# Reimagine the station network for digital rail

## A communications network blueprint for digital station operations and passenger experiences

White paper

Rail operators are working to build, upgrade and transform train stations to keep pace with growing ridership and address the evolving needs of modern travelers. For many operators, the first step on this transformation journey is to embrace the paradigm of digital stations. This means adopting digital applications that will improve passenger safety and situational awareness, increase the operational efficiency and reliability of station equipment, and provide reliable Wi-Fi coverage in every part of the station.

To succeed with these new applications, operators need to reimagine the station networks that support them. A digital station communications network needs to be able to connect and power a plethora of digital equipment, support high resiliency and deterministic quality of service (QoS), distribute accurate time synchronization and fight off sophisticated cyber threats. This paper introduces a comprehensive digital station communications network blueprint that will enable rail operators to meet these needs and deliver superior passenger experiences for years to come.

# Contents

# Introduction

The rail system is a network of train stations where journeys start and end. As mobility needs increase, people are taking the train more often and more passengers are flowing through train stations. Sometimes, train stations become popular places for citizens to meet, dine and socialize, which increases their usage. To serve the evolving needs of passenger and station operations, train stations need to be transformed.

Today, rail operators (abbreviated as operators hereafter) are using applications such as public address (PA) systems and passenger information systems (PIS) in train stations. With an ever-growing number of people using train services and station facilities, operators need to embrace the paradigm of digital stations. This means adopting digital technologies such as CCTV and video analytics to improve passenger safety and situational awareness, using SCADA and predictive maintenance to increase the operational efficiency and reliability of station equipment, and providing high-coverage Wi-Fi for passengers.

Looking ahead, operators seeking to build digital stations will need to integrate edge cloud computing to host artificial intelligence (AI) applications for high-performance real-time applications such as crowd and intrusion detection.

**Figure 1. Operators are adopting new and existing digital applications in train stations**

Digital station applications

**Safety-critical**
- Fire/smoke detection
- CCTV
- Video analytics
- Public address system

**Operation-critical**
- Operational voice
- Operational private wireless
- SCADA
- Smart IoT sensor

**Service-essential**
- PIS
- Ticketing
- Passenger Wi-Fi

# Current station networks fall short of new needs

Operators need an expansive station communications network to connect digital equipment in stations with operations control centers (OCCs). Most have been running station networks for many years. Many have Ethernet networks deployed in stations as extended enterprise LANs. This paradigm works well when there are few applications and application subsystems to be connected. However, the advent of the digital station ushers in many new applications with new network requirements that stretch beyond current station LAN capabilities. Operators face four major challenges for the digital era:

1. Connecting and powering a plethora of equipment with bandwidth for growth
   In addition to typical station applications such as operational telephony, ticketing and passenger information display systems (PIDS), new digital station applications such as CCTV and Wi-Fi require extensive deployments of cameras and access points. With stations hosting more amenities and more passengers, it is no longer uncommon to have hundreds of cameras and a few dozen to hundreds of access points in one station. Some stations also have time displays in every corner for passengers' convenience.

As more station equipment is deployed, the access switch in the station network needs to support greater Ethernet port density. It must also provide high wattage to support high fan-out of Power over Ethernet (PoE) technologies and avoid the need for separate power cabling.

Furthermore, the volume of data to be transported in the station network is increasing rapidly. Switch capacity needs to increase and the switch trunk Ethernet port needs to scale beyond 1 Gb/s to 10 Gb/s to support the multitude of video streams and Wi-Fi data.

2. High resiliency and deterministic quality of service (QoS)

   Applications such as voice communications, CCTV and PA systems are critical to station safety and situational awareness. Network outages cause these applications to fail, which means they can't be used to detect anomalies or alert passengers and staff to dangers in the station. Therefore, the station network needs to support redundancy protection so that communication service can be quickly restored to maintain high application availability.

   The digital station network must carry delay-sensitive data such as emergency voice communications and life-critical applications such as PA systems. Deterministic QoS is necessary to ensure this data is delivered with priority.

3. Distribution of time synchronization

   Operators are embracing predictive maintenance technology for the rail infrastructure, including station equipment such as escalators and ventilation systems. They need ubiquitous connectivity for sensors that monitor the operating conditions of the equipment. As operators deploy new generations of train-to-ground (T2G) communication systems based on LTE or 5G, they can use small cells to extend wireless coverage throughout the station.

   T2G communication systems depend on accurate timing information to function properly. But bringing in GPS/GNSS signals for time synchronization is very often not feasible, particularly for underground stations. The station network can play a pivotal role in maintaining system performance by distributing time synchronization using IEEE 1588 and Network Time Protocol (NTP).

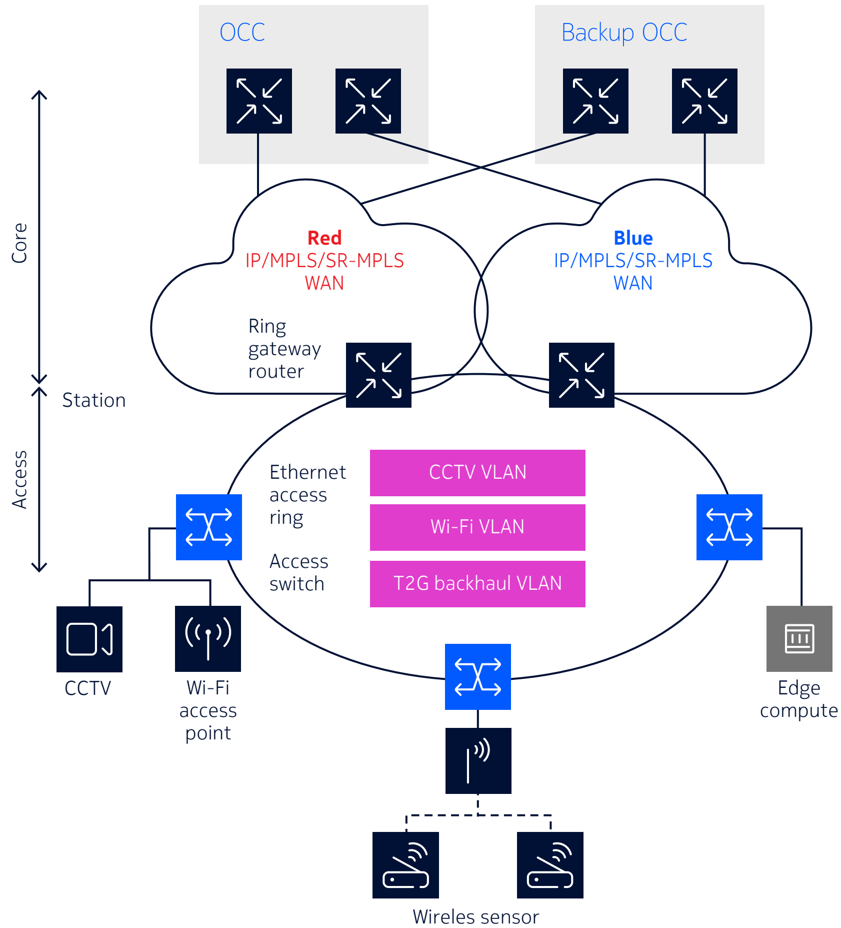
4. Cybersecurity

   With the rise of cyber threats, cybersecurity has become a top concern for operators. The station network itself needs to evolve to become part of the cyber defense framework.

# Nokia digital station communications network blueprint

Operators need to reimagine their station networks to address the demands of the digital era. While the actual network design will vary depending on each operator's requirements and topology constraints, this white paper presents a blueprint network (Figure 2) as a reference architecture that can help any operator tackle the challenges explained above.

Figure 2. The Nokia digital station backhaul blueprint




This blueprint comprises access Ethernet rings that would interconnect to the red/blue redundant wide area networks (WANs)[1] shown in Figure 2.

In the access ring, instead of the 1 Gb/s connectivity supported in station networks today, the blueprint access switch utilizes the fiber system to form a 10 Gb/s access ring based on ITU-T G.8032 Ethernet Ring Protection Switching (ERPS) technology.

The ring connects access switches along the way, collecting all data from station assets to the ring gateway router pair in the train station. The ring gateway router pair form the WAN pair (red and blue networks) with router pairs in other stations, connecting to the active/backup OCC pair.

The network blueprint is built with access switches and ring gateway routers.

## Access switches

Access switches are compact, fanless, AREMA-compliant and temperature-hardened platforms that form a resilient Ethernet ring topology. Due to physical space constraints, these switches require DIN rail-mounting flexibility for easy installation in cabinets. To support numerous station devices, they feature high PoE port density and large power capacity. They utilize standards up to PoE++ (IEEE 802.3bt)

1 Read the Nokia white papers The Journey towards Smart Metro Transit and Is your backbone network ready for FRMCS? to learn about rail backbone core networks.

for demanding devices such as pan–tilt–zoom (PTZ) cameras, Wi-Fi access points and PA systems.[2] Furthermore, these switches distribute precise network synchronization using IEEE 1588v2 Precision Time Protocol (PTP) and NTP.

For larger stations that require enhanced capacity, a dedicated aggregation Ethernet ring can be layered above the access rings to consolidate the traffic to the WAN.

## Ring gateway routers

Ring gateway routers play the key role of joining Ethernet rings with the redundant WANs. In the example shown in Figure 2, they aggregate data from all subtending rings and deliver it to OCCs over the blue or red WAN with dedicated, tailored IP/MPLS services.

# How the blueprint overcomes today's network gaps

The Nokia station communications network blueprint supports multiservice capabilities. With a service-centric approach, the access switch can offer different point-to-point and multipoint Ethernet services in a scalable way, with tailored QoS profiles for each individual station application (Table 1).

**Table 1. Application-aware QoS profile reference example**

| | Latency | Bandwidth | QoS class | Criticality |
|---|---|---|---|---|
| Emergency call system | Low | Low | High-1 | High |
| PA system | Medium | Low | High-1 | High |
| Time/clock distribution | Low | Low | High-1 | High |
| CCTV | Medium | High | High-2 | High |
| Ticketing system | High | Low | Low-1 | Medium |
| PIDS | High | Medium | Low-2 | Medium |
| Passenger Wi-Fi | High | High | Best effort | Low |

Additionally, the network blueprint brings the following capabilities to overcome the station network challenges described earlier in this paper.

## High fan-out 10GE access ring ready for data growth

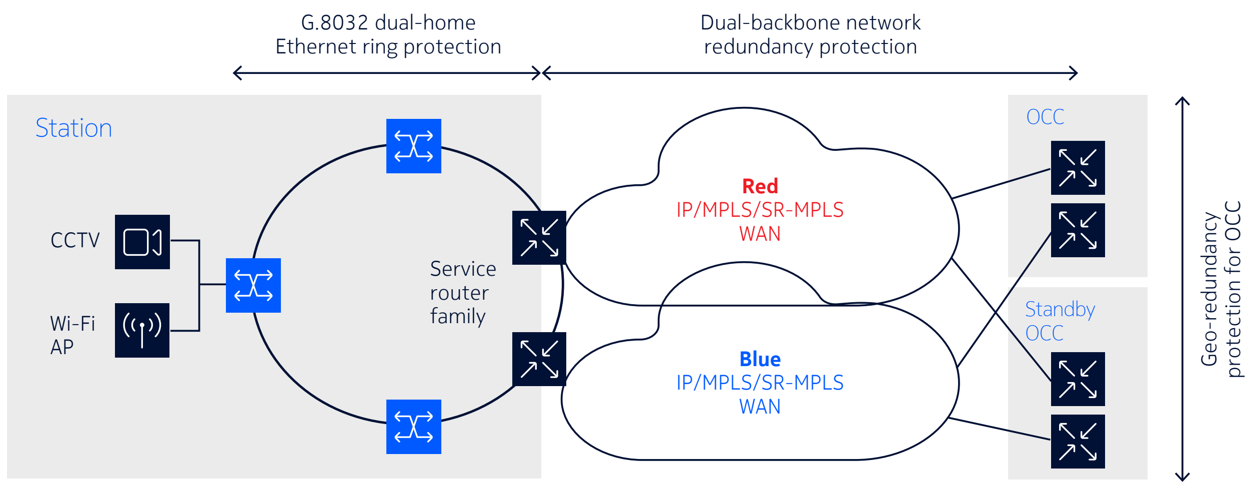
With a compact, space-efficient, DIN rail mounting-capable chassis, the access switch used for the blueprint can massively scale up the access ring bandwidth, Ethernet port fan-out and wattage supplied when connecting to multitudes of equipment, ranging from CCTV cameras to Wi-Fi access points and VoIP phones. It also supports 10 Gb/s Ethernet (10GE) to form a 10GE access ring that satisfies unrelenting bandwidth demand for today and tomorrow. The switch provides flexible mounting options (DIN, wall and rack) that allow it to be deployed anywhere in the station and rail infrastructure.

## Redundancy protection for high resiliency

The access ring is based on ITU-T G.8032 Ethernet Ring Protection Switching. The access switch dual-homes on a redundant gateway router pair. This dual-home ring seamlessly internetworks with the dual-backbone core network to connect with the active and standby OCCs (Figure 3). The result is comprehensive redundancy protection.

2 PTZ cameras, Wi-Fi access points and PA systems need more than 15 watts. They can benefit from PoE+, PoE++ and HPoE support on the high-wattage switches.

Figure 3. End-to-end redundancy protection




## Access ring with redundant gateway

ITU-T G.8032 is a protection switching technology for Ethernet rings where data is forwarded in one direction to the gateway. If a link or a node along the ring fails, the adjacent nodes will rapidly detect the failure. The adjacent upstream node will then inform all other upstream ring switches to switch the traffic in the other direction.

The ring gateway is the only exit point for all ring traffic. If it fails, all ring traffic will be "blackholed" (Figure 4a). Therefore, it is important to provide nodal redundancy protection for the gateway. The fact that the ring switch is dual-homed, i.e., doubly connected to a redundant gateway pair, brings a significant boost to resiliency, as shown in Figure 4b and described below:

1. The active gateway is no longer reachable because of a failure of the gateway itself or an element in the path (fiber or switch), and the failure is detected by the standby gateway.
2. The standby gateway assumes the role of active gateway for the devices affected by the failure.
3. On learning of the redundancy switching at the gateway, all ring nodes affected by the failure forward data in the other direction to reach the newly active gateway.
4. Data continues the journey to the backbone core network.

Figure 4a. A single-home G.8032 ring "blackholes" traffic when a gateway fails

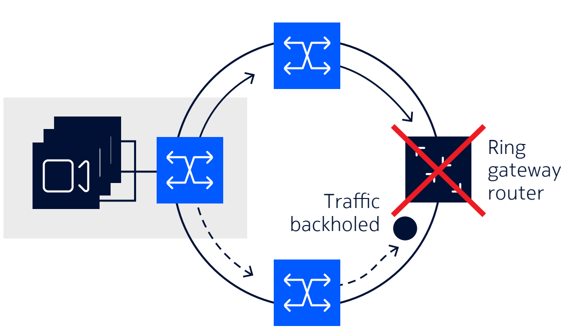
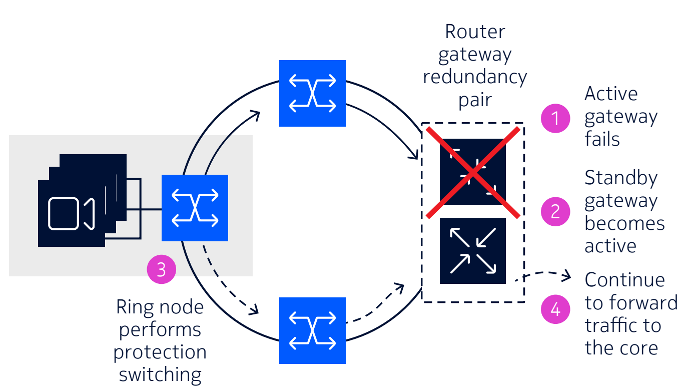



Figure 4b. A dual-homed G.8032 ring protects against gateway failure



### Ring gateway pair interworks with the redundant core networks and OCC pairs

Operators deploy redundancy protection for their WANs and OCC. It is important for the access ring to internetwork seamlessly to maintain this redundancy. The ring gateway pair supports IP/MPLS, with its field-proven redundancy and flexibility, so the access ring can connect station equipment seamlessly to either OCC through either core network.

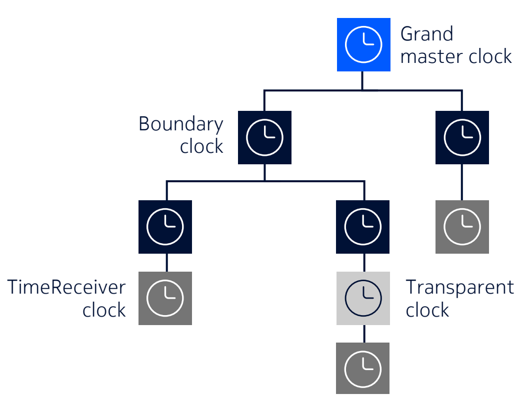
## Synchronization distribution

Operators can expand the T2G LTE/5G network to extend wireless coverage to the station with small cells. This allows for rapid deployment of non-critical sensors to support station equipment condition monitoring for predictive maintenance. It is not always practical to bring GPS/GNSS signals to small cells for time synchronization, particularly in underground stations. Using IEEE 1588v2 Precision Time Protocol (PTP) is a viable and recommended technical option for distributing highly accurate frequency and time synchronization from the WAN through the station network to small cells deep in the station.

A 1588v2 synchronization architecture is based on a hierarchical topology of 1588v2 clocks (see Figure 5) where synchronization is distributed downstream to each 1588v2 clock, of which there are the following types:

- Grand master clock (GMC): The primary clock reference, typically with a high-precision time source.
- GPS signal or atomic clock: Acts as a TimeTransmitter clock[3] to other clocks below it in the hierarchy.
- Boundary clock (BC): Acts as a TimeReceiver clock[4] to the upstream TimeTransmitter clock and the TimeTransmitter to the downstream TimeReceiver clock.
- Transparent clock (TC): Forwards all 1588v2 messages received downstream. The TC has hardware-based capabilities that can modify timestamp information in the messages to account for any delays it causes. It has no TimeTransmitter/TimeReceiver peering relationship to other 1588v2 clocks.
- TimeReceiver clock: Receives PTP messages from the associated TimeTransmitter clock to recover frequency, phase and time information.

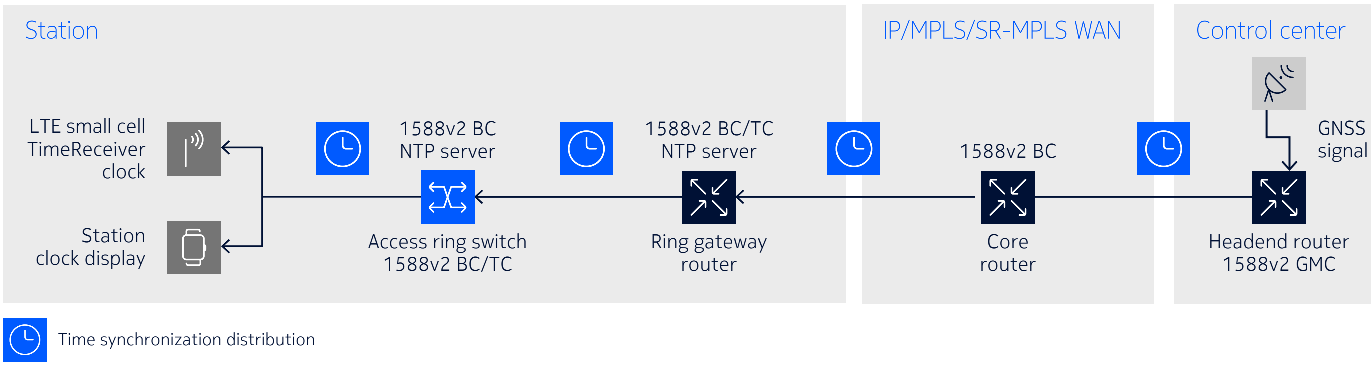
**Figure 5. A hierarchical 1588v2-based synchronization architecture**




The station network blueprint incorporates 1588v2 to distribute time synchronization to small cells and other station equipment that require it (Figure 6). The blueprint also distributes the NTP locally for equipment that requires less precise time synchronization.

3 TimeTransmitter clock has replaced the term “master clock” as per IEEE 1588g-2022
4 TimeReceiver clock has replaced the term “slave clock” as per IEEE 1588g-2022

Figure 6. Station network blueprint integrated with 1588v2




## End-to-end encryption and device authentication

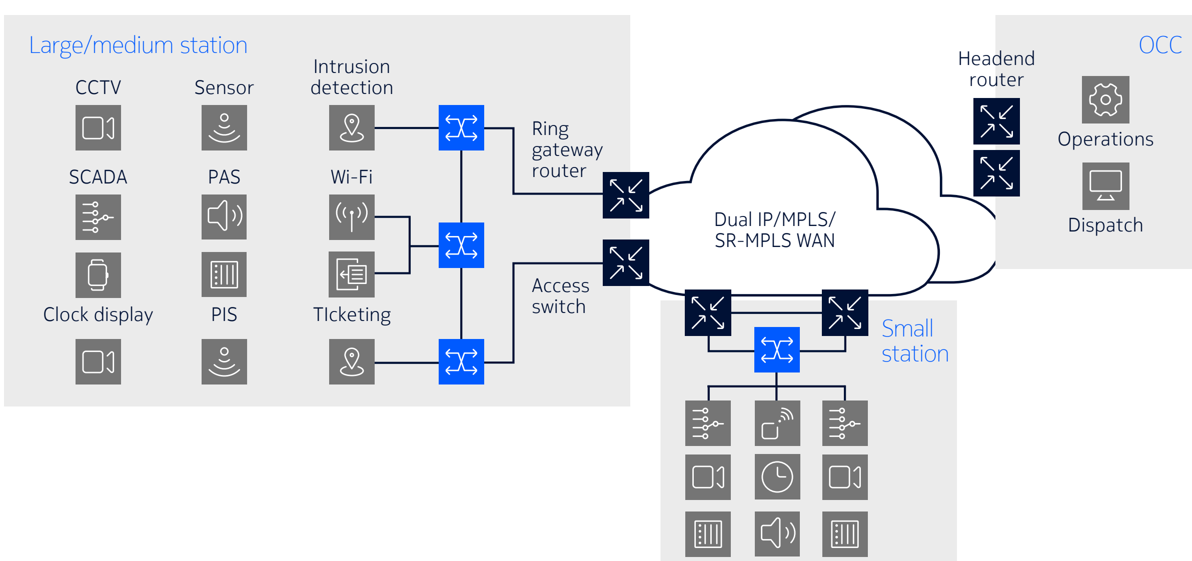
Rail infrastructure is a high-profile target for cyberattacks. As cyberattacks evolve, a multilayer cyber defense is necessary. The station network blueprint forms a formidable defense perimeter with two key measures that stop illicit traffic:

1. Encrypting CCTV traffic: By harnessing the power of MACsec in the Ethernet access domain at 10 Gb/s speed, the blueprint safeguards the confidentiality, integrity and authenticity of station data in the access network.
2. Authentication: By capitalizing on IEEE 802.1X authentication capabilities, operators can ensure only legitimate devices are attached to the Ethernet port of the switches.

## Converged station networking for large and small stations

Operators are embracing more applications and installing digital devices everywhere in stations. The blueprint can evolve and scale to provide operators with a converged station network foundation for digital applications and devices (Figure 7).

Figure 7. A converged station network blueprint

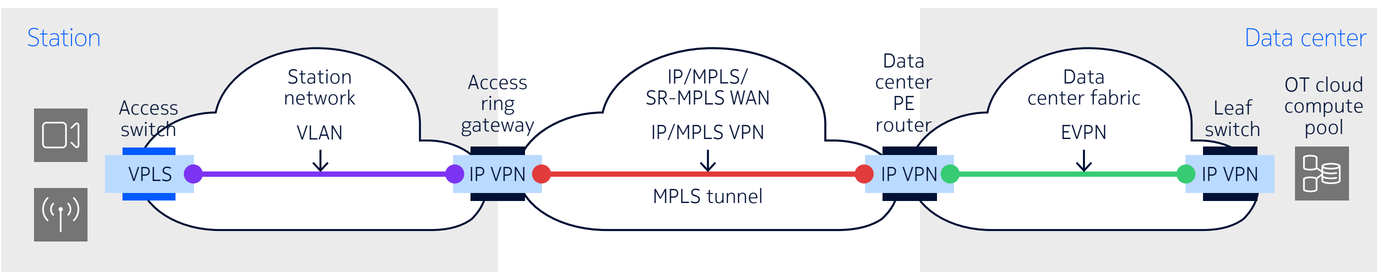


# Looking ahead: Interconnection with OT cloud

The blueprint has more to offer. Many operators now deploy critical smart rail applications such as communications-based train control (CBTC) radio core and automatic train operation (ATO) in a set of segregated on-premises servers that operate in a cloud environment hosted within their private data centers. This environment is known as operational technology (OT) cloud.

The Nokia blueprint provides connectivity that can be extended into the data center for end-to-end OT cloud networking.[5] Its ring gateway router can form the IP/MPLS or Segment Routing MPLS (SR-MPLS) WAN that interconnects the data center network fabric through the provider edge (PE) router, which acts as the data center gateway. This approach enables end-to-end communications between station equipment and the virtualized application workload in the OT cloud compute pool (Figure 8).

Figure 8. Seamless interconnection from station to OT cloud




# Conclusion

Rail operators are at a critical juncture. Population mobility needs are increasing at a rapid pace and will continue to do so in the foreseeable future. The corresponding growth in train traffic puts new pressure on operators to provide reliable, sustainable and safe urban mobility. In addition to digital railway operation technologies such as ATO, operators must deploy digital station applications to serve passengers as they begin and end their train journeys. A new station network blueprint that can support new, emerging and future station applications is an essential enabler for the digital transformation of train stations.

The Nokia digital station communications network blueprint addresses this need with a broad communications product portfolio that spans IP/MPLS, data center networking, LTE/5G, packet optical and microwave. This portfolio is complemented by a full suite of professional services, including audit, design and engineering practices, as well as integration for the railway industry. With this broad range of products and services, Nokia has the unique capability and flexibility to help operators plan and transform their urban railway networks for the future.

To learn more about Nokia solutions for railways, visit our Railways web page.

5 Please read the Nokia white paper Accelerate the digital rail journey: Harnessing the power of OT cloud for a full discussion of OT cloud.

# Abbreviations

| | |
|---|---|
| AI | artificial intelligence |
| AP | access point |
| AREMA | American Railway Engineering and Maintenance-of-Way Association |
| ATO | automatic train operation |
| BC | boundary clock |
| CBTC | communications-based train control |
| CCTV | closed-circuit television |
| DIN | Deutsches Institut für Normung |
| ERPS | Ethernet Ring Protection Switching |
| GE | Gigabit Ethernet |
| GMC | grand master clock |
| GNSS | Global Navigation Satellite System |
| HPoE | high-power PoE |
| GPS | Global Positioning System |
| IEEE | Institute of Electrical and Electronics Engineers |
| IP | Internet Protocol |
| LAN | local area network |
| LTE | Long Term Evolution |
| MACsec | Media Access Control Security |
| MPLS | Multiprotocol Label Switching |
| NTP | Network Time Protocol |
| OCC | operations control center |
| OT | operational technology |
| PA | public address |
| PE | provider edge |
| PIDS | passenger information display system |
| PIS | passenger information system |
| PoE | power over Ethernet |
| PTP | Precision Time Protocol |
| PTZ | pan–tilt–zoom |
| QoS | quality of service |

| | |
|---|---|
| SCADA | Supervisory Control and Data Acquisition |
| SR-MPLS | Segment Routing MPLS |
| T2G | train to ground |
| TC | transparent clock |
| WAN | wide area network |



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

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