

COURSE 6

RAILWAY COMMUNICATION

SYSTEMS

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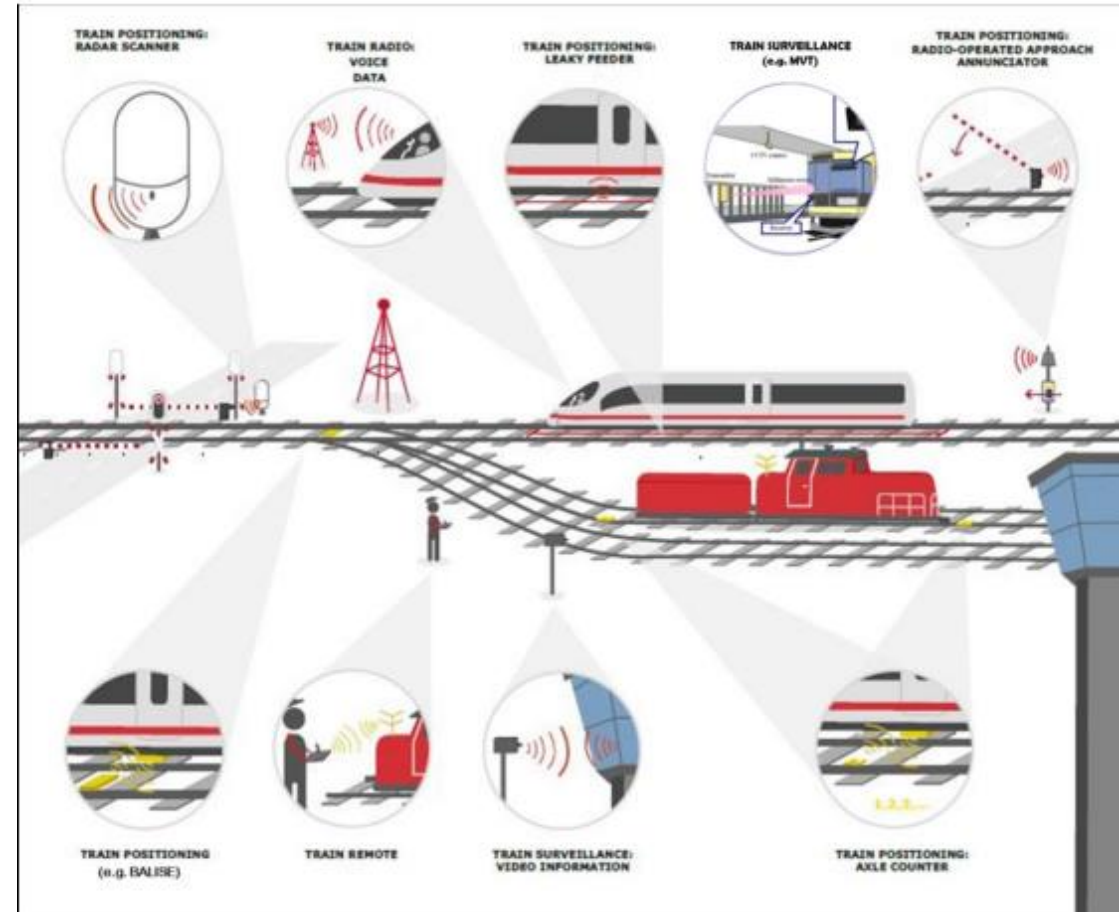


INTRODUCTION

- ❑ Standardization organizations for railway communications are ETSI and ITU-R
- ❑ The ITU-R M.2418-0 report describes the main communication systems between trains and infrastructure (RSTT – Systems between Train and Trackside)
 - The system enhance traffic control, passenger safety and operational security
 - The system architecture includes the radio access unit (antennas, base stations), on-board train equipment, other infrastructure elements
- ❑ The main applications are:
 - Radio in the train used for signaling and traffic management
 - Provides data and voice communications
 - Train control

INTRODUCTION

- Maintenance
- Emergency situations
- Train information
 - Information in stations and trains for passengers
- Train localization
- Balises
- Leaky cable
- Radar
- Remote control
- Surveillance



*ITU-R



INTRODUCTION

□ The technologies used for RSTT are:

○ In-train radio

- Analogue radio
- Digital radio digital – conventional, based on TETRA (Europa) and B-TrunC (China)
- GSM-R, LTE-R
- LCX (Leaky Coaxial Cable)

○ Remote control and surveillance

- Analogue and digital radio
- GSM-R, LTE-R
- B-TrunC and mm wave (Japonia)



TETRA

- ❑ TETRA (Terrestrial Trunked Radio) is an ETSI standard developed for governmental agencies, emergency services, railway transportation and military applications
- ❑ TETRA terminals can communicate in DMO (Direct Mode Operation) or TMO (Trunked Mode Operation) and can act as relays
- ❑ TETRA advantages
 - High coverage range
 - Supports both voice and data communications
 - Provides almost constant performance regardless of the speed of the terminals (up to 500km/h)
 - It is used for subways and high-speed trains in many countries
 - Ensures terminal authentication and data encryption



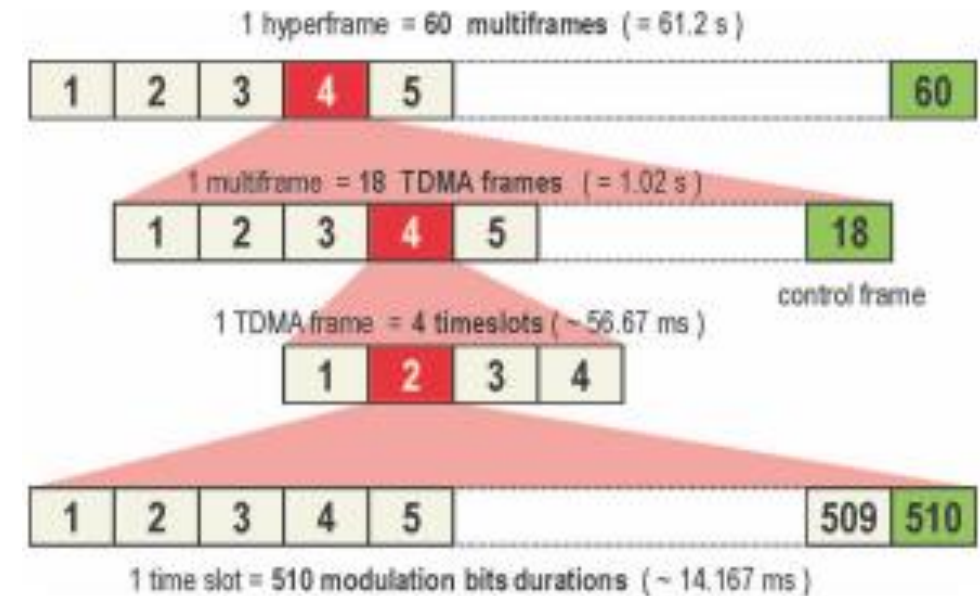
TETRA – RADIO INTERFACE

□ Radio interface

- $\pi/4$ -DQPSK modulation with symbol rate 18000Baud is used, with 2 bits/symbol, meaning 36000 bps
- TETRA uses TDMA with 4 interleaved channels/user
 - The channel separation is 25 kHz
- The voice signal is sampled with 8 kHz frequency and encoded using ACELP (Algebraic Code-Excited Linear Prediction)
- The frequencies allocated for TETRA varies in different countries
 - > 350 – 370 / 380 – 400 MHz
 - > 410 – 430 / 450 – 470 MHz
 - > 870 – 876 / 915 – 921 MHz

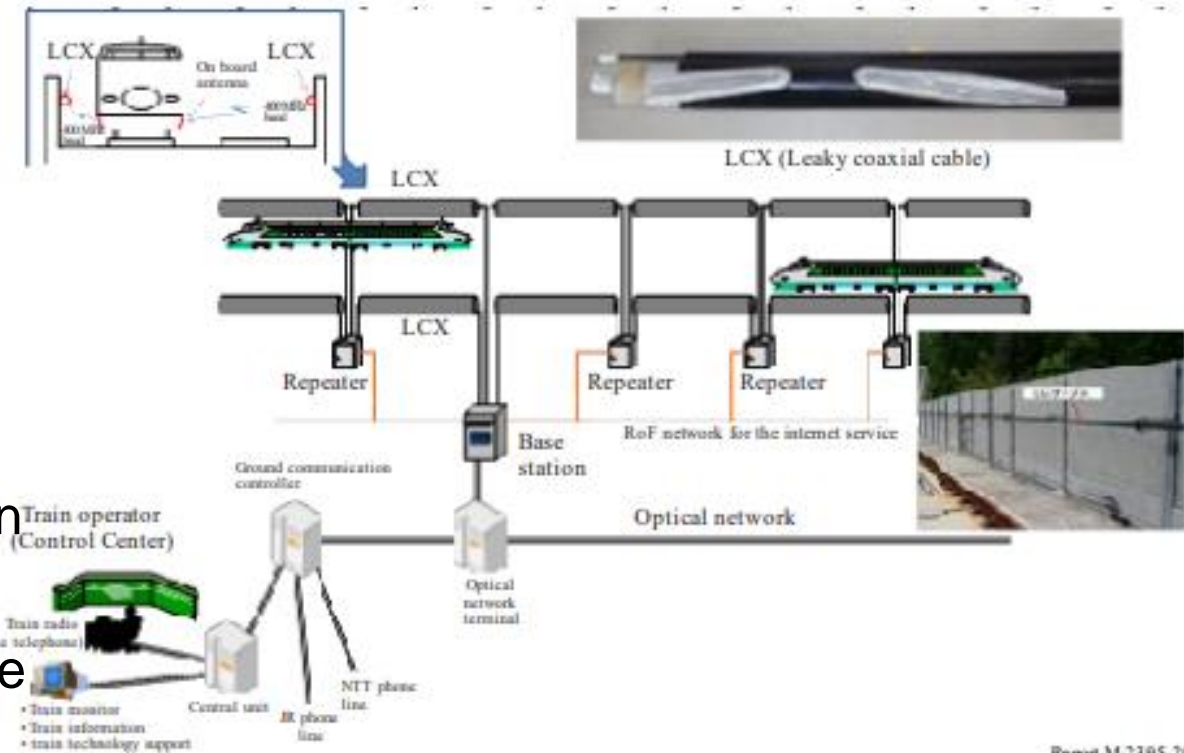
TETRA – FRAME STRUCTURE

- One TETRA hyper-frame includes 60 multi-frames
- One TETRA multi-frame has 1.02s duration and is formed of 18 frames
 - 17 frames are used for data
 - 1 frame is for control information
- One frame is composed of 4 TDMA slots
- One slot has 255 data symbols



LCX

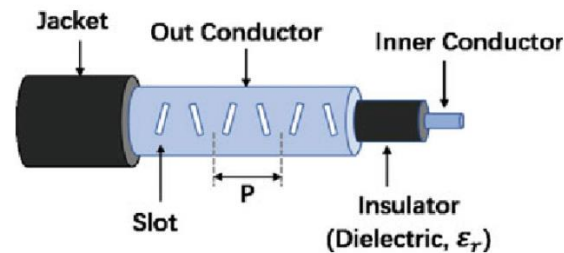
- ❑ LCX (Leaky Coaxial Cable) is used in areas with weak radio coverage, e.g. tunnels
- ❑ LCX lines are installed along the train tracks and the base stations are connected to these lines
 - The distance between base stations is 1.3km
- ❑ Through cables and the antennas on the train (4 antennas) communications between the base stations and mobile stations are possible



Report M.2195-20

LCX

- ❑ LCX was developed in 1967
- ❑ The coaxial cables have slots which allow the propagation of radio waves outside the cable
 - The information is transmitted in the 400 MHz frequency band between the slots and antennas
 - The throughput is 384 kbps
 - The bandwidth is 288 kHz
- ❑ LCX is used for Shinkansen trains in Japan, but also for metro lines





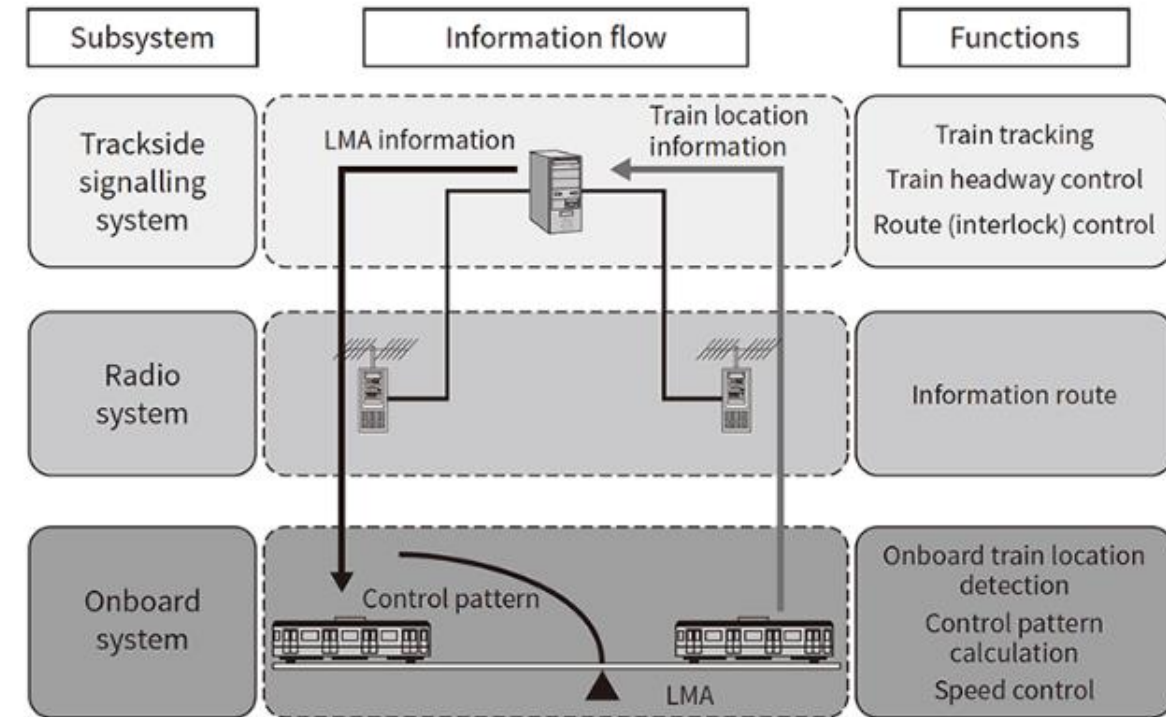
TRAIN CONTROL SYSTEMS

- Worldwide multiple systems are used for train control
 - JRTC – Japan Radio Train Control System in Japan combined with LCX
 - ERTMS – European Rail Traffic Management System in Europe
 - CBTC – Communication Based Train Control
 - Defined in IEEE 1474
 - Information about the speed, direction, location are continuously transmitted to the access points next to the tracks
 - The information is obtained from data balises, tachometers, Doppler radar, GPS
 - The traffic control center computes the maximum speed and distance allowed for the train (LMA – Limit Movement Authority)
 - CBCT is based on WiFi access points with overlapping coverage ranges
 - The access points are interconnected by cables

CBCT

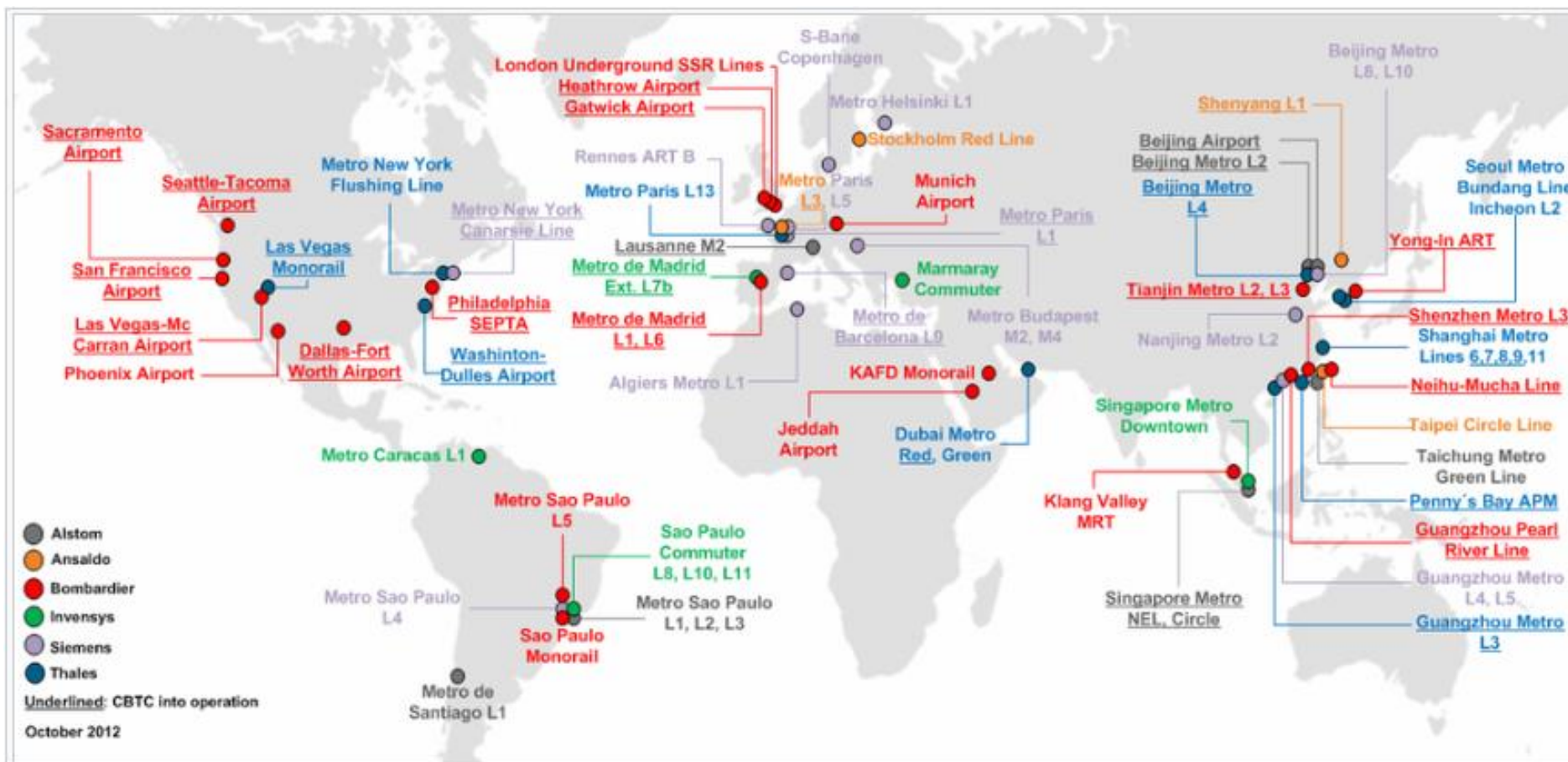
□ CBCT defines 4 levels of automation:

- GoA1 – manual
- GoA2 – semi-automated, partial human intervention is necessary
- GoA3 – human assistant is necessary
- GoA4 – complete automation





CBCT



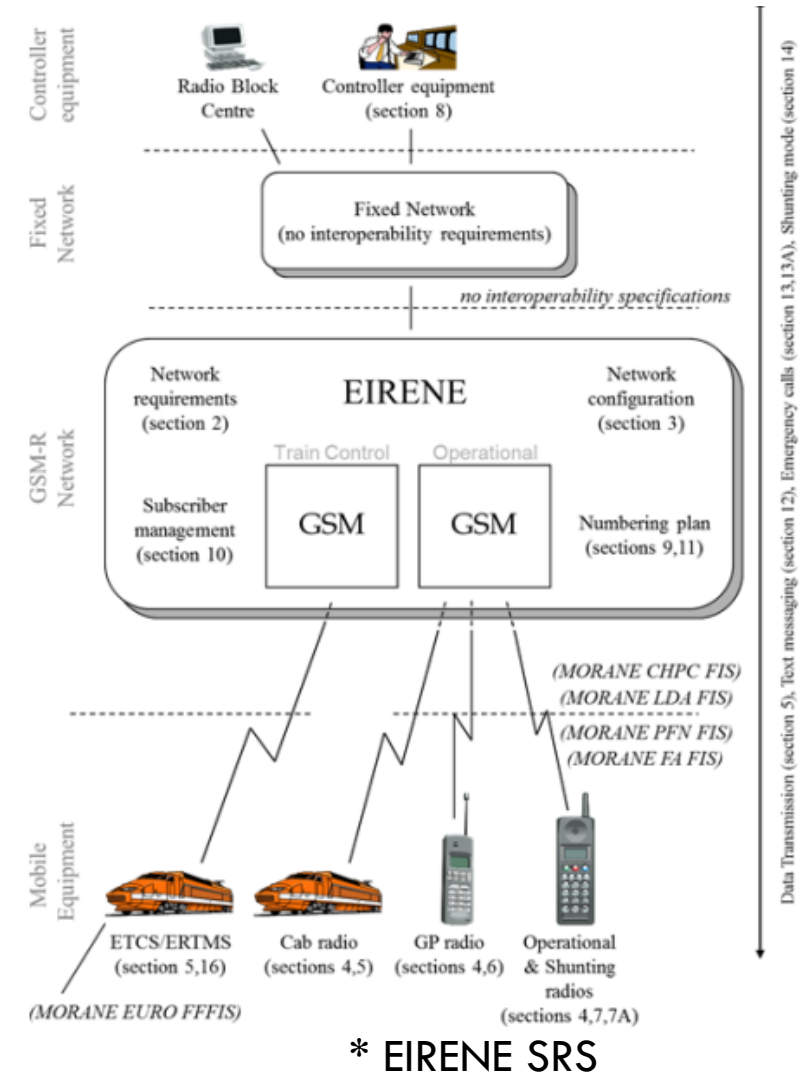
ERTMS

□ ERTMS (European Rail Traffic Management System) is a European project for railway network interoperability which defines the railway signaling standard

- EIRENE – European Integrated Railway radio Enhanced Network

□ ERTMS is composed of 3 major parts:

- GSM-R (Global System for Mobiles – Railway)
- ETCS (European Train Control System)
- ETML (European Traffic Management Layer)





GSM-R

- GSM-R is identical with GSM system, but it offers dedicated functionalities for railway communications:
 - VGCS (Voice Group Call Service)
 - Facilitates group calls between trains and base stations, or between controllers and maintenance teams from stations and allows a great number of users to participate in a call
 - Users of VGCS: talker, listener and dispatcher.
 - Talker can become listener by releasing the PTT (Push-To-Talk) key, listener becomes talker by pressing the key
 - VGCS has higher spectral efficiency than GSM conference calls
 - VBS (Voice Broadcast Service) broadcast messages are sent to a group of trains by the controller or by another train in the same area
 - The main difference compared to VGCS is that only the call initiator can speak, all other participants are listeners



GSM-R

- eMLPP (Multi-Level Enhanced Precedence and Pre-Emption) defines user priority
 - A and B: Highest priority levels (not used by GSM-R networks)
 - 0: Highest priority levels for ASCI (Advance Speech Call Items) and normal calls (mainly used for REC – Railway Emergency Calls)
 - 1: Lower priority than level 0
 - 2: Lower priority than level 1
 - 3: Lower priority than level 2
 - 4: Lowest priority level (default priority, assigned to Point-to-Point calls)
- Shunting mode offers information for the group of persons involved in shunting operations
 - A Link Assurance Signal (LAS) is provided to give reassurance to the driver that the radio link is working
 - The LAS signal is an intermittent audio tone at $820\pm 5\text{Hz}$ frequency, with 1-10s duration and 5-10s silence



GSM-R

- Functional addressing: a train can be addressed by a number identifying the function for which the train is used
 - Many railway staff need to be addressed by functional rather than personal numbers
 - The initiator of the call only has to know the train number
 - A translation facility is provided to allow calls to functional numbers to be forwarded to the most appropriate personal number at that time
 - A follow-me service is implemented using GSM Unstructured Supplementary Service Data (USSD) to allow users to establish and terminate the forwarding of calls from a functional number to their personal number
 - For communication the USSD messages manage the following types of functional numbers: Train number, Engine number, Coach number, Shunting team number, Maintenance team number

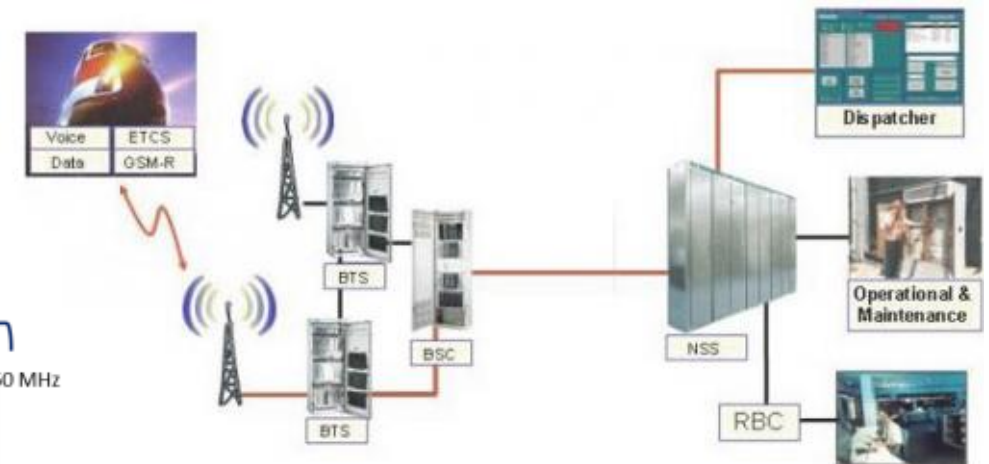
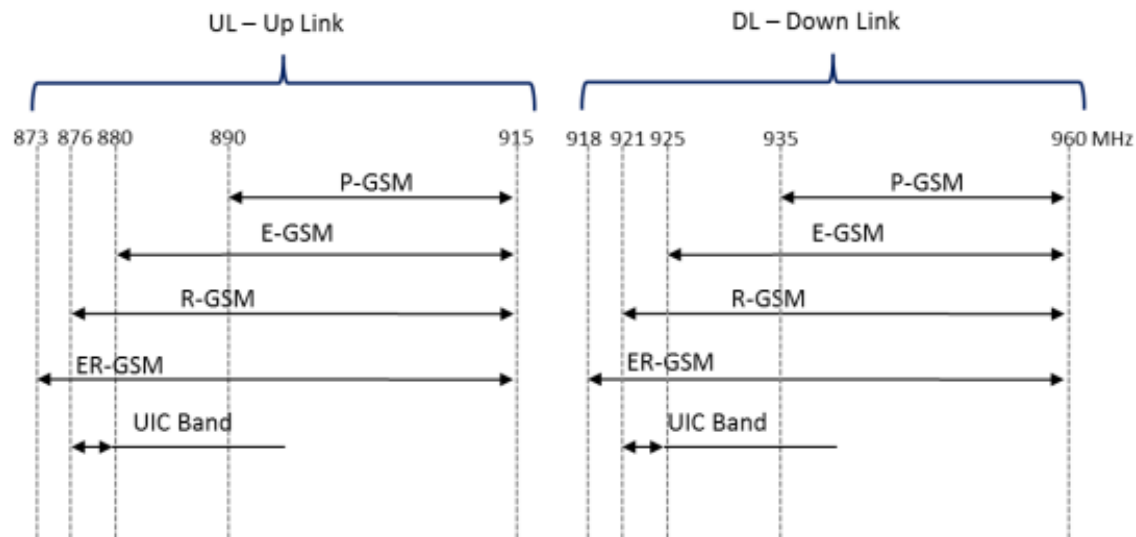


GSM-R

- Location dependent addressing
 - Train drivers need to be able to contact controllers and other staff at the push of a single button
 - As the train moves through different areas, controllers are liable to change. It is necessary to provide a means of addressing calls from a train to certain functions based on the location of the train
 - Location depending addressing can be provided by:
 - Cell based routing
 - Using location from external sources
 - Depending on the radio cell in which the call initiator is located the call is routed to a specific fixed-line number given

GSM-R

- GSM-R is implemented using base stations installed along the railway tracks
 - The distance between 2 base stations is 7-15 km in Europa and 3-5 km in China





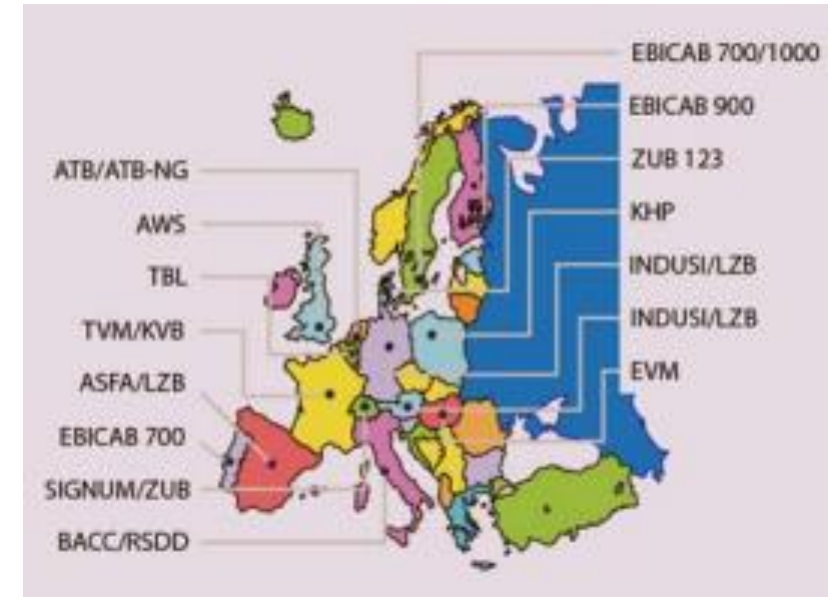
GSM-R

□ GSM-R limitations:

- Interference with public networks
- Capacity: the 4MHz bandwidth can support 19 channels with 200kHz frequency, which is sufficient for voice communications but not for continuous data transmissions
- Capability: the maximum throughput is 9.6 kbps, and delays can be up to 400ms, this delay is too high for real-time applications
- It is foreseen that it will be phased out in 2030

ETCS

- ❑ ETCS is a unitary railway signaling system which aims to replace the different standards used at EU level
- ❑ ETCS (European Train Control System) allows trackside equipment to send information to the trains
 - The trains can compute the maximum allowed speed based on the received information
 - The information is sent by standardized beacons, called euro-balises
 - This corresponds to ETCS level 1

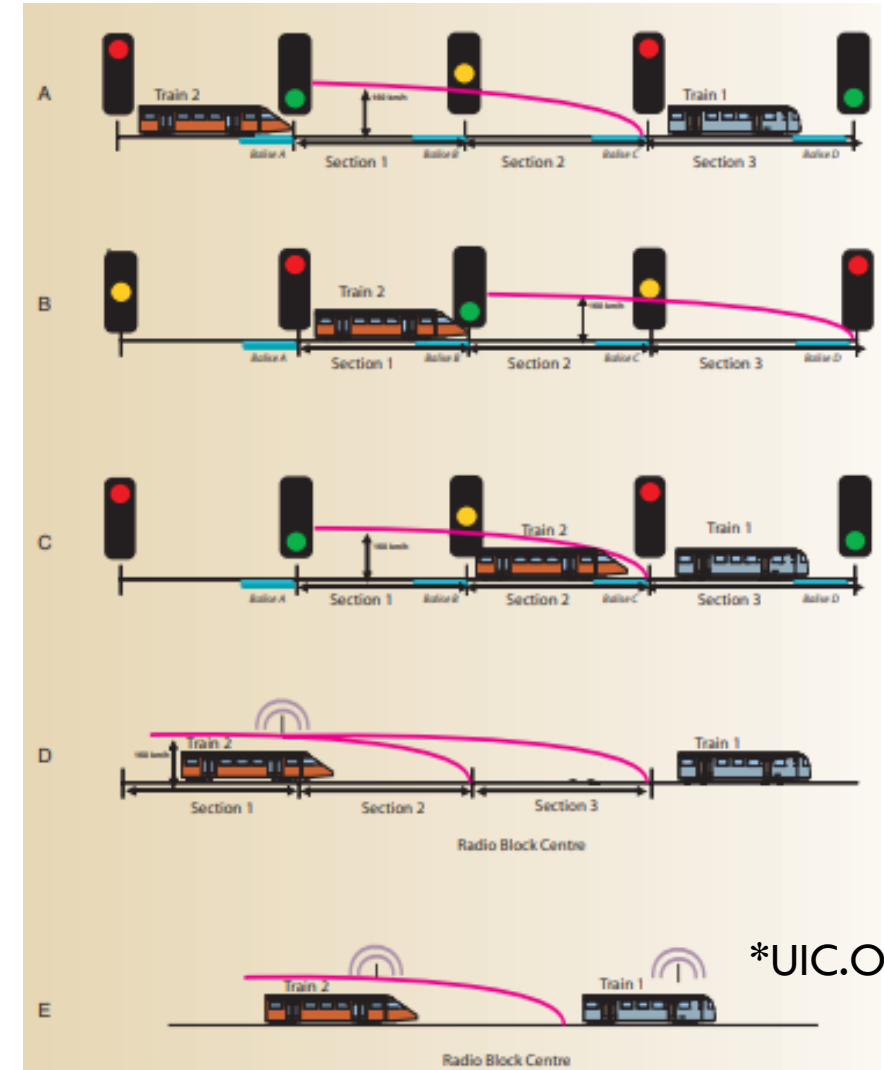


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ETCS

ETCS defined 3 levels:

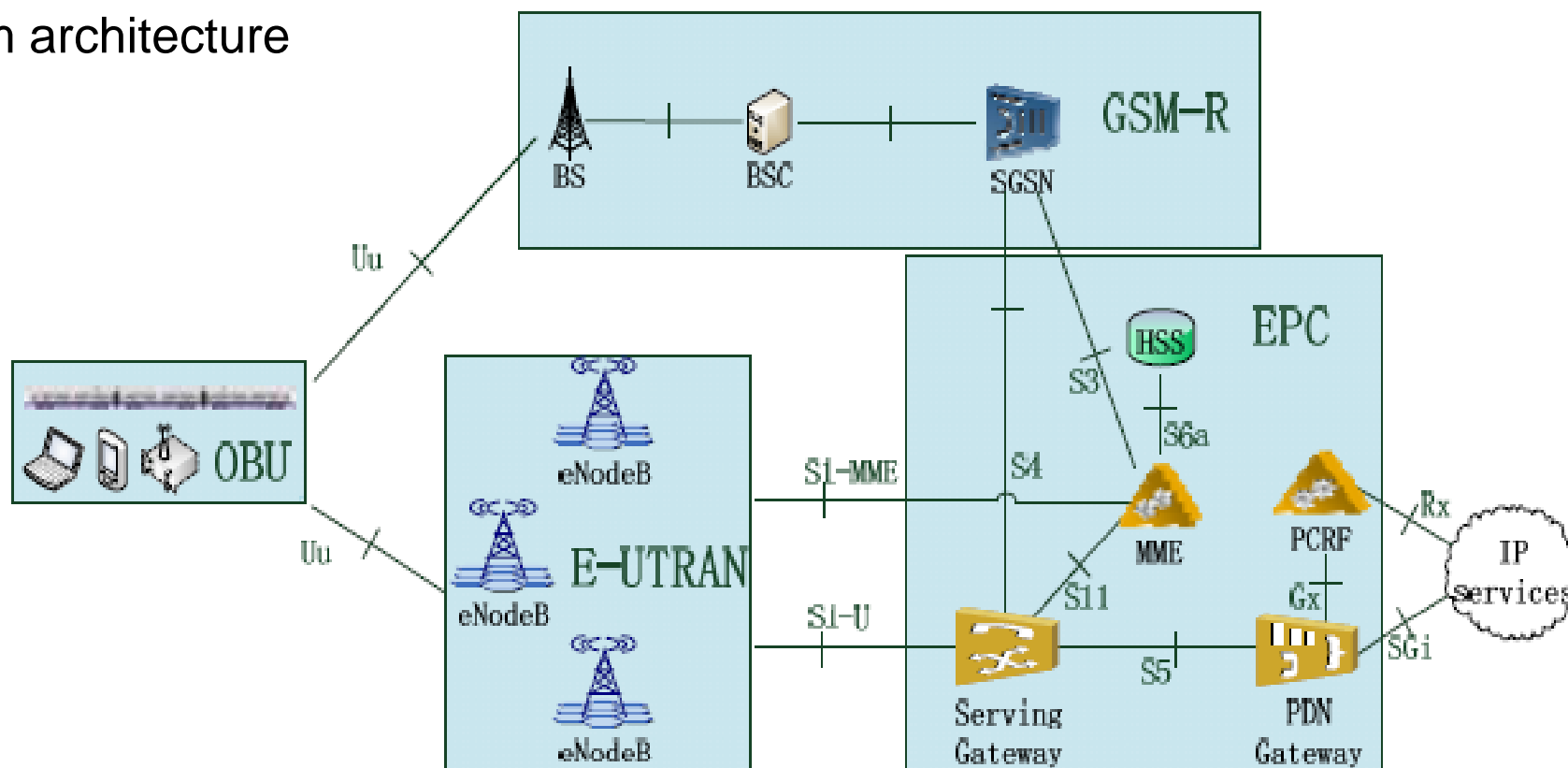
- Level 1: GSM-R is only used for voice communications (A, B, C)
- Level 2: GSM-R is also used for sending movement authorizations, the positions of the trains are sent by the trackside equipment
- Level 3: The trains are capable to send their own positions (E)



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LTE-R

□ System architecture



LTE-R

□ Services

- Real-time control information with delays less than 50 ms
- Real-time video monitoring of the infrastructure
- Multimedia dispatch
- Emergency communications
- Railway IoT: real-time train and cargo tracking
- Passenger services



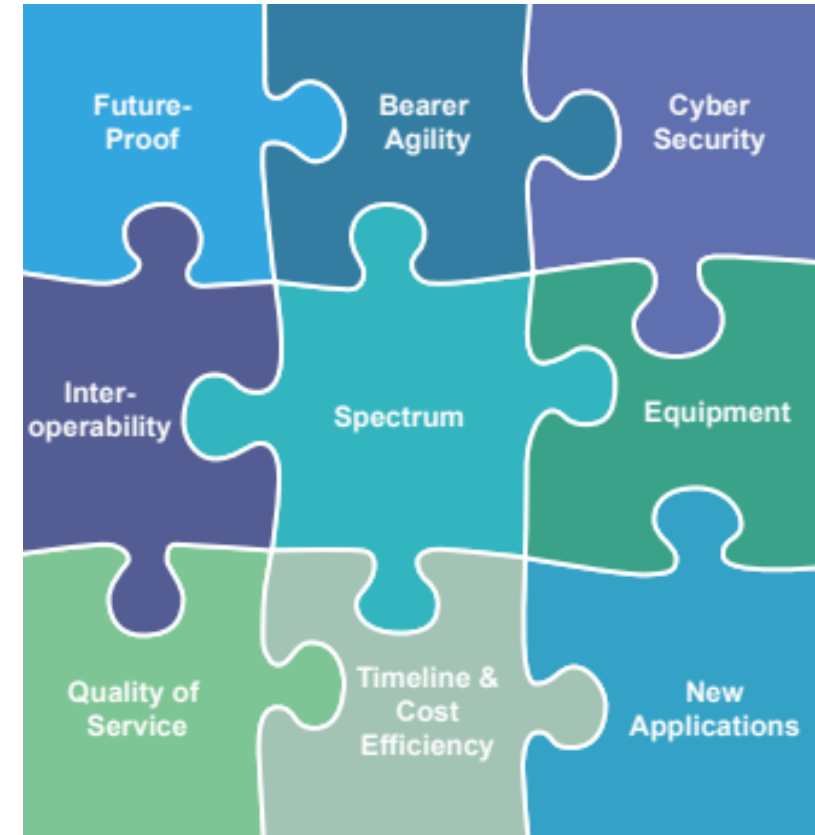


GSM-R VS LTE-R

	GSM-R	LTE-R
Uplink frequency	870-880 MHz	450, 800 MHz, 1.4 GHz
Downlink frequency	921-925 MHz	1.8 GHz
Bandwidth	0.2 MHz	1.4 – 20 MHz
Modulation	GMSK	QPSK/16-QAM
Cell radius	8 km	4-12 km
Maximum mobility	500 km/h	500 km/h
MIMO	No	Only 2x2
Data transmissions	Needs voice call	Packet switching
Handover	Hard	Soft
Downlink/uplink throughput	172 kbps	50/10 Mbps
Max. spectral efficiency	0.33 bps/Hz	2.55 bps/Hz

FRMCS

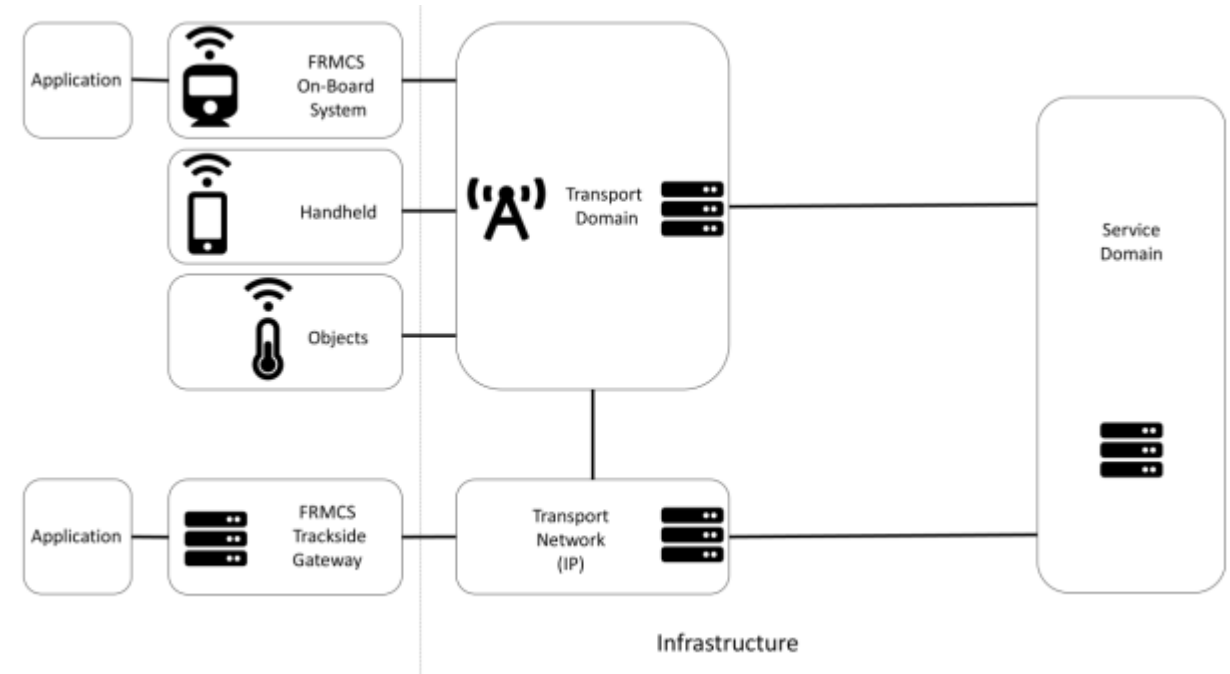
- ❑ FRMCS (Future Railway Mobile Communication System) is the system which is planned to replace GSM-R
 - In Europe, the LTE-R implementation most probably will be skipped and FRMCS designed for 5G will be implemented instead
 - The first tests in real systems are taking place 2023
 - FRMCS will be introduced around 2025
- ❑ FRMCS allows ETCS level 3 and ATO (Automatic Train Operation) meaning automation level GoA4
 - A communication system with delays $\leq 10\text{ms}$, minimum uplink throughput of 6-7 Mbps and high reliability network is necessary



FRMCS – ARCHITECTURE

□ Major functional blocks of the FRMCS architecture (*FRMCS SRS)

- The On-Board System provides communication services via capabilities of the Transport Domain to and from onboard applications / entities
- The Trackside Gateway provides access to communication and supplementary services supported by the FRMCS System to and from trackside applications
- The Transport Domain comprises one or more FRMCS Transport Domains and zero or more Non-FRMCS Transport Domain
- The Service Domain includes a MCX infrastructure, including a SIP Core





FRMCS – 5G

- ❑ FRMCS is architected to achieve maximum flexibility by separating the railway functions from the network and radio bearer
- ❑ FRMCS can use standard mobile radio technologies such as LTE, 5G or even satellites, but 5G is preferred
- ❑ Frequency bands
 - 3GPP 5G NR technology for the paired frequency bands [EC Decision 2021/1730] of:
 - 874.4-880.0 MHz, uplink
 - 919.4-925.0 MHz, downlink
 - 3GPP 5G NR technology for the unpaired frequency band [EC Decision 2021/1730] of:
 - 1900-1910 MHz

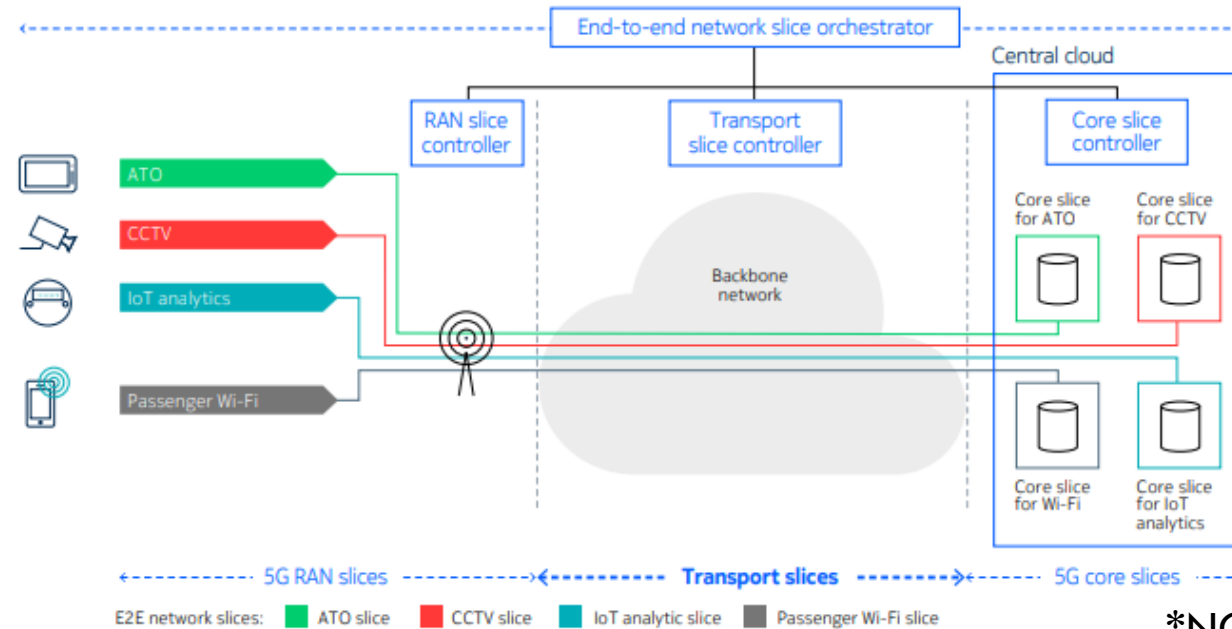


FRMCS – 5G

- ❑ Existing backbones which link with various access domains (cable, optical fiber, different generations of wireless technologies) will connect to 5G
 - The backbone has to meet the 5G transport challenges
- ❑ Dynamic 5G transport slicing
 - 5G brings allows networking slicing that enables a shared wireless network to offer multiple services while meeting stringent QoS requirements such as bandwidth and deterministic delay for each rail application
 - A 5G network slice is a virtual network partition that contains dedicated resources to support a specified set of services, applications or users with different QoS or security levels
 - For example, ATO requires stringent latency for train control while CCTV is very delay tolerant

FRMCS – 5G

- Creating a 5G slice requires orchestrating the provisioning of a slice in the RAN, core and transport domains and seamlessly interconnecting them
 - The automated orchestration can be done by an end-to-end network slice orchestrator



*NOKIA

FRMCS – 5G

❑ Cross-layer IP/optical network management

- 5G capacity triggers bandwidth-intensive applications, the backbone must run on an extensive optical transport layer, using DWDM (Dense Wavelength-Division Multiplexing) technology

❑ Time synchronization

- 5G requires time-of-day synchronization for TDD base stations and advanced cellular capabilities such as coordinated multiple point transmission and reception

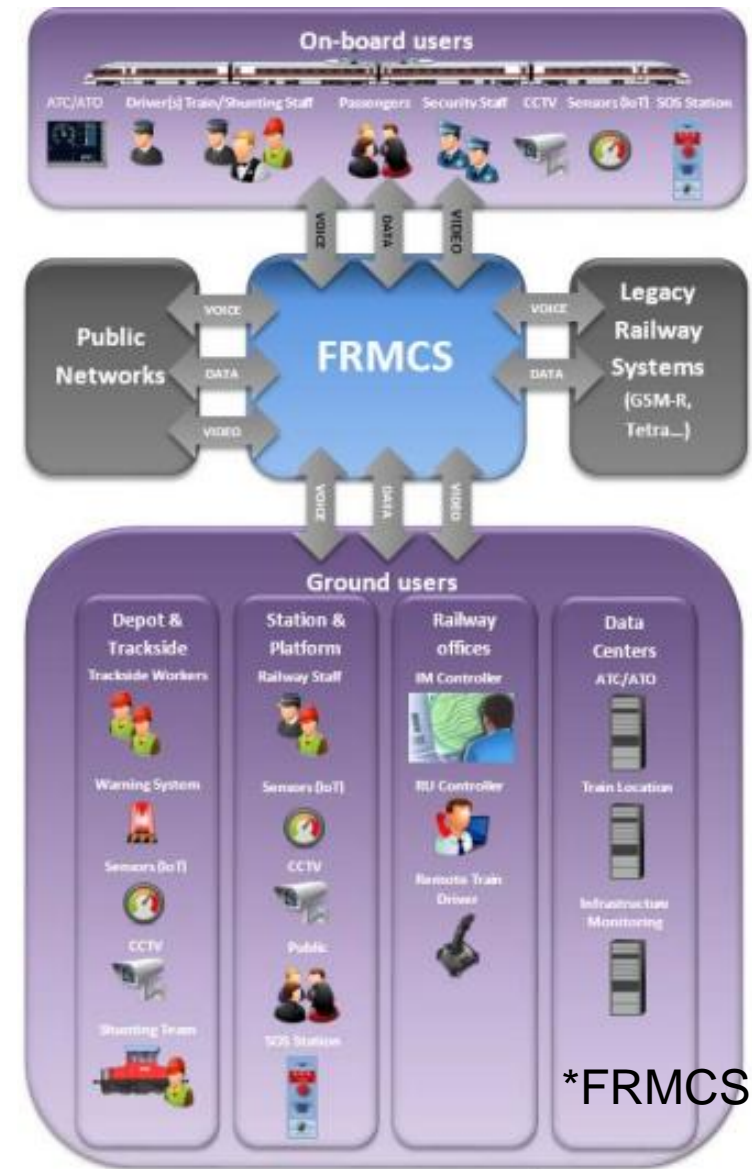
❑ Cloud interconnect

- 5G has a cloud-native architecture
- The 5G core slice can be hosted in a data center or at the edge cloud
- This requires the backbone network to seamlessly interwork with the data center switch fabric and edge cloud.

FRMCS USAGE

□ According to Nokia FRMCS will be used for the following areas:

- Automated train operation
 - Increase the operational and energy efficiency, train density and punctuality by supporting ATO
 - Precise positioning for obstacle detection, remote control and automation
 - Critical video support for driverless trains (ATO levels 3 and 4)
 - Future ETCS including train integrity
 - Shunting automation





FRMCS USAGE

○ Passenger information systems

- Improve the passenger experience and provide better individual mobility assistance by enhancing passenger information systems
 - Smart connectivity of different transportation modes through a passenger app
 - Enhanced real-time information on train status and seating availability
 - Connectivity for wireless displays
 - Video announcement on passenger devices

○ Smart rail maintenance

- Streamline operations, improve safety and replace soiled solutions by automating maintenance of rolling stocks, track and trackside asset
 - Augmented reality-enabled and predictive maintenance
 - Automated rail flaw detection
 - Remote-controlled drones for supervision



FRMCS USAGE

- Smart station
 - Modernize station operations by using digital communications to improve safety, streamline passenger handling and save energy
 - CCTV, emergency management, incident response, automated monitoring to ensure safe on- and off-boarding of passengers
 - IoT-based control of station facilities: bins, vending machines, elevators, lighting, ventilation
 - Smart power distribution and traction control systems
- Management support systems
 - Make business processes more efficient, increase automation and enable continuous optimization
 - Unified management of main control systems
 - Real-time information on passenger and traffic flows
 - Automated processing for ticketing
 - Use of digital twins to enable dynamic simulation of train operations and infrastructure



FRMCS USAGE

- Smart infrastructure
 - Increase efficiency and safety by supporting use cases that help digitalize the complete rail infrastructure
 - Connected railroad crossings and automated alerts
 - Automated hazard detection
 - Real-time management of passenger and traffic flows
 - Flawless perception of vehicles and trackside through multi-modal sensing (cameras, radar, LIDAR)