COURSE 6
RAILWAY COMMUNICATION SYSTEMS

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COMMUNICATIONS DEPARTMENT

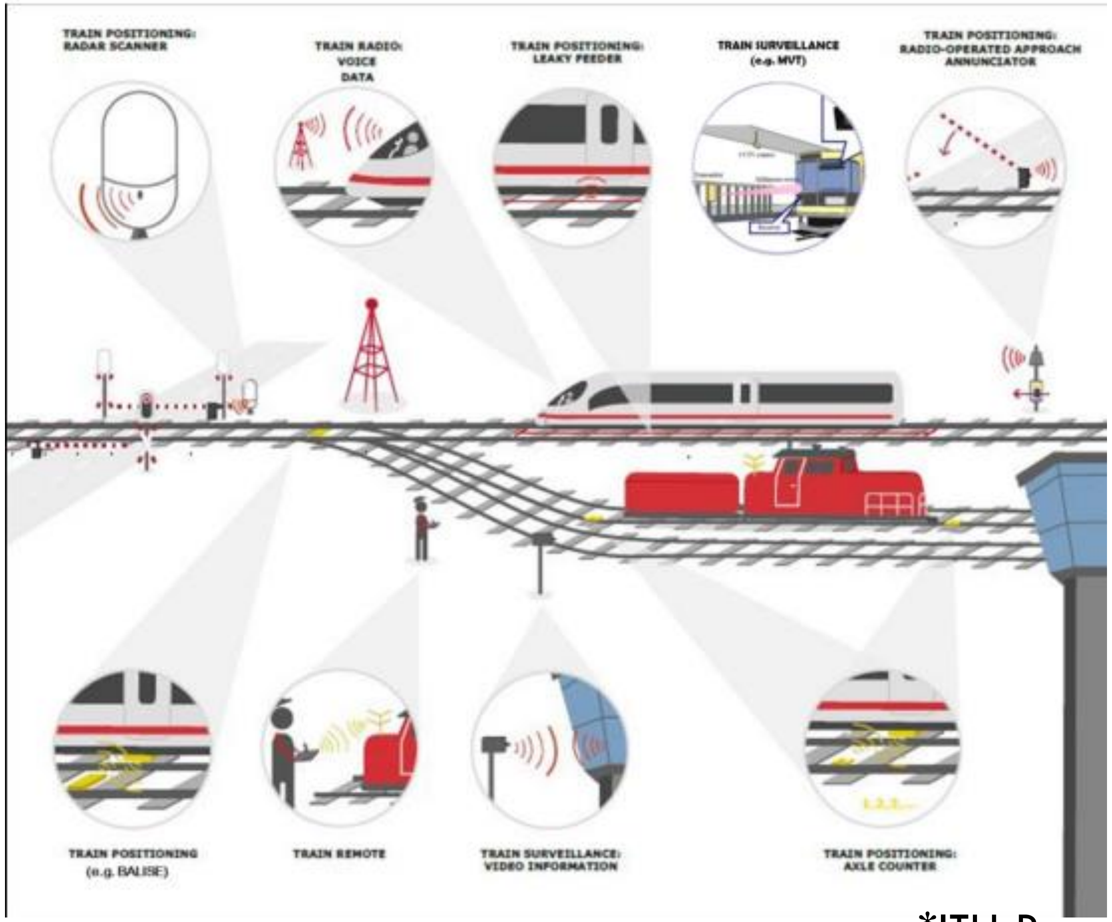
CONTENT

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

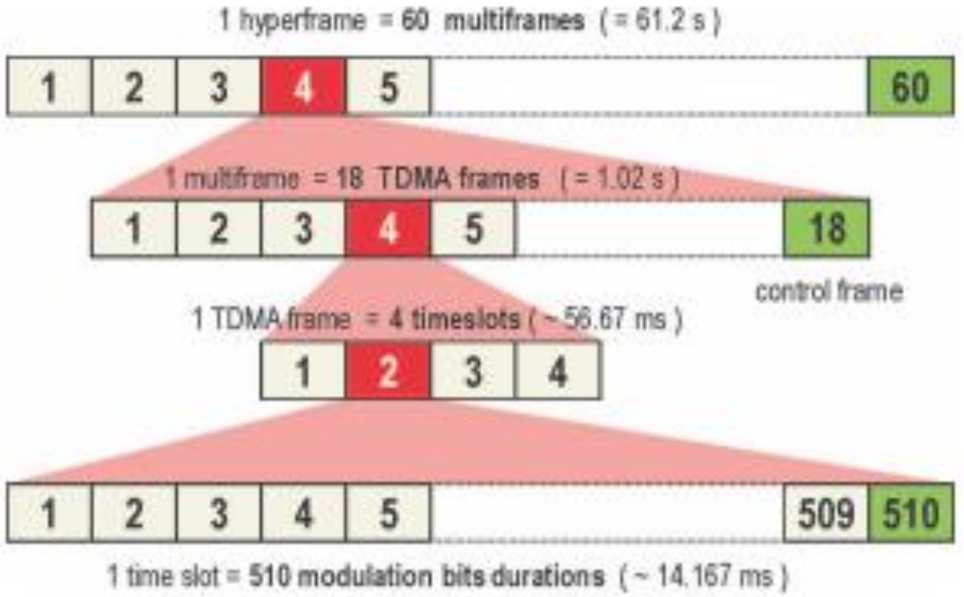
- TETRA (Terrestrial Trunked Radio) is an ETSI standard developed for governmental agencies, emergency services, railway transportation and military applications
- TETRA terminals can communicate in DMO (Direct Mode Operation) or TMO (Trunked Mode Operation) and can act as relays
- TETRA advantages
  - 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
  - π/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

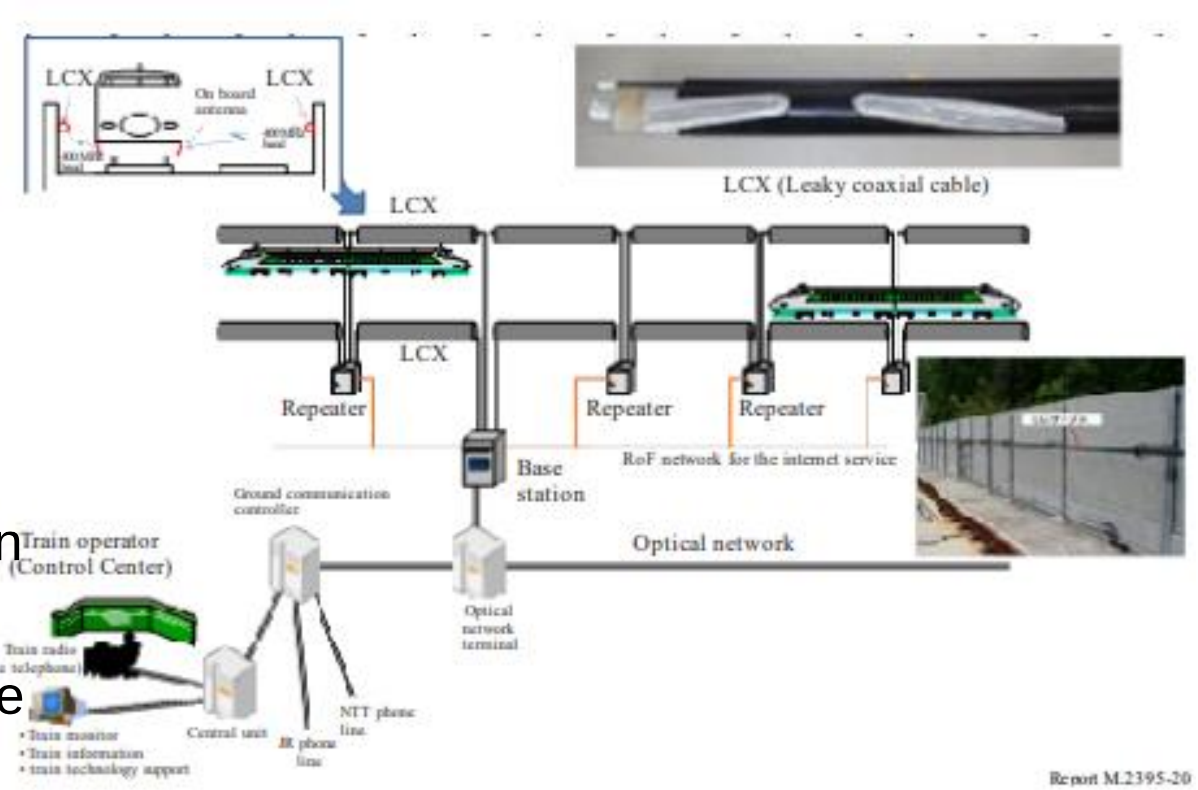
TETRA – FRAME STRUCTURE

- 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



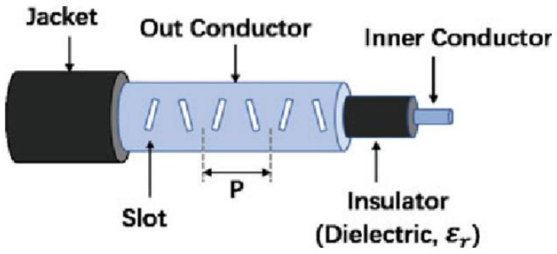
LCX

- 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



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

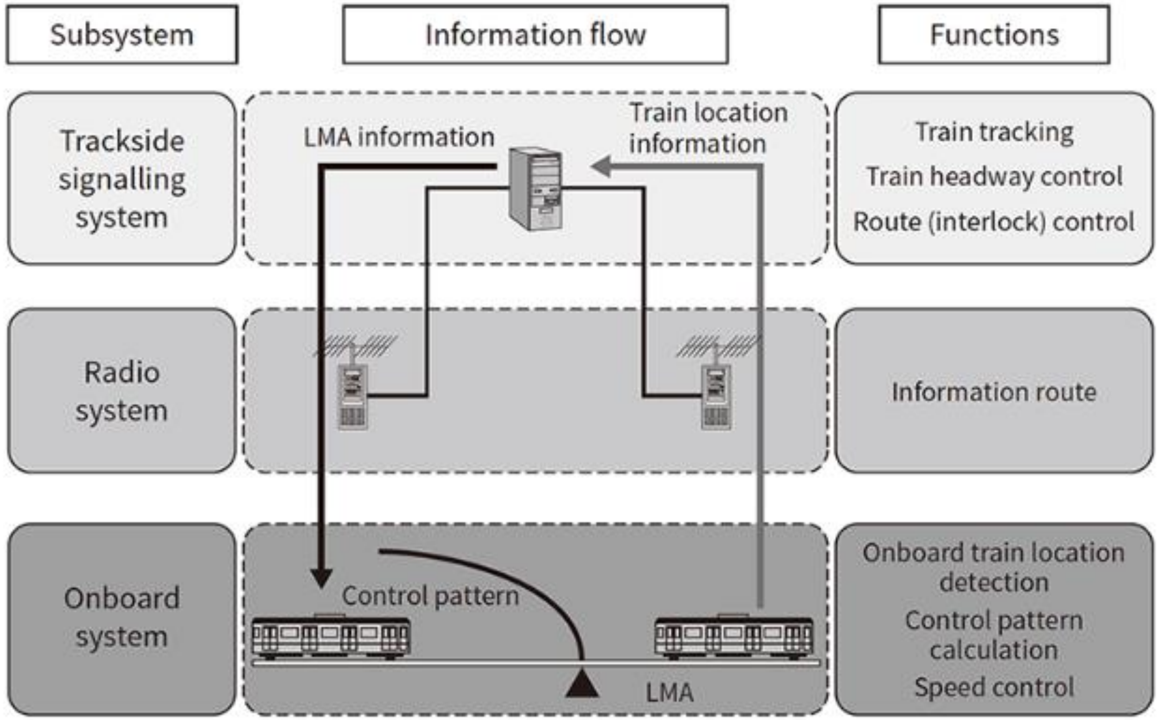


TRAIN CONTROL SYSTEMS

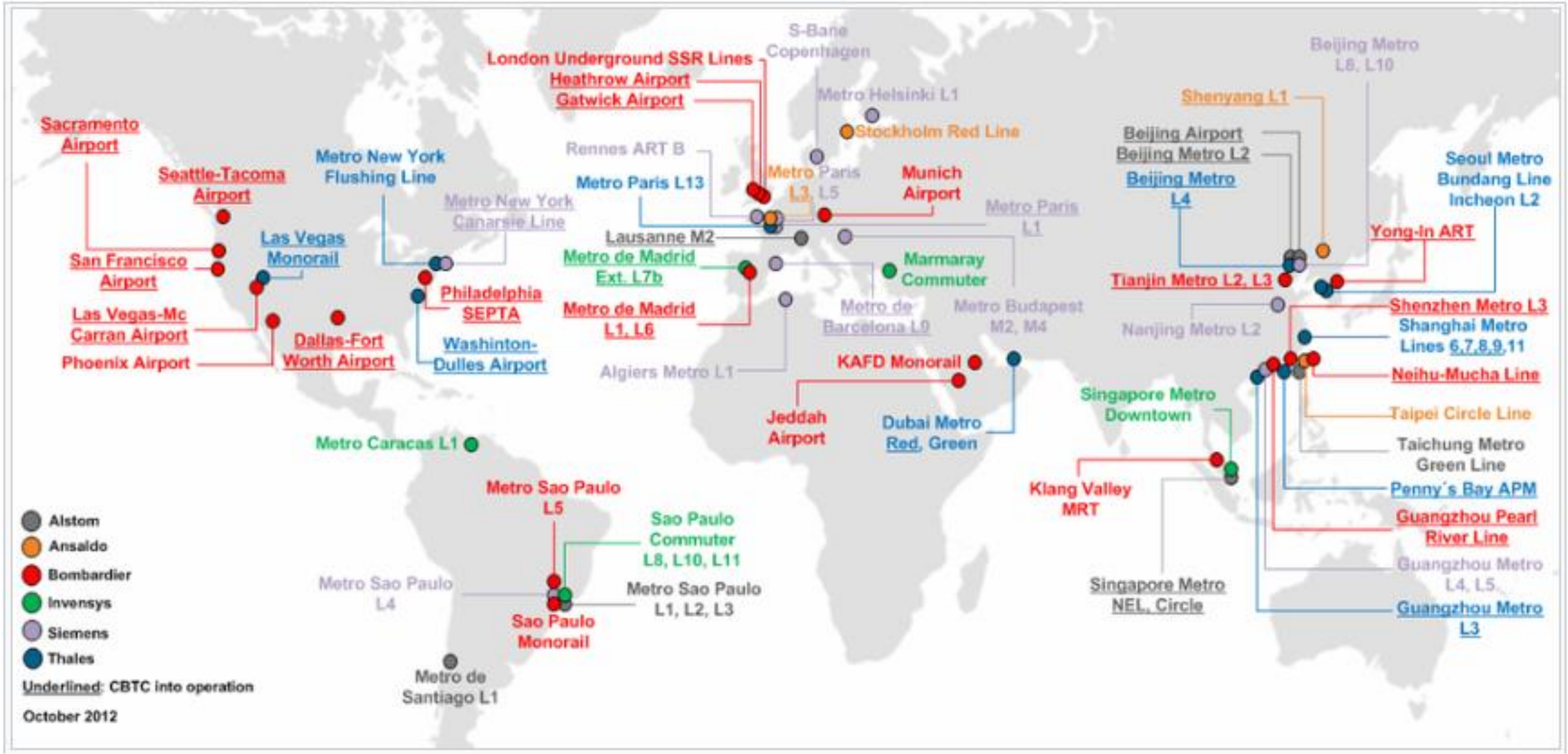
- Worldwide multiple systems are used for train control
  - JRTC – Japan Radio Train Control System in Japan combined with LCX
  - ERTMS – European Rail Traffic Management System in Europe
  - CBTC – Communication Based Train Control
    - Defined in IEEE 1474
    - Information about the speed, direction, 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

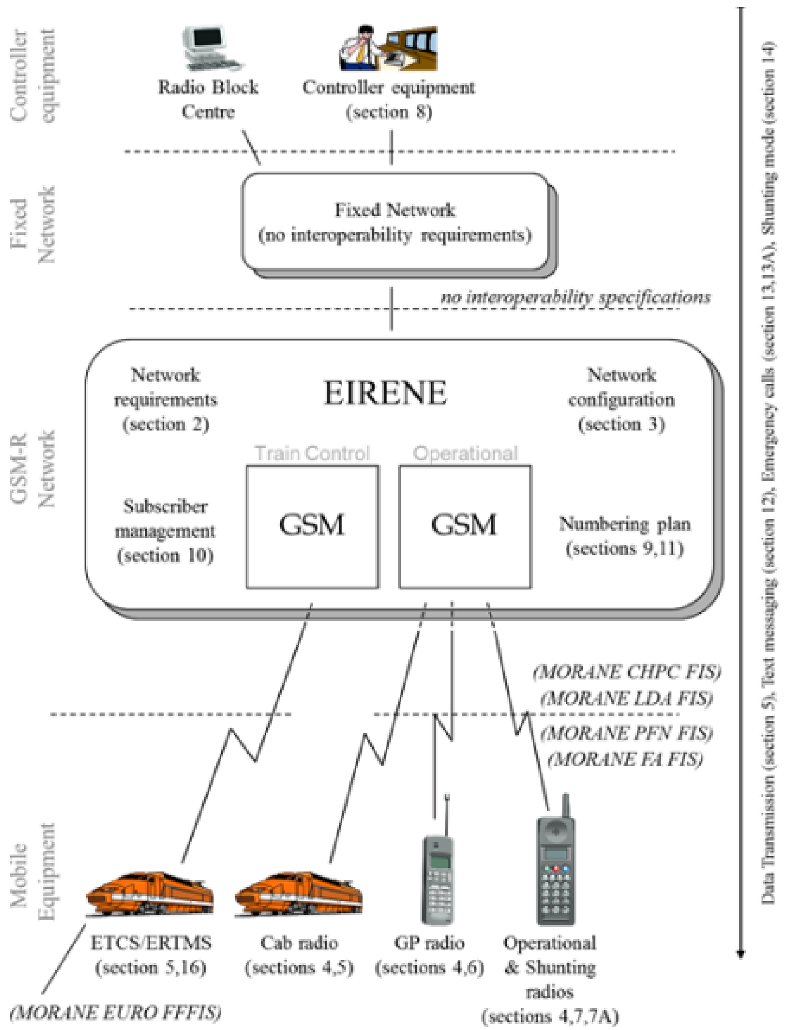


CBCT


S-Bane Copenhagen
London Underground SSR Lines
Heathrow Airport
Gatwick Airport
Metro Helsinki L1
Beijing Metro L8, L10
Shenyang L1
Stockholm Red Line
Sacramento Airport
Seattle-Tacoma Airport
Metro New York Flushing Line
Rennes ART B
Metro Paris L13
Metro Paris L3, L5
Munich Airport
Beijing Airport
Beijing Metro L2
Beijing Metro L4
Seoul Metro Bundang Line Incheon L2
Metro New York Canarsie Line
Metro Paris L1
Yong-In ART
Las Vegas Monorail
Lausanne M2
San Francisco Airport
Metro de Madrid Ext. L7b
Marmaray Commuter
Tianjin Metro L2, L3
Philadelphia SEPTA
Metro de Madrid L1, L6
Metro de Barcelona L9
Metro Budapest M2, M4
Shenzhen Metro L3
Las Vegas-Mc Carran Airport
Shanghai Metro Lines 6,7,8,9,11
Nanjing Metro L2
Dallas-Fort Worth Airport
Washinton-Dulles Airport
Phoenix Airport
Algiers Metro L1
KAFD Monorail
Neihu-Mucha Line
Singapore Metro Downtown
Taipei Circle Line
Jeddah Airport
Dubai Metro Red, Green
Metro Caracas L1
Taichung Metro Green Line
Penny's Bay APM
Metro Sao Paulo L5
Klang Valley MRT
Guangzhou Pearl River Line
Sao Paulo Commuter L8, L10, L11
Guangzhou Metro L4, L5
Metro Sao Paulo L4
Metro Sao Paulo L1, L2, L3
Singapore Metro NEL, Circle
Guangzhou Metro L3
Sao Paulo Monorail
Alstom
Ansaldo
Bombardier
Invensys
Siemens
Thales
Underlined: CBTC into operation
October 2012
Metro de Santiago L1

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)



* EIRENE SRS

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 Brodcast 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±5Hz frequency, with 1-10s duration and 5-10s silence

GSM-R

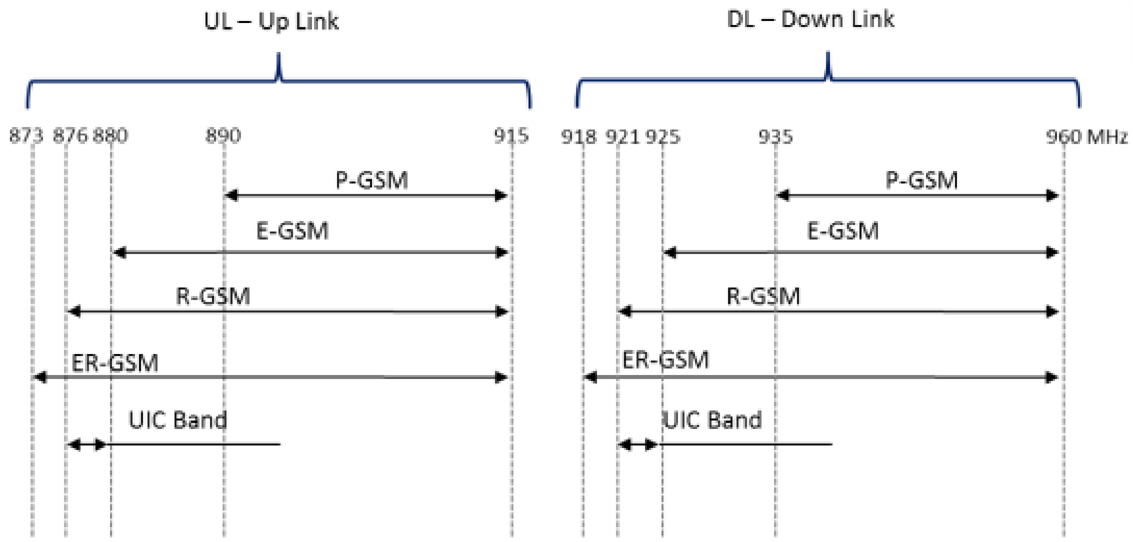
- Functional addressing: a train can be addressed by a number identifying the function for which the train is used
  - Many railway staff need to be addressed by functional rather than personal numbers
  - The initiator of the call only has to know the train number
  - A translation facility is provided 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

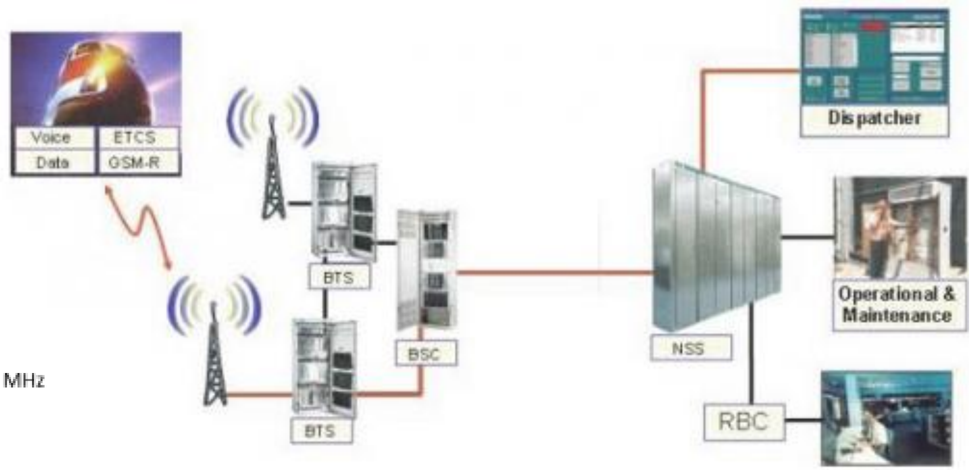
GSM-R

- 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



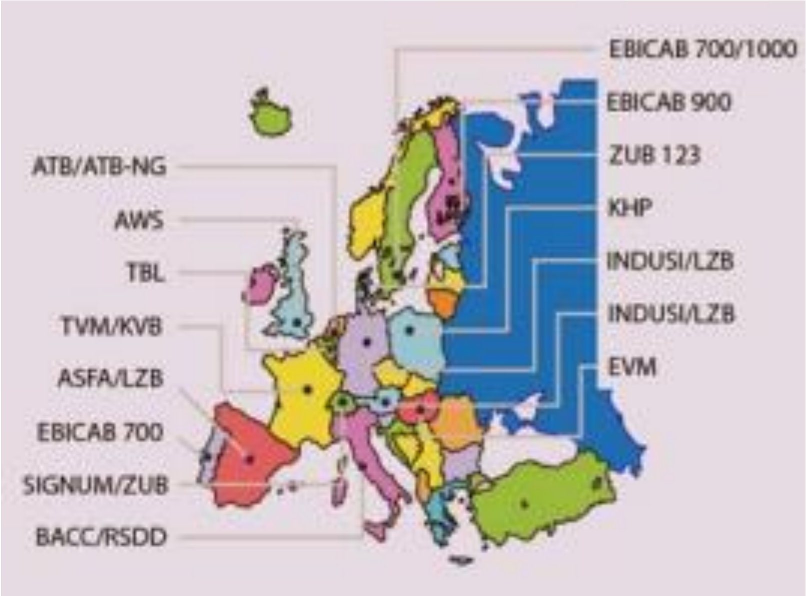


GSM-R

- 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: de 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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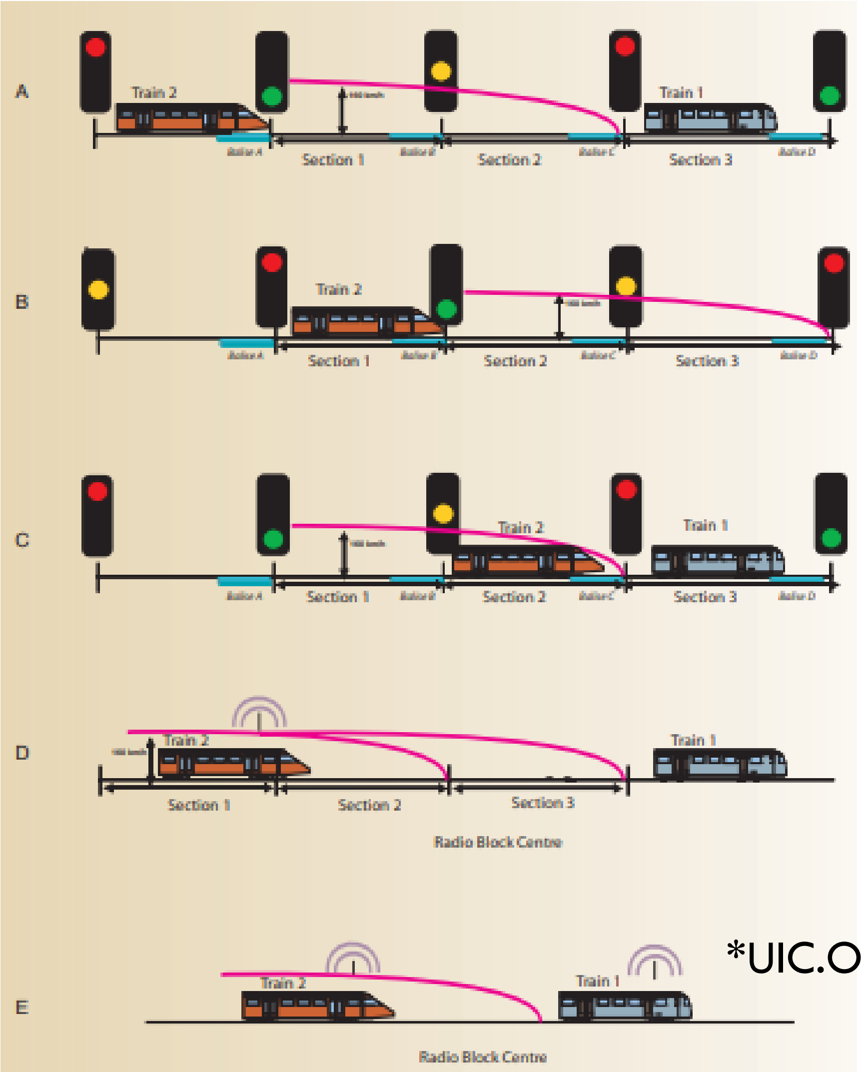
ETCS

- 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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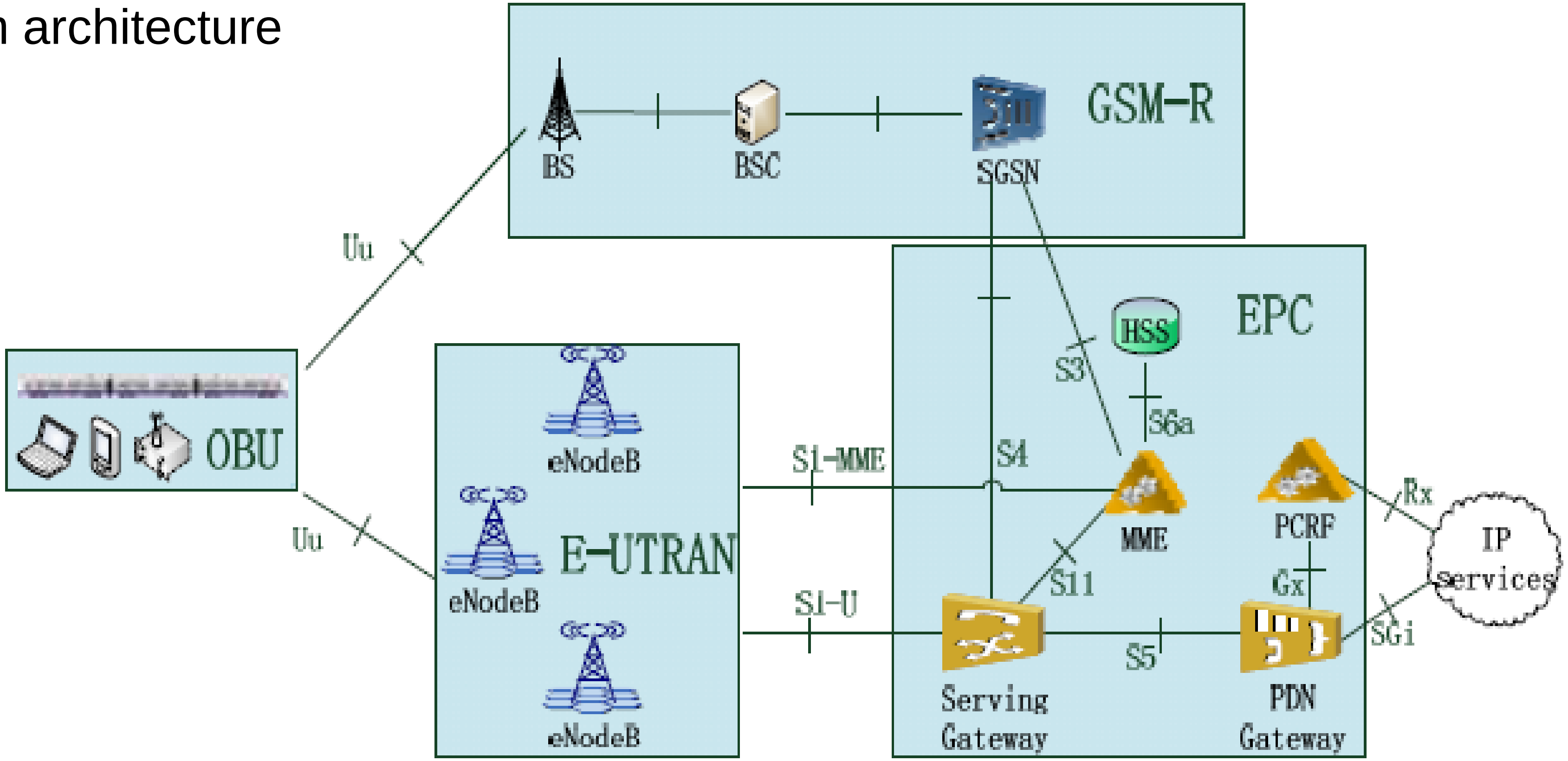
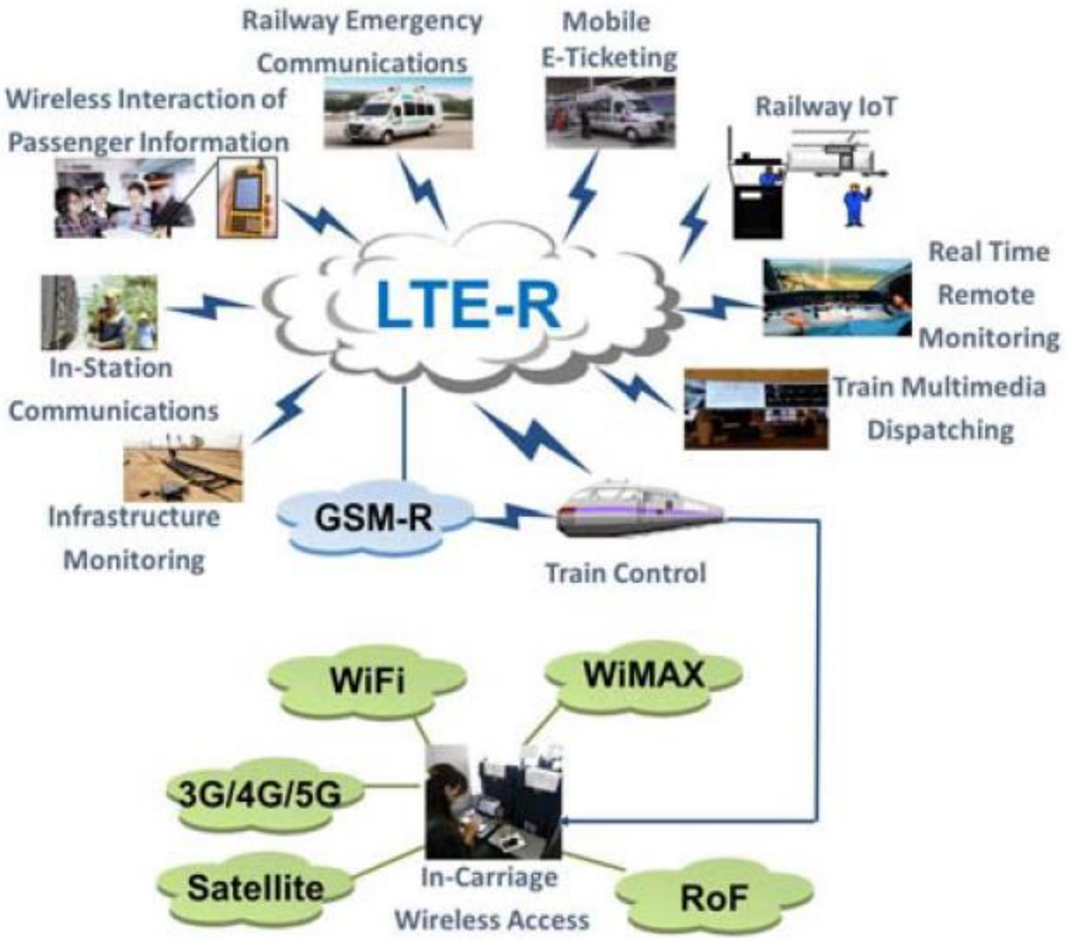
LTE-R

- 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

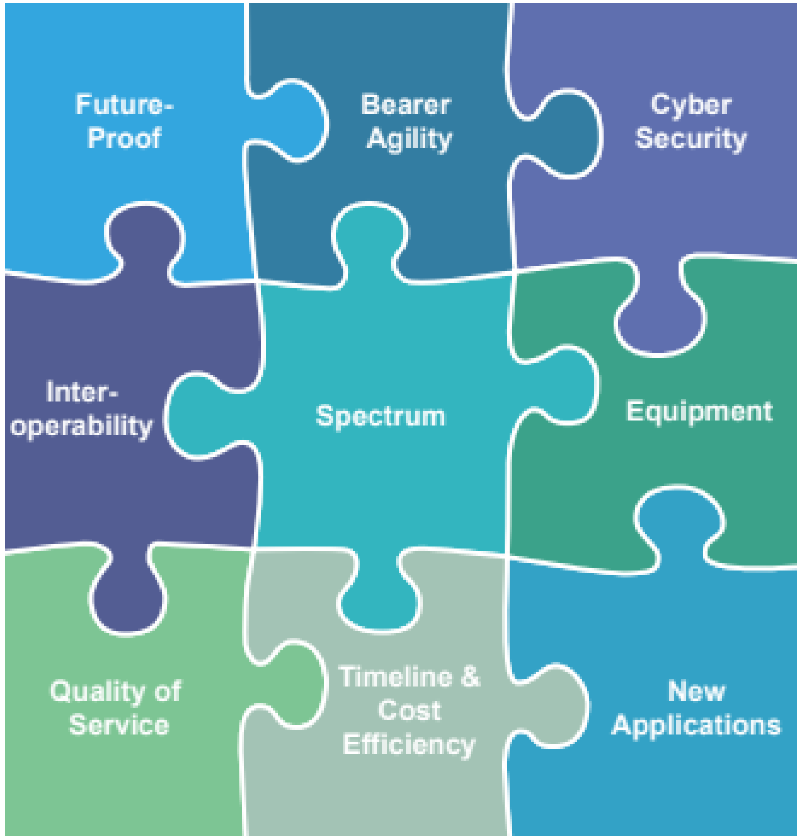


GSM-R VS LTE-R

	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

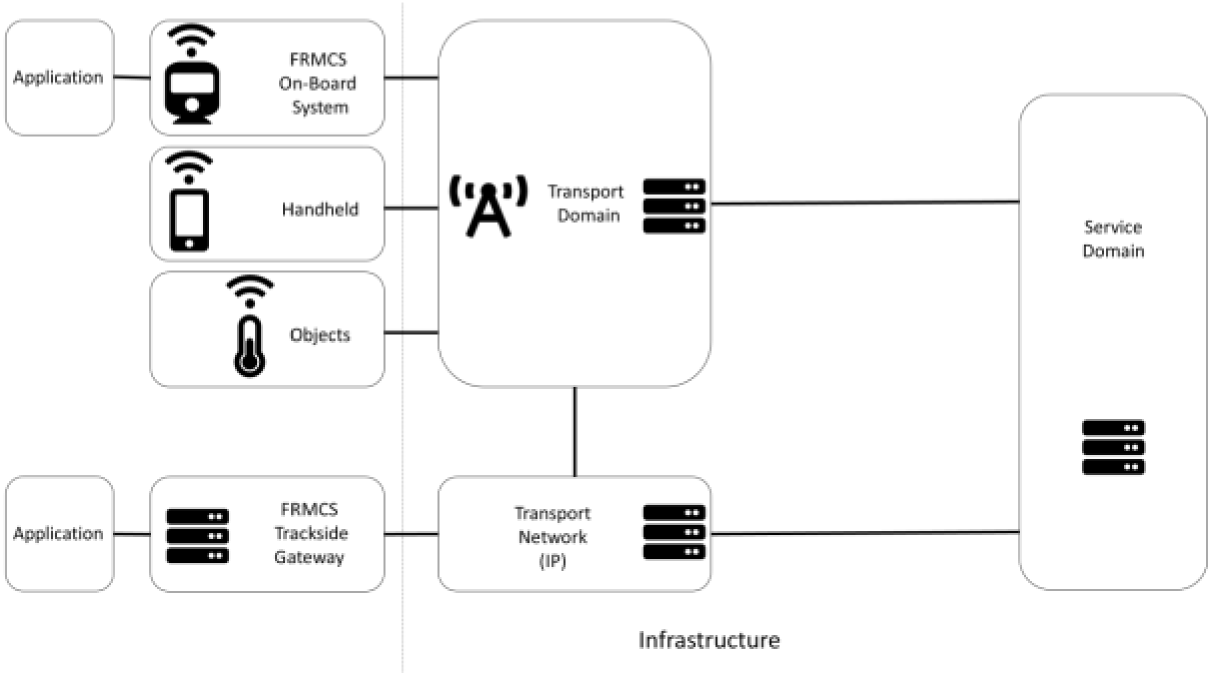
FRMCS

- 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 <= 10ms, 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

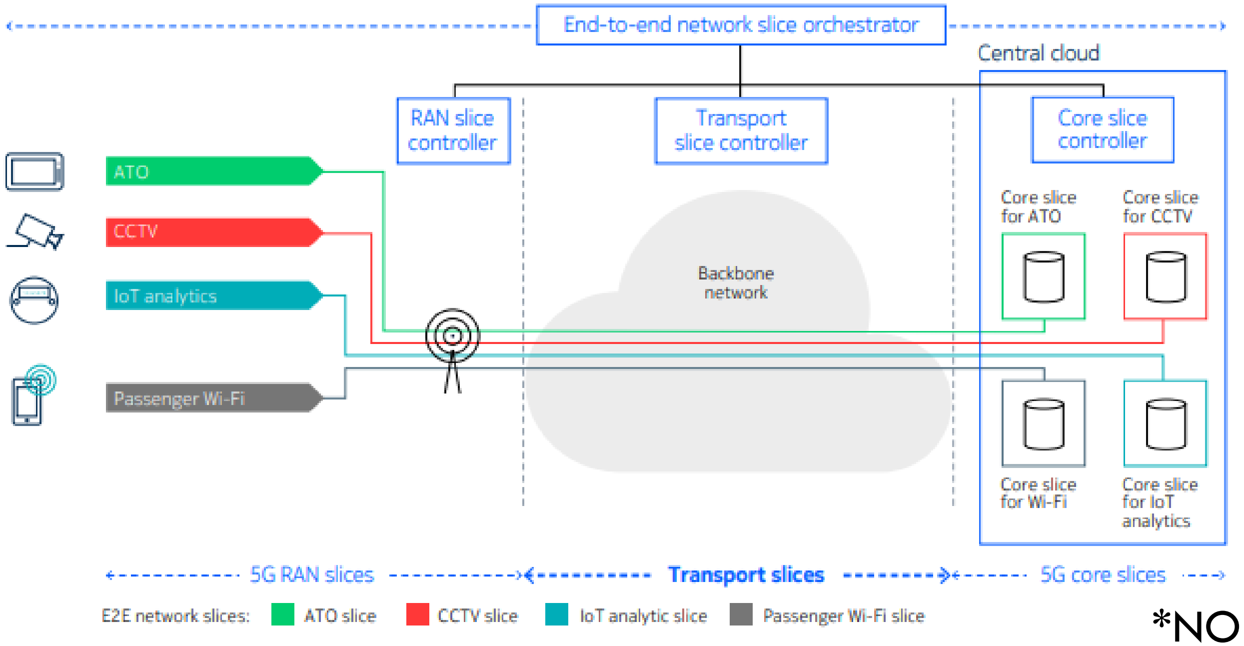
- FRMCS is architected to achieve maximum flexibility by separating the railway functions from the network and radio bearer
- FRMCS can use standard mobile radio technologies such as LTE, 5G or even satellites, but 5G is preferred
- Frequency bands
  - 3GPP 5G NR technology for the paired frequency bands [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



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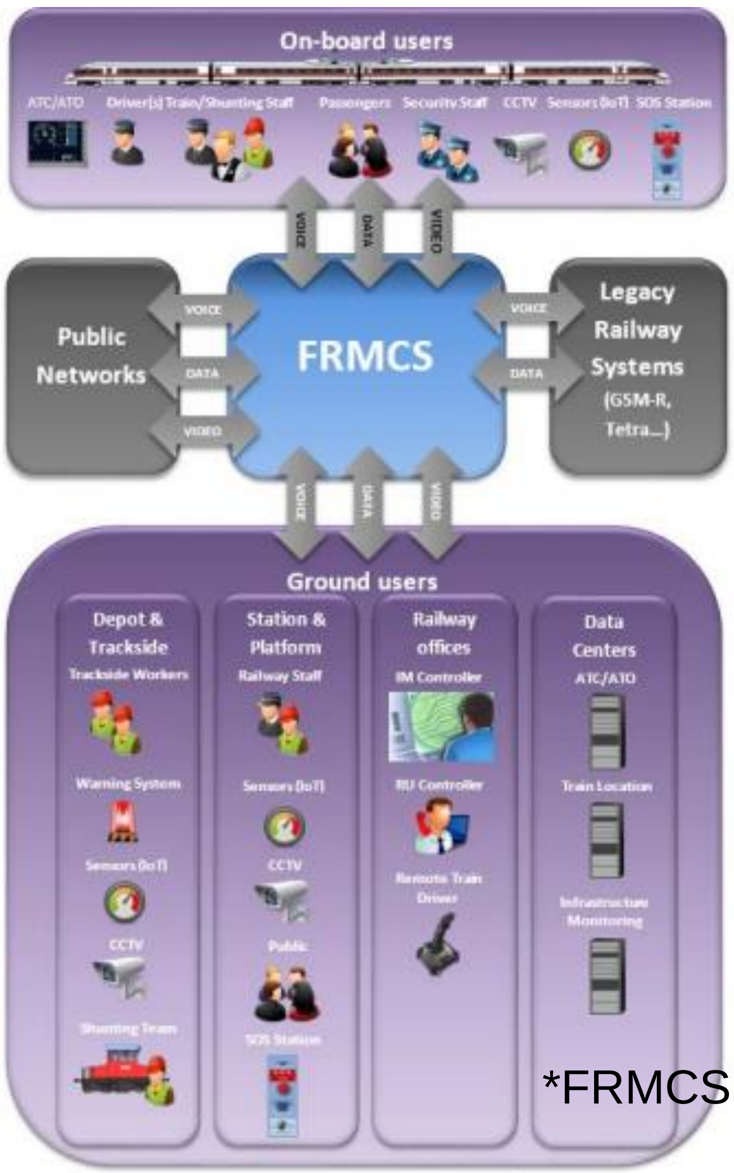
FRMCS – 5G

- 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 FRS

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)