilities to expedite restoration.

The NSP is also ready to evolve to an SDN controller, ushering in new network optimization and programmability capabilities when necessary.

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3   For details, read the white paper "Cyber Security for Railways"

Bridging from the past to the future

Many railway infrastructures still have legacy SCADA and emergency voice communications systems based on communications interfaces such as RS-232/V.24 or E&M 4-wire interfaces. With a long useful life, these legacy systems will continue to be in use in the foreseeable future. With its large portfolio of supported interfaces (see Figure 11),combined with deterministic QoS, the Nokia IP/MPLS network has proven to be fully interoperable with many older systems and can support migrating application traffic gracefully without disruption to operations[4].

Figure 11. Wide legacy interface support
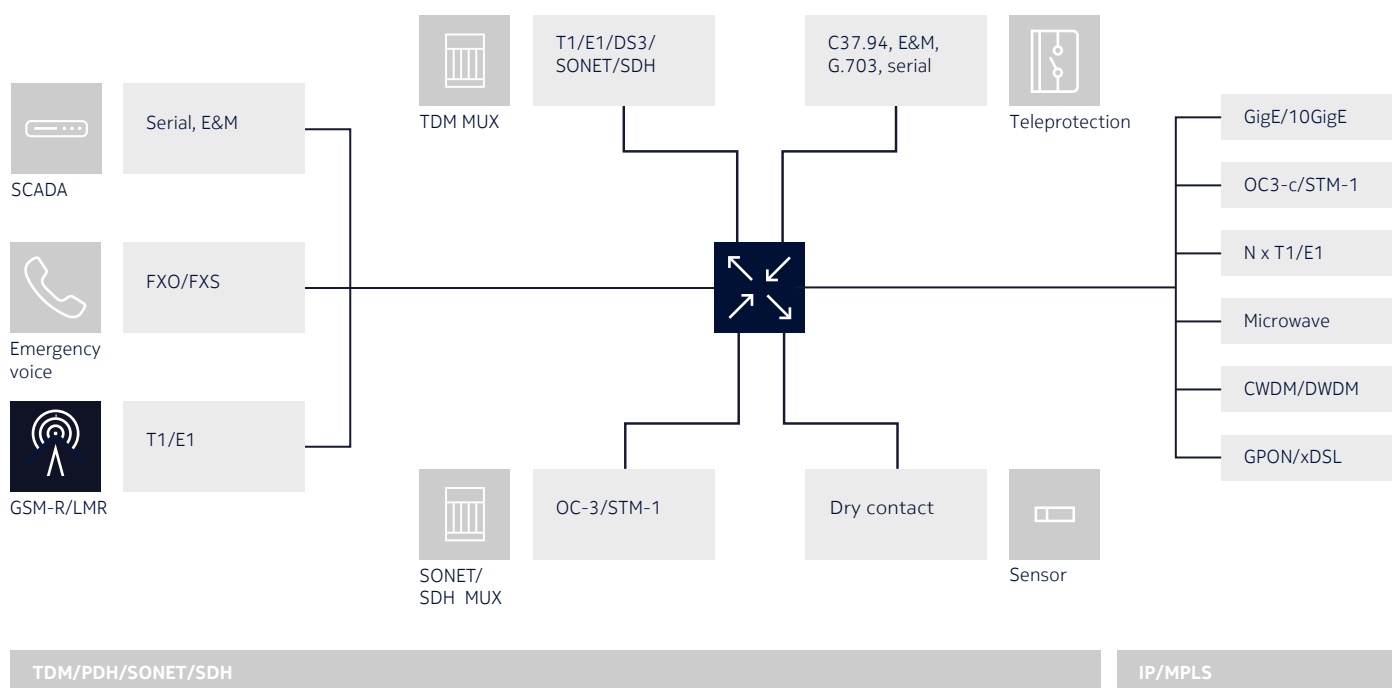
Many applications have become IP-based to take advantage of ubiquitous internet connectivity. In addition, they are also embracing the cloud paradigm to harness the agility and elasticity of cloud computing.

For example, the latest cellular base station (4G/LTE eNB and 5G gNB) and IoT applications such as sensors measuring train track temperature send data to applications residing in the cloud, which is a dynamic pool of compute resources in data centers. To extend connections in the backbone networks into the data center reaching the compute endpoint, the backbone network needs to become cloud-friendly.

A Nokia IP/MPLS network is interoperable with software-defined networking (SDN) technology, the accepted standard in data center network fabric. The Nokia IP/MPLS network seamlessly links field equipment such as gNB and sensors to the application endpoints in the cloud (see Figure 12).

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4   For details, read the white paper "Migrating from SDH/SONET to IP/MPLS networks"

![NOKIA]

Figure 12. IP/MPLS converged network is cloud friendly
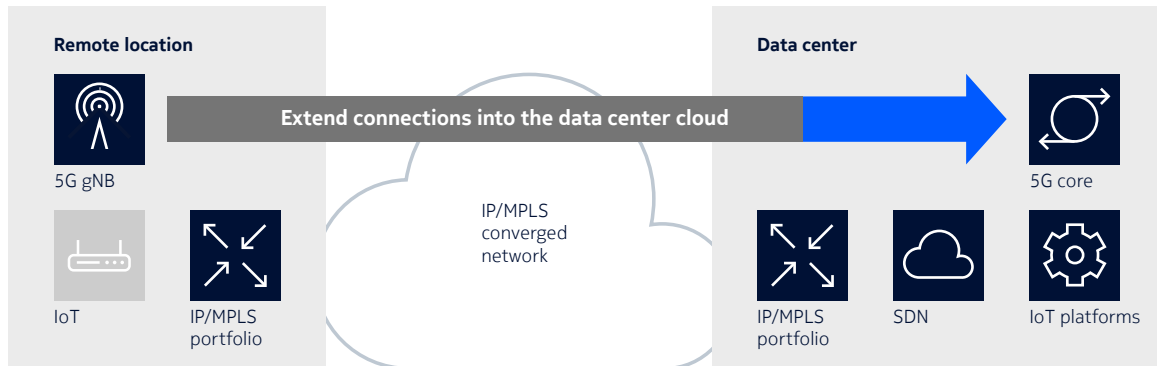
With all these capabilities, the NSP greatly simplifies operations, attains optimal efficiency and supports continued network evolution to address emerging requirements.

Conclusion

Railway operators are at a critical juncture. Rapid urbanization, increasing highway congestion and climate change present challenges but also a unique opportunity for railways to grow. To realize these opportunities, operators need to quickly evolve to offer highly attractive and reliable service. To do so, they need to embrace new innovations and technologies to transform the railway infrastructure into a modern railway system.

An IP/MPLS-based converged backbone communications network is the nexus of this new digital, smart, always-connected rail infrastructure, linking all assets and facilities reliably and delivering information when and where needed.

Nokia offers a broad product portfolio that spans IP/MPLS, SDN, packet optical, microwave, GSM-R, LTE/5G, security, IoT and analytics. Complemented by a full suite of professional services (network audit, design and engineering practices), Nokia has the unique capability and flexibility to help railway operators implement their network transformation to thrive in the digital future.

To learn more about Nokia solutions for railways and the Nokia IP/MPLS portfolio, visit our Railways web page and IP/MPLS portfolio web page.

Abbreviations

ATO	automatic train operation
CCTV	closed circuit television
CWDM	coarse wave division multiplexing
DSL	digital subscriber line
DWDM	dense wave division multiplexing
ETCS	European Train Control System
FRMCS	Future Railway Mobile Communication System
FRR	fast reroute
FXO	Foreign eXchange Office
FXS	Foreign eXchange subscriber
GPON	Gigabit Passive Optical Network
GPS	global positioning system
GSM-R	Global System for Mobile Communications – Railway
ICT	information and communications technologies
IoT	Internet of Things
IP	Internet Protocol
IT	Information technology
LMR	land mobile radio
LSP	label switched path
LTE	long term evolution
MPLS	multiprotocol label switching
MUX	multiplexer
OECD	Organization for Economic Cooperation and Development
OT	operational technology
PIDS	passenger information display system
PTC	Positive Train Control
PTT	push to talk
QoS	quality of service
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SDH	Synchronous Digital Hierarchy
SDN	software-defined network/software-defined networking

SONET	Synchronous Optical Network
TDM	time division multiplexing
UHF	ultra high frequency
UIC	International Union of Railways (Union Internationale des Chemins de fer)
VHF	very high frequency
VPN	virtual private network
WDM	wave division multiplexing