The road to high-performance intelligent transportation systems

The Converged IP/MPLS Network for Highways solution

Application note
Abstract

Highway systems are an integral part of transport infrastructure in a modern society, bringing people together and connecting the fabric of society. The road operators responsible for operating and maintaining highway systems are challenged to handle more vehicles, reduce traffic-related fatalities and accommodate the rapid adoption of connected vehicles.

To meet these challenges, they need to embrace digital transformation and adopt new, innovative applications. Many are exploring intelligent transportation systems, which integrate communications, control and information technologies into the highway infrastructure. But ITS applications require a high-performance backbone communications network to deliver their voice, video and data, which are pivotal to advance highway system performance.

This application note explains how the Nokia Converged IP/MPLS Network for Highways solution can become the communications foundation of ITS and enable operators to meet the needs of today and tomorrow.
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Challenges for road operators

A highway system, comprising highways, tunnels and bridges, is an integral part of transport infrastructure in a modern society. It links cities, towns and rural areas, bringing people together and connecting the fabric of society.

Highway agencies, tunnel and bridge operators and departments of transportation (summarily referred to as road operators) are responsible for operating and maintaining the highway system as well as attaining high performance\(^1\) to provide fast accessibility and agile mobility for economic and social activities. These are critical to a robust economy and high quality of life, and are the foundation of a prosperous and sustainable society.

Road operators are facing momentous challenges\(^2\) to fulfill their missions. These challenges include:

- Handling more vehicles
- Reducing traffic-related fatalities
- Accommodating the rapid adoption of connected vehicles.

Also, due to strained budgets, governments are under sustained pressure to expand the use of their infrastructures and find new revenue streams. Consequently, many road operators are exploring new ways to exploit the highway systems to improve the highway economics.

The need for ITS and a converged backbone

To meet the challenges they face, road operators are embracing digital transformation and adopting new, innovative applications. Many are exploring or are in the process of deploying intelligent transportation systems (ITS) to reduce congestion and pollution, improve traffic safety and prepare for connected vehicles.

Comprising roadside devices and central application systems, ITS integrate communications, control and information technologies into the highway infrastructure. The results are better traffic management, more intensive monitoring of road and weather conditions, and early detection of incidents and emergencies.

Some of the prevalent ITS applications used or in trials by road operators today include:

- Traffic management
- Electronic toll collection (ETC)
- Tunnel and bridge management
- Emergency roadside call systems (ERCSs)
- Structural health monitoring
- Vehicle-to-everything (V2X) communications.

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1. Although the key indicators of highway performance vary from operator to operator, the general indicators are usually the number of vehicles that can travel a prescribed distance per hour and the average vehicle speed.

2. For a full discussion of challenges, read the Nokia white paper “Converged communications for intelligent highways: efficiency today, flexibility for the future.”
While these applications are at different stages of adoption, they all require reliable and secure network connectivity along the routes to link roadside devices to central application systems. Therefore, it is fundamental to deploy a high-performance backbone communications network to deliver the voice, video and data of these applications that are pivotal to improve highway system performance.

A reliable, secure backbone communications network that supports all deployed ITS applications is the nexus of highways systems (see Figure 1).

Figure 1. A backbone communications network is the nexus supporting ITS

The essential attributes of this new backbone communications network for intelligent highways are discussed in the following sections.

**Full network service convergence**

In the past, many road operators deployed a purpose-built network when they implemented a new application. As a result, they need to operate multiple discrete, segregated network domains using various older generations of network technology that offer no path of network evolution. This silo paradigm hampers application integration, hinders innovations and significantly decreases network operations efficiency—preventing road operators from improving traffic flow and reducing road fatalities.

Furthermore, with the extensive adoption of ITS applications, this old paradigm is no longer feasible in a world of pervasive applications. Operators need a converged network architecture that can scale and support network segmentation for a multitude of applications, with each application using a dedicated VPN for domain segregation. Because each application has different networking requirements, it’s essential that flexible VPN service capability can support point-to-point or multipoint IP-, Ethernet- or TDM-based communications.
New applications such as traffic management systems are IP-based systems with a plethora of endpoints such as sensors and cameras along the highway. IP VPN service is desirable because it can scale up to support the endpoints and is free from broadcast storms and loop formations\(^3\). Moreover, with multicast capability, IP VPN is well suited for closed circuit television (CCTV) stream delivery.

**Deterministic QoS**

There is a diverse set of applications across the highway systems, and each has a different QoS requirement (see Table 1). Real-time, safety-critical applications such as ERCS require strict delay. Other applications, such as CCTV and variable message signs (VMSs), have less demanding network performance requirements. With deterministic QoS, the network can consistently meet different application-specific requirements, ensuring that all application performance levels are attained consistently.

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**High network availability**

With denser highway traffic, to improve road safety, it is important to constantly monitor traffic and provide timely congestion condition updates to drivers. As weather events become more intense and frequent, it is also crucial that road operators keep travelers out of harm’s way. They need to continuously monitor road conditions and warn travelers in time if there is any danger ahead. Therefore, it is imperative that sensors and CCTV cameras can reliably transmit data back to the control center. Road operators also need to update messages in the VMS systems. When travelers are stranded, they need to be able to call for assistance. Finally, with automated driving technology starting to gain adoption, V2X communications will be required all the time. For all these reasons, it is imperative that the backbone communications network has the utmost network resiliency to carry critical highway applications data.

**Versatile use of transmission media**

Because highway systems span dense urban centers, sparse rural areas and even uninhabited terrain, operators need full flexibility to use various network transmission media, including microwave, fiber, copper and even communications service provider (CSP) VPN services, to provision connectivity everywhere.

**Rigorous security**

With the wide use of information and communications technologies (ICT), the attack surface is greatly expanded, engendering new vulnerabilities that can severely impact traffic flow and safety. For example, compromising VMS control can cripple traffic flow, bring chaos and even cause crashes. Therefore, cyber security has become a top concern. Road operators need a robust network defense to thwart malicious attacks.

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\(^3\) Although Carrier Ethernet and VLAN technologies can also provide the connectivity, scalability to handle multitudes of endpoints is limited due to their broadcast nature. These technologies are also prone to loop formation and broadcast storms caused by configuration errors.
Bridging the past to the future

Since the 1980s, road operators have deployed highway applications such as signaling, messaging and ERCS as well as SCADA for tunnel monitoring and control. The roadside devices, equipped with legacy interfaces such as serial and 4-wire E&M analog, typically communicated with central systems over a TDM circuit. Many of these will remain in service for a number of years. It is crucial that the backbone communications network is fully interoperable with these legacy systems with no performance degradation or operations disruption.

Simplified management

Managing a reliable network that carries 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.

Shared network

In addition to supporting highways applications, the backbone communications network is a valuable asset because of its wide reach and high-bandwidth capacity. By sharing spare bandwidth, it can carry smart-city Internet of Things data in dense, urban centers; link new, smart energy infrastructure such as solar and wind farms in the country and electronic vehicle charging stations along highways; and perform data backhaul for rural ISPs in sparse, remote rural areas (see Figure 2).

Figure 2. Highways integrated with smart, green energy infrastructure and commerce

However, it is imperative that this shared network paradigm does not degrade critical highway application performance at any time.
Converged IP/MPLS Network for Highways solution

The Nokia Converged IP/MPLS Network for Highways solution is based on a converged, service-centric architecture to support all ITS applications. It provides assured QoS, high resiliency, robust cyber security and full interoperability with legacy applications. A common backbone communications network provides the required performance and security.

Solution blueprint

The highway infrastructure typically consists of a hierarchy of control centers and multitudes of gantries, sign posts and roadside cabinets with various devices (e.g., displays, sensors and controllers) on long stretches of roads. Due to the critical nature of these applications, it is crucial that connectivity is still available even during extreme weather events or ferocious forest fires in order to maintain full road condition awareness and provide timely travel advice to keep travelers safe.

The Converged IP/MPLS Network solution blueprint (see Figure 3) is grounded in global, standards-based IP/MPLS technology that:

• Supports point-to-point and multipoint TDM, Ethernet and IP network services with IP/MPLS VPN technology
• Integrates tightly with optical and microwave transmission and is interoperable with CSP VPNs
• Attains the utmost network resiliency through route-rich topologies such as mesh and ring of rings
• Expands network use by offering multiservice using spare bandwidth capacity for other infrastructure such as renewables, rural broadband and smart cities without jeopardizing critical applications performance.

Figure 3. Nokia converged IP/MPLS network solution blueprint for highways
Solution components
The network solution extends IP/MPLS and service capabilities throughout the highway infrastructure, interconnecting all application subsystems and devices. The solution includes the following main components:

- Nokia 7750 Service Router (SR)
- Nokia 7250 Interconnect Router (IXR)
- Nokia 7210 Service Access Switch (SAS)
- Nokia 7705 Service Aggregation Router (SAR)
- Nokia 1830 Photonic Service Switch (PSS)
- Nokia Wavence microwave transport
- Nokia Network Services Platform (NSP)

The Nokia solution provides routing, switching and multiservice capabilities, enabling road operators to carry critical applications such as ERCS and SCADA as well as best-effort applications such as Wi-Fi in the same network, without compromise. Tight integration with optical and microwave transmission equipment gives road operators wide deployment flexibility by fully exploiting available transmission assets.

Nokia solution benefits
The Nokia Converged IP/MPLS Network for Highways solution capitalizes on IP/MPLS capabilities to offer road operators a wide variety of benefits.

Higher communications network efficiency and improved economics through service convergence
The Nokia solution offers flexible IP/MPLS VPN service capability to support IP, Ethernet and TDM communications in both point-to-point and multipoint configurations to meet the communications requirements of different highways applications. Each application is carried over a dedicated VPN, segregated from all other applications.

The solution’s native IP routing and TDM capabilities eliminate the need for external routers and TDM multiplexers, minimizing equipment management efforts, power consumption, cooling, sparing and footprint. A Nokia IP/MPLS network also prepares operators to embrace emerging technologies such as private LTE, low-power wide-area (LPWA) network and roadside cloud.

Moreover, by harnessing the power and flexibility of IP/MPLS VPN service convergence, highway operators can adopt a shared network paradigm and backhaul traffic for other infrastructures and users without any degradation of critical application performance (see Figure 4).
Assured application performance with deterministic QoS

Using a hardware-based QoS mechanism, including hierarchical queuing and scheduling, the solution supports deterministic QoS with no performance compromise. Road operators can design and configure custom QoS policies to ensure that QoS parameters (such as bandwidth, delay and jitter) required by different applications can be met constantly (see Figure 5).
Uninterrupted operations with ultra-high network availability

The solution supports ultra-high network availability, which is imperative for road operators to continue to monitor road conditions and alert travelers even under extremely inclement weather. With the Nokia solution’s utmost resiliency, highway applications can continue to run despite multiple network faults.

Traditional ring topology can offer strong protection from one network fault. When a fault occurs, data will be rerouted in the opposite direction with little impact to applications.

However, extreme weather events are more likely to affect multiple locations at once. In this case, rerouted data is black-holed by the second point of failure. This causes the highway segment between the two points of failure to be isolated, leaving operators blind and travelers in the dark (see Figure 6).
Capitalizing on its dynamic networking capability, Nokia’s solution can reroute IP/MPLS VPN traffic around all points of failure as long as there is physical connectivity. In the sample multi-ring network shown in Figure 7, because of the network’s abundant path diversity, data flows can be restored despite multiple faults.

**Seamless transmission medium integration**

By innovatively combining with Nokia’s optical and microwave portfolios and technologies, the solution offers seamless integration with optical and packet microwave transmission, in the form of functionality incorporation or cross-domain unified network management. Moreover, data can be forwarded without restriction by various transmission media. This facilitates simplified, elegant network design and enables high network operational, space and power efficiency.

**Higher network operations agility with unified, simplified network management**

Traditionally, road operators rely on discrete management systems for IP/MPLS, optical and microwave domains. The Nokia NSP has the capabilities to consolidate the service, network and element management layers across IP/MPLS into a unified manager.

The Nokia NSP greatly simplifies management tasks by supporting fast, easy and highly flexible provisioning; proactive service assurance that helps to resolve problems early on; and intelligent alarm correlation capabilities that expedite restoration. The Nokia NSP is also ready to evolve to a software defined networking (SDN) controller, ushering in new network optimization and programmability capabilities when required.

**Robust network defense for secured operations**

As an infrastructure becomes connected 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 that sabotage communications facilities and sever cables.

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4 For more details on security, read the white paper “Impregnable network defense for critical infrastructures.”
A Nokia IP/MPLS network is an integral part of a comprehensive defense framework to protect from cyber and physical threats. With designed-in cyber security, it offers a wide range of network defense capabilities, including encryption and a firewall. Its resiliency is a bulwark against physical threats. Coupled with security best practices, a Nokia IP/MPLS network can effectively deter attacks, enabling the infrastructure to operate without compromise (see Figure 8).

**Figure 8. Comprehensive network security with a Nokia IP/MPLS network**

![Network security features](image)

**Bridge from the past to the future**

As ICT advances, newer applications systems have evolved to become IP/Ethernet-based. However, older highways infrastructures still have SCADA and ERCS based on communications interfaces such as RS-232/V.24 and E&M 4-wire. 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 9), the Nokia IP/MPLS network has proven to be interoperable with many older systems and can support migrating application traffic gracefully.

**Figure 9. Full interoperability with legacy systems**

![Interoperability chart](image)

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5 For migration details, read the white paper “Transformation of mission-critical communications networks: Migrating from SDH/SONET to IP/MPLS networks.”
Conclusion

A safe, efficient and modern highway system is one of the pillars of a prosperous and green society. By efficiently and reliably connecting densely populated cities and sparsely populated countryside, people and businesses are better linked; this improves the social quality of life, facilitates economic expansion and reduces pollution. As road operators adopt ITS technology to serve current and future transportation needs, a converged IP/MPLS network is the nexus of this new, intelligent and connected highway system that constantly provides necessary on-time, fast and safe accessibility to people and businesses.

Nokia’s broad communications product portfolio spans IP/MPLS, SDN, packet optical, microwave and LTE. This portfolio is complemented by a full suite of professional services, including audit, design and engineering practices. With this broad range of products and services, Nokia has the unique capability to help road operators plan and transform their backbone communications networks today, to be ready for the future.

To learn more about Nokia solutions for highways, visit our Highways web page.

Abbreviations

ANPR automatic number-plate recognition
CCTV closed circuit television
CSP communications service provider
CWDM coarse wave division multiplexing
DWDM dense wave division multiplexing
ERCS emergency roadside call system
ETC electronic toll collection
FXO Foreign eXchange Office
FXS Foreign eXchange Subscriber
GPON Gigabit Passive Optical Network
ICT information and communications technologies
IP Internet Protocol
ITS intelligent transportation systems
LTE long term evolution
MPLS multiprotocol label switching
MUX multiplexer
PDH plesiochronous digital hierarchy
QoS Quality of Service
RTU remote terminal unit
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SCADA Supervisory control and data acquisition
SDH Synchronous Digital Hierarchy
SONET Synchronous Optical Network
TDM Time Division Multiplexing
VLAN virtual local area network
VMS variable message sign
VPN virtual private network
xDSL any digital subscriber line