

Backbone for the Digital Railway

Malcolm D'Cruz, M.E. Mechatronics, Calibre Global

David Lim, MSc. in Telecommunication Management, Hitachi Rail STS

SUMMARY

Railways are always increasing the number of network services to cope with emerging technologies. The success of Communication Based Train Control (CBTC) depends on the ability of the backbone communication system to guarantee high bandwidths and reliability. Thus the traditional role of railways as a network operator is gradually moving towards a service provider for both internal as well as external clients.

The quick fix solution that railways currently adopt is to deploy parallel networks over the communication backbone system to cope with the demand of emerging technologies like Video Analytics in Closed Circuit Television Cameras (CCTV), Long Term Evolution 4G digital radio and CBTC. This basically means adding a new box each time a new network service is required and the funding comes on top of the operational costs for maintaining the railway in the form of capital expenditure for an Information and Communications Technology (ICT) refresh.

The drawback with hardware-based solutions is that they rapidly reach end of life and require a reiteration of the design-integrate-deploy cycle with little or no revenue benefit and require operational outages for deployment of changes or upgrades. Passenger railway operators are not profit driven, the "no-revenue benefit" factor doesn't really appeal to them instead passenger railways are more worried about public relations and the impact caused by prolonged or unexpected outages. Therefore, minimizing impacts to the operating systems and the railway overall is more appealing to passenger rail operators.

The challenge for backbone railway communication networking is to have a common platform for all network services whilst being ready for emerging technologies like CBTC.

Telecom service providers are faced with the same set of problems every time there is a new network service to be launched, the most common problems are high equipment costs of parallel networks, increased power consumption by addition of new hardware, space issues for retrofitting new hardware, longer deployment times means reduced lifecycle benefits of the hardware, since the technology becomes obsolete by the time the hardware is deployed.

To address these issues, Telecom service providers have embraced the virtualisation trend in information technology to perform network functions which are traditionally provided by hardware such as routers and switches.

The aim of this paper is to show how Software Defined Networks (SDN) adopted by telecom service providers as a common platform for all network services can benefit the railway networking environment to cope with constantly emerging technologies.

1 INTRODUCTION

1.1 Current and Future State of Backbone Communication Networks

Since digital technology was first deployed in the railways, the demand for backbone communication with high reliability and bandwidth keeps on increasing. Western Australia in the 1990's used a PDH MUX, followed by a SDH network using 2Mb/s Pulse Code Modulation to provide that deterministic reliability over the length of the railway.

As new technologies kept emerging, the demand for bandwidth kept increasing to a point where the PDH could not provide the necessary bandwidth for network services like CCTV, Passenger Information Systems and Long Line Public Address Systems. This led to the introduction of Ethernet based IP networks running in parallel to the PDH MUX. The reason that the railways chose to retain the PDH MUX was because whilst the Ethernet networks could handle the demand for high bandwidth, the lack of deterministic properties for data routing, was a good argument in retaining the PDH MUX for mission critical network services like train control. Today we are faced with the problem that both PDH and SDH technologies have reached obsolescence.

With the emergence of CBTC, the field interlocking is replaced with a centralised interlocking controller and train detection is no longer done through track circuits, but with 4G digital radio base stations transmitting vital information back to the centralised interlocking controller. Now the backbone communication network is faced with the challenge of providing high bandwidth and high reliability for vital signalling systems. Latency on the backbone communication network could now lead to a wrong side failure or delay to train operations.

To meet the demands of high bandwidth and reliability for CBTC, some railways are investing in a third parallel network which is a packet switched deterministic networking solution called MPLS, thereby combining the benefits of both Ethernet and the PDH MUX. In simplistic terms this means an additional more expensive box in the field to cope with the demands for CBTC

Therefore, in the past whilst it was acceptable to have a SIL 2 or SIL 0 train control system because the interlocking in the field was SIL 4, with CBTC it is essential to have a centralised SIL 4 system for issuing movement authorities.

This puts an added importance on the transmission system because if there are delays in the transmission or errors in the data packets, the safety of the signalling system is compromised. EN 50159 – Safety Related Communication in Transmission Systems, see reference 1, which specifies that

“If the safety related electronic system involves transfer of information between different locations, the transmission system then forms an integral part of the safety related system and it shall be shown that the end to end communication is safe in accordance with EN 50129”.

It is also for this reason that railways invest and build private communication networks. Besides rail operations and throughput, it is predicted that passenger experience will be a significant driver of innovation in the rail industry.

According to the International Transport Forum, by 2050 passenger mobility will increase by 200-300% as per reference 5, this will require real-time analysis and monitoring putting pressure on the backbone transmission system to handle big data at faster rates.

The following are just a few examples of future passenger services, some of them are shown in Figure 1 – Rail Services in 2050, competing for faster big data handling capabilities and network resources from the backbone communication system:

1. Station congestion monitoring to allow for better crowd handling;
2. Platform trip or fall detection systems interlocked with train braking; particularly useful in driverless metros;
3. Real time train delay notification and timetable updates;
4. Cashless ticketing systems;
5. Internet of Things;
6. Passenger Internet Access;
7. E-commerce for Station Stores.

Passengers will expect certainty in terms of time, therefore accurate, real-time information will be the key.

Thus with the emergence of new technologies, the demand for bandwidth and reliability on backbone communication networks keeps on increasing and pushing the railway towards investing in a carrier grade network.

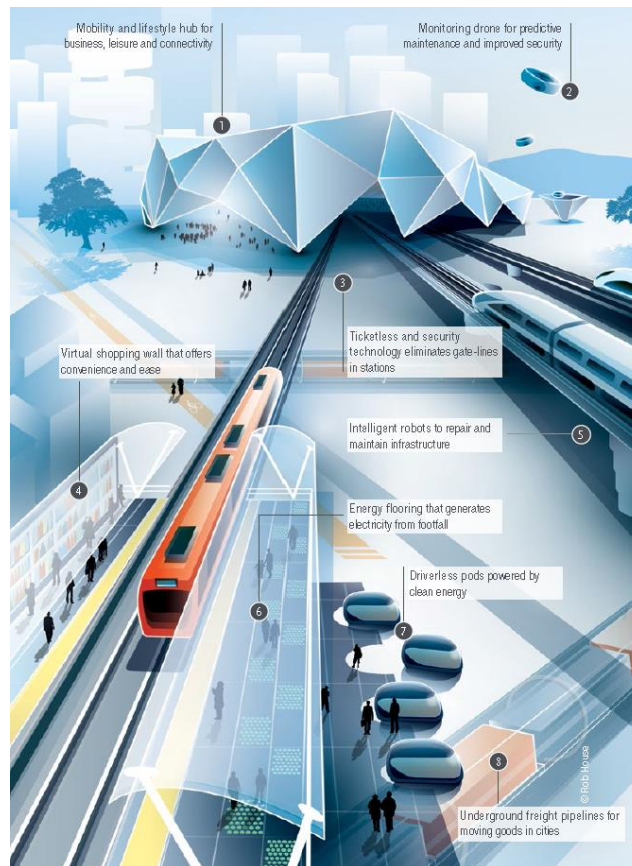


Figure 1 – Rail Services in 2050 (reference 5)

1.2 Challenges faced by Telecom Service Providers

The telecom industry is already facing some of these challenges today and requires a solution now. With the emergence of smart phones and 4G, telecom service providers have to grapple with handling big data so that each customer can have a personalised experience on the telecom service provider's network. Such as a mobile phone plan where customers can pick and choose the services they want.

To cope with new network services new hardware had to be installed on the backbone communication network. However, this is not the ideal solution due to the obvious costs associated with deployment of new hardware.

1.3 Parallel Networks Not the Ideal Solution

Addition of parallel networks to cope with emerging technologies is something that is happening at a faster rate, in the order of every 4-5 years, this presents the following problems for telecom service providers and modern railways:

1. Finding capital to invest in the new technologies;
2. Finding space and power to accommodate a new box each time the technology changes;
3. Up skilling of staff to design, install and maintain new complex hardware on the railway;
4. As innovation accelerates in modern times, the hardware becomes obsolete very fast, putting additional funding pressures for network upgrades.

1.4 Software based Solutions is the Answer

Telecom service providers are now looking at software running on computer servers to perform network functions. Leveraging from the IT industry's virtualisation trend, there is great benefits in coding different network functions in virtual machines within a single computer server.

Use of software to define Network Functions provides the following benefits:

1. Reduced equipment costs and power consumption through consolidation of networking hardware;
2. Faster deployment times as changes and upgrades are only software based; this means the network becomes ready for the challenges of emerging technologies;
3. Services can be rapidly scaled up or down based on demand; network service settings like Quality of Service (QoS) can now be modified centrally;
4. Software based network solutions also expand the market to software developers instead of pure hardware manufacturers. Therefore, the railway is not confined to type approving a new product each time there is a need to update the backbone networking technology. Instead only software testing and validation is required through the process defined in EN 50128, see reference 3.

Therefore, type approval is not limited to the product lifecycle because the software version is the main focus of the type approval. The software version can still have a product lifecycle, but it is not as short as the hardware product lifecycle because software can be subjected to a continuous improvement process.

2 NOTATION

4G	4 th Generation
API	Application Programming Interface
ASIC	Application Specific Integrated Circuits
CAPEX	Capital Expenditure
CBTC	Communications Based Train Control
GENELEC	European Committee for Electrotechnical Standardization
CCTV	Closed Circuit Television
COTS	Commercial Off The Shelf
GUI	Graphical User Interface
ICT	Information and Communications Technology
IT	Information Technology
LAN	Local Area Network
LTE	Long Term Evolution
MPLS	Multi Protocol Layer Switching
MUX	Multiplexer
NFV	Network Function Virtualisation
NMS	Network Management System
OPEX	Operating Expenditure
ONF	Open Networking Foundation
PC	Personal Computer
PDH	Plesiochronous digital hierarchy
QoS	Quality of Service
SDH	Synchronous Digital Hierarchy

SDN	Software Defined Networking
SIL	Safety Integrity Level
VLAN	Virtual LAN

3 WHAT IS SDN, IN A NUTSHELL?

3.1 Viewing the simple Network Device from a System Point of View

Network device functionality can be grouped into 2 sub-systems namely the control plane and the forwarding or data plane, which are shown in Figure 2 – Control Plane and Data Plane.

The control plane consists of the network architecture and the routing protocols and rules for how packets from different applications are to be treated such as Label Distribution Protocol used in MPLS.

The data plane is the proprietary hardware within a particular router or switch in the network that actually transports the packets from one hop to another such as Network Address Translation Tables inside the ASIC of the router hardware.

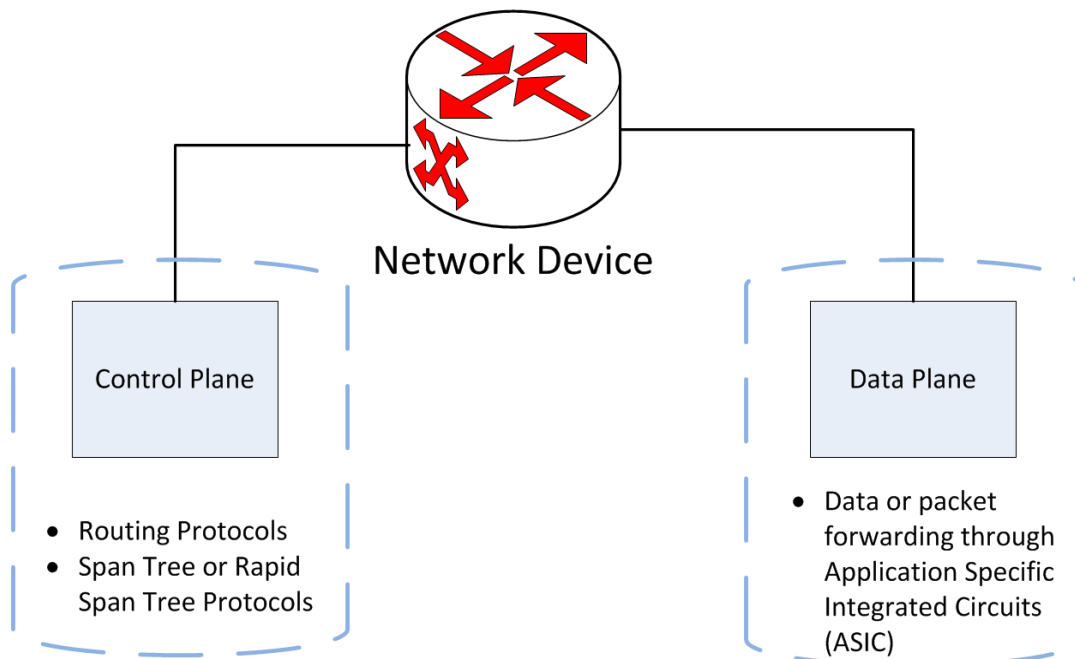


Figure 2 – Control Plane and Data Plane

3.2 Replacing the Control Plane with Software Defined networking

Most network routers and switches use a COTS microprocessor carrying out the functions of the Control Plane.

SDN replaces the function of the control plane with software running on a centrally located computer or server called the SDN Controller, as shown in Figure 3 – Control Plane Functionality in SDN.

Therefore in SDN territory, whenever there is a change in routing protocol or rules, this can be done on the fly by simply updating the software on the computer or server.

With SDN, Changing from Ethernet to MPLS can be done simply by updating the software on a centralised server because the control plane is no longer a distributed protocol, requiring updates or upgrades for each device in the field.

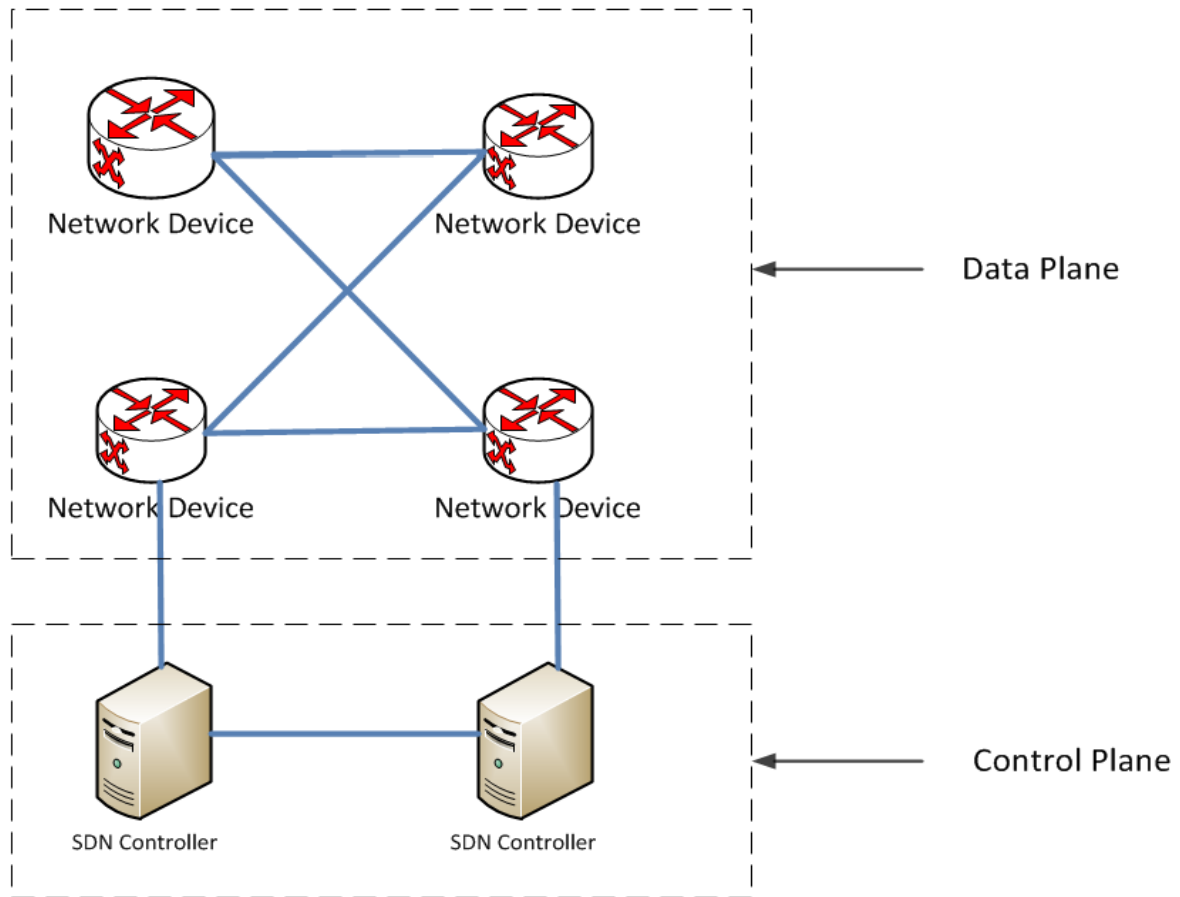


Figure 3 – Control Plane Functionality in SDN

In a SDN-enabled backbone communication is more agile, in respect to being able to adapt to the needs of emerging technologies and end-users applications. As the handling requirements for each type of data packet can be better managed in a centralised server through software.

3.3 Taking it a step further- Network Function Virtualisation

Leveraging of the virtualisation trend in the IT industry for servers, we can now use virtual servers to perform auxiliary network functions like Network Management, Firewalls and storage of network address tables as shown in Figure 4 – Network Function Virtualisation

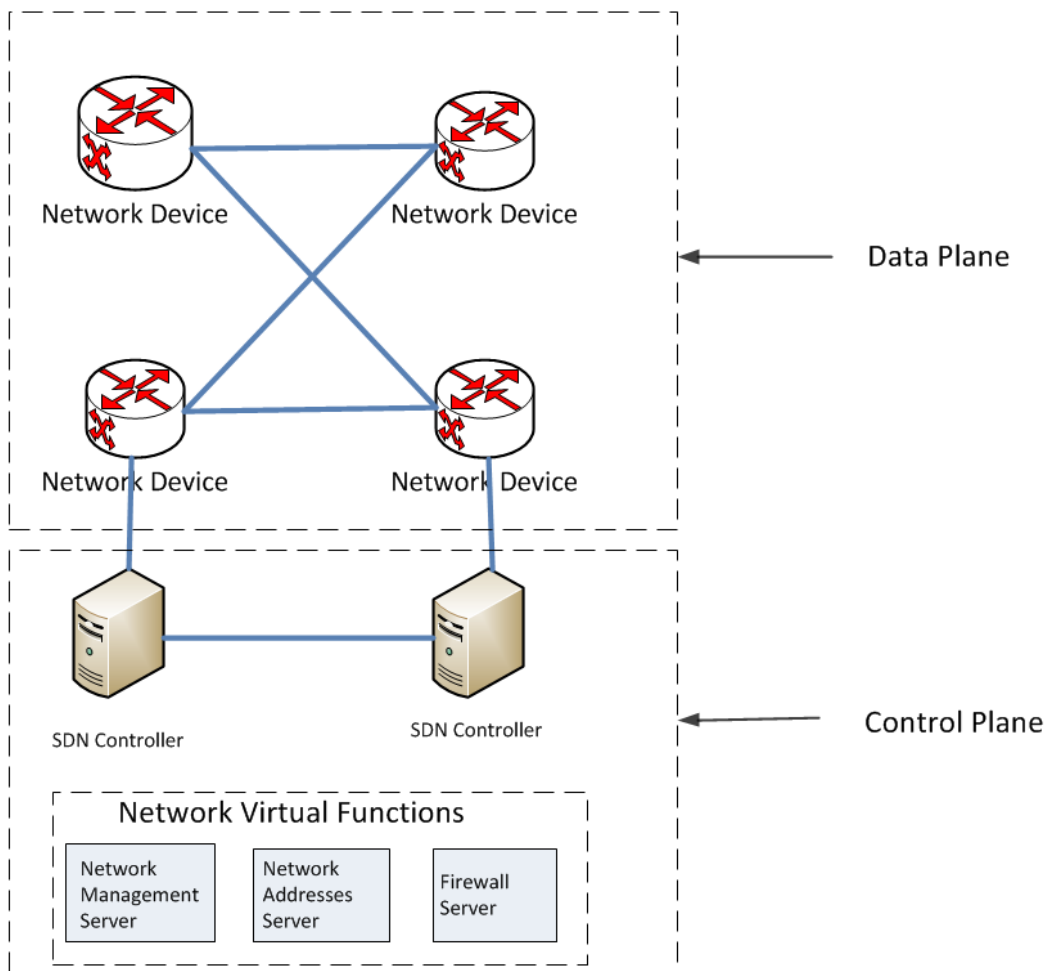


Figure 4 – Network Function Virtualisation

3.4 Next Step - Developing the Software for SDN Language & Platform

Presently the Open Networking Foundation (ONF) has developed an open standard protocol called OpenFlow for implementing SDN.

Besides OpenFlow there are several other APIs for management of SDN solutions like OpenStack, OpenNaaS or OGF's NSI.

Besides the open source standards, certain hardware manufacturers have seen the potential and have developed their own SDN APIs to work with their products such as Cisco's One Platform Kit (OnePK) and Juniper's Junos SDK.

3.5 Fitting it all in the World of Railways

Rail software developers use the CENELEC Standard EN 50128, see reference 3, to ensure safety and reliability of the code.

The same can be applied for SDN application where vital data is required to be transmitted. The software developer can now construct a requirements specification and traceability for the SDN controller to handle certain data from vital safety systems with higher priority versus data from non-vital systems.

Instead of traditional QoS and port priority settings on the field network device, the software developer can now prepare use-case diagrams and requirement traceability matrixes to show how data from vital systems are to be handled, and how custom routing protocols are developed in SDN.

Therefore there is a lot of visibility and much more control of the network controls than was previously possible with hardware based solutions.

3.6 Long term benefits of SDN on Railways

If a new network service is to be installed on the railway, previously this would require design, procurement of hardware and installation on the live system requiring an outage. With SDN this is reduced to a simple configuration update.

Network alarms and faults can be displayed in a user friendly graphical user interface making it easier and faster to identify and fix network faults. In a conventional network this would be harder to diagnose and maintenance personnel would have to travel to different sites to diagnose system faults.

Therefore while it may appear that the upfront investment and development costs are high, the real gains are in operational costs and cost savings from performing updates or upgrades almost on the fly and during operational hours, simply because the network controller is now centrally located and is software based.

Due to the centralised SDN controller, fault finding and fault management is more efficient as the alarms are consolidated and permits the application of root-cause analysis and simpler. Using software and virtual machines separate fault servers can be created to log network faults.

User friendly GUIs can be created to analyse faults faster than was previously possible with distributed network devices.

4 BUSINESS DRIVERS FOR SDN – RAILWAY APPLICATIONS

There are hard dollar savings in the operational expenses or OPEX expenses associated with adoption of a SDN network. These savings come from savings in real estate, power, cooling and cabling.

Long term cost savings for the railway industry come from fault management and change management to cope with emerging technologies and addition of new network services.

Change management on an operational railway network is a costly exercise. When a railway is facing a decision to upgrade the existing telecommunication infrastructure, very often the change management will have to go through the following stages:

1. Completion of a Technical Study;
2. Business case to justify the funding;
3. Approach the market for a solution;
4. Design;
5. Construct;
6. Test and Commission the system;
7. Approval for Service Outage in order to enter to service – *This is generally the hardest part, as rail operators do not easily give approvals for network shut downs.*

The above mentioned stages are time consuming and once the cycle is completed, the full benefits of the technology cannot be achieved, as the electronic components, or in some cases may reach its useful life, thus the a new cycle begins again.

In an SDN network, changes can be done very quickly as they are software based and the cost and time to implement new network services becomes reduced.

4.1 Run your Business more efficiently- the centralised SDN Controller

The SDN Controller is the brains of the network and it is centrally located, this means that railways will have reduced maintenance overhead costs associated with having technicians located at different sites to reduce travel times to fault locations.

4.2 No Vendor Lock-in

Because the SDN Controller is a PC based server that runs the network control software, the railway is no longer locked in with a particular type approved vendor for networking equipment. This means that the problems faced

with railways today in dealing with equipment becoming obsolete no longer exists. Not being locked in to a particular vendor also enables the railway to go to the market looking at a broad range of vendors to get a better price.

The network solution is now open to software developers and is no longer limited to manufacturers of hardware.

However, it is recognized that proprietary SDN solutions which are vendor specific will continue to play a role in the market for clients who are seeking customized features.

4.3 Time and Cost associated with up skilling of field staff

Transition to new technologies requires up skilling of site based maintenance personnel, sometimes to the point where personnel with engineering degrees are required on site for maintenance because of the complexity of the system. In a distributed networking solution, more of these highly skilled staff would have to be employed on site to cope with emerging technologies.

Because the SDN Network is software controlled and typically through a single platform therefore the system stays the same, but the software keeps evolving to the needs of the business.

Subsequently the training needs can be better targeted at the system level so that staff can develop the core skills for maintaining the SDN controller which remains as a constant element of the system, while the field networking devices could change and evolve as the business grows. Traditionally training has focussed heavily on the hardware and staff would have to be retrained every time there is a vendor change or even a model update within the same vendor.

With SDN the complexity of the network is in the software running on the centrally located SDN controller. The field devices are basic network switches with no complex configuration thereby eliminating the need to have highly trained networking and software engineers in the field. Therefore the railway now has the ability to move the maintenance and operations of the network to where personnel who are better suited for the task are located, versus having to locate them on site.

4.4 Better Network Management – Agile and Responsive Networking

The software based nature of the SDN controller makes it more agile to the changing needs of different network service providers. This gives the operator the capability to better manage network traffic flow to meet the changing end-user and end-application requirements and provides the benefit of a single management tool commonly used by all operators; this is moving away from the traditional single NMS which can only manage a few specific vendor hardware.

For example, if the latest on-board automatic train controller configuration has to be downloaded when the train is stopped at a station, the network traffic flow can be modified to prioritise the configuration download request over the CCTV footage from the station.

4.5 Improved Network Security

Network security can be maintained by configuration of private VLANs so that data from one network cannot enter the other. The SDN Controller can be configured to monitor suspicious data packets and shut down the particular VLAN, without affecting the networks.

Setting up of VLANs is not new technology and can be done in a regular Ethernet network, but the dynamic ability to monitor traffic on the different VLANs and shut down affected VLANs is something that is unique to SDN.

The Firewall and encryption settings all reside in the centrally located SDN controller and can be updated at any time by the network manager to address specific threats.

4.6 Ability to cater for different types of traffic on a common platform

Previously railways operated parallel networks such as PDH MUX and Ethernet or MPLS and Ethernet to get the benefits of a high availability, low latency deterministic network and a high bandwidth non-deterministic network.

With SDN there is no need for multiple types of networking hardware in the field to cater for the different types of traffic. The software in the SDN controller can be configured to manage data packets from the different network

services either deterministically or non-deterministically, giving more options to the user group who can choose to customize the service to fit their application requirements.

In simplistic terms the SDN controller can be configured to ensure that critical services like signalling always takes the same path for networking.

4.7 Ability to apply railway RAMS in the networking software

As the networking software is user configured and not a proprietary configuration inside the networking hardware, we can use CENELEC Standards like EN 50128, see reference 3, and EN 50126, see reference 4, on the SDN controller software to define a level of SIL for the handling of safety critical network traffic. Previously this was not possible because there was no visibility of the network device's control plane configuration and railways would only type approve a network device based on its application and performance history on other railways.

5 CASE STUDY – EAST JAPAN RAILWAY COMPANY (JR-EAST)

5.1 The Challenge

Railways in Japan are a major means of passenger transport and a railway station such as Tokyo Station is equipped with a high number of networks. Usually when a new service was required a separate network was built to cater for that particular network service which led to complexities in cable management and inflated timeframes for maintenance or upgrades to the network.

As the physical network required an outage for implementation of changes, the window for carrying out the works was after the last train has left the station and until the first train arrives in the morning.

These parallel networks introduced the same problems as discussed in Section 1.3

5.2 The Solution

The East Japan Railway Company took a decision to bring all the different networks into a common network and call this the station network.

The solution adopted for the common station network was the use of a SDN network solution.

5.3 The Results

By leveraging the SDN solution, JR-East has successfully improved the quality of service at Tokyo Station, by using the user friendly GUI to immediately rectify the cause of the network faults. .

Updates to the system can be done on the operational system through careful design of the software and installation of updates.

As the SDN can be configured centrally anytime to create separate VLANs, JR-East is trialling a new passenger congestion system to detect passenger over-crowding on the concourse and train platforms using IP cameras in the station. This system will give updated information on tablet PCs carried by station personnel to better direct the flow of people in the station. Previously to implement such a system would require installing a separate network and an outage of the running network to complete the installation works.

The SDN network at Tokyo Station is called the "Common Station Network". The results from the installation at Tokyo Station proved to be beneficial enough to justify the roll-out of the SDN based Common Station Network across all 36 stations in the Yamanote Line Area of Greater Tokyo. Figure 5 – SDN at East Japan Railway Station shows the stations services currently operating on the SDN-enabled network.

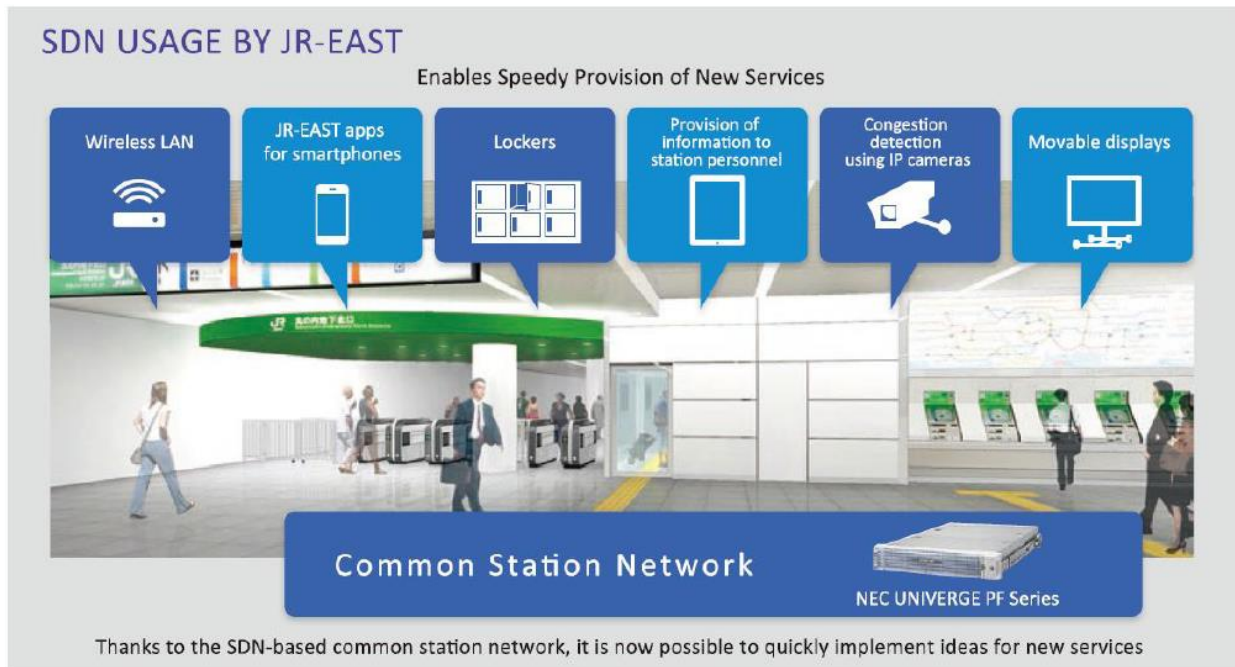


Figure 5 – SDN at East Japan Railway Station (reference 8)

The main selling point for the roll-out of the Common Station Network is the ability of the backbone communication system to respond quickly to changes in the station environment. No longer would there be a need to wait for the station to shut down so that configuration changes will have to be carried out on one of the parallel networks.

Another benefit is that there is more control of network paths and routing protocols to optimise the use of bandwidth by each network service and provide stable network services.

6 FUTURE CONSIDERATIONS FOR SDN IN THE RAILWAYS – WHERE TO FROM HERE?

The concept of SDN has proved that the future of networking will be defined by software and there are several products that bring this concept into realisation such as Cisco OnePK, NEC’s Programmable Flow, IBM and many more.

There is still work to be done in developing protocols and standards to make SDN a really software based solution that is not proprietary hardware driven.

From a railways perspective, work can be done in the area of developing specific SDN software that follows the process for SIL rating, so that the SDN can be used in safety critical applications like CBTC and transmission of movement authorities.

The advantage of having networking software that is SIL rated will eliminate the need for special hardware boxes in the field to encrypt the vital signalling data in the field and transfer it over the transmission backbone network.

For example, to upgrade a legacy signalling equipment for CBTC applications, a hardware based protocol converter is required in the field to convert the protocol of the legacy equipment to Unisig- Subset 098 protocol for CBTC Radio Block Centre (RBC) communications, see reference 6.

Instead the existence of a SIL rated software used for SDN, eliminates the need for the separate protocol converter hardware. The protocol conversion can be built directly into the networking software.

It is features like these that are very specific to railways which need to be developed to make SDN the preferred networking technology for CBTC and other vital rail systems.

Even with today's standard block signalling applications, there is legacy hardware installed in the field only because there is no replacement product that can communicate in certain proprietary serial protocol for train control applications.

However SDN can be used to provide that facility to translate and package signalling data in whatever protocol required.

In SDN the user has visibility and control on the networking software and can define this software to be safety critical following the process of SIL rating described in EN 50128, see reference 3. No longer is the packet translation and routing protocol proprietary software inside a proprietary piece of hardware.

7 CONCLUSION

Bringing the Control Plane functionality out of the network device and into a centrally located PC based server with software allows the network control to build on the innovations in the IT and cloud based architecture.

For this reason Telecom Service Providers and large data centres have embraced SDN technology so that the backbone network has the agility and flexibility to cope with changing demands of network services.

This paper has shown that historically railways have gone down the path of parallel networks each time a new network service was required. This has introduced challenges for installation and maintenance. At a higher level the time taken to design and deploy parallel networks introduces problems of obsolescence of hardware immediately after deployment.

A common network which is software based in the form of SDN gives the railways the flexibility to adapt to changing needs of the network and at the same time have additional capacity to cope with the requirements of new and emerging technologies.

8 REFERENCES

1. EN 50159 – Safety Related Communication in Transmission Systems
2. EN 50129 - Railway Applications - Communication, Signalling And Processing Systems - Safety Related Electronic Systems For Signalling
3. EN 50128 - Railway Applications - Communication, Signalling And Processing Systems - Software For Railway Control And Protection Systems
4. EN 50126 - Railway Applications - The Specification And Demonstration Of Reliability, Availability, Maintainability And Safety (rams)
5. Arup Future of Rail 2050
6. UNISIG – Subset 98 – RBC to RBC Safe Communication Interface
7. An Implementation of EURORADIO Protocol for ERTMS Applications - World Academy of Science, Engineering and Technology - International Journal of Computer, Electrical, Automation, Control and Information Engineering Vol:7, No:6, 2013.
8. NEC Case Study – Software Defined Networking Solution – East Japan Railway Company