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GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS -RAILWAYS (GSM-R) IN INDIA

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ABSTRACT

The European Rail Traffic Management System (ERTMS) is the first international standard for train command-control and train-to-ground communication. In the late 1980s, European countries realized that segmentation of the railway market becomes a significant problem for the future development of rail transport. The lack of interoperability was especially problematic for high-speed railways, whose advantages could not be fully realized without cross-border services.

INTRODUCTION

The European railway industry began work on a common standard.Development of ERTMS involved a broad representation of the railway industry and European institutions: European Union (EU) bodies, International Union of Railways (UIC), railway operators gathered in ERTMS User Group, Union Industry of Signaling (UNISIG), and—from 2004—the European Railway Agency (ERA). This process started in 1989, when the first studies and research was initiated by the European Commission (EC). Development and tests continued for many years and resulted in the initial specifications, which were published inApril 2000. However, the work on ERTMS has been continued and many updated specifications have been published since then.

The most important features and advantages brought by ERTMS are as follows:

- Improvement of railway interoperability by establishment of new common European standards, which allows uninterrupted cross-border train operation.
- Introduction of a new command-control system for high-speed trains, which would eventually replace legacy command-control standards in Europe.
- Increase of efficiency and safety of high-speed trains due to in-cab signaling and Automatic Train Protection (ATP).
- Increase of the track capacity by usage of the moving block concept and dynamic braking curves.
- Reduced complexity of train driver work, thanks to a single standardized Driver Machine Interface (DMI) for all European trains.
- Reduction of trackside signaling equipment.
- Creation of a single radio communication system, which would support the new command-control system. The new radio system would also replace all legacy voice communication radios, e.g.: train-to-ground radio, tunnel radio, shunting radio, etc.
- Introduction of Railway Emergency Call (REC) that offers fast and reliable communication in case of a dangerous situation.

- Cost reductions thanks to a single European market. Standardization of the command-control and communication system opens the local national markets to foreign competition. It also increases number of suppliers.

COMPOSITION OF ERTMS:

Consists of two complementary elements: ETCS and GSM-R as shown in Figure. ETCS is a digital railway control-command system. It includes in-cab signaling, ATP system, standardized DMI, moving block and many more. The other ERTMS element is GSM-R. This radio communication technology has two main purposes. Firstly, it enables ETCS by offering data channels interconnecting trains and centralized control centre's. Secondly, GSM-R is a unified solution for all railway voice communication.ERTMS was initially developed in the EU for interconnecting the railway systems on the continent. The EU, via European Council Directives and European Commission Decisions, obliged European railways to deploy ERTMS.

However, due to many advantages of the system, other countries around the world also began to deploy it. Outside of Europe, ERTMS is used or planned to be used in: Algeria, Argentina, Australia, Brazil, China, Egypt, India, Indonesia, Kazakhstan, Libya, Malaysia, Mexico, Morocco, New Zealand, Russia, Saudi Arabia, South Korea, Taiwan, Turkey, and the United Arab Emirates. Hence, ERTMS gradually

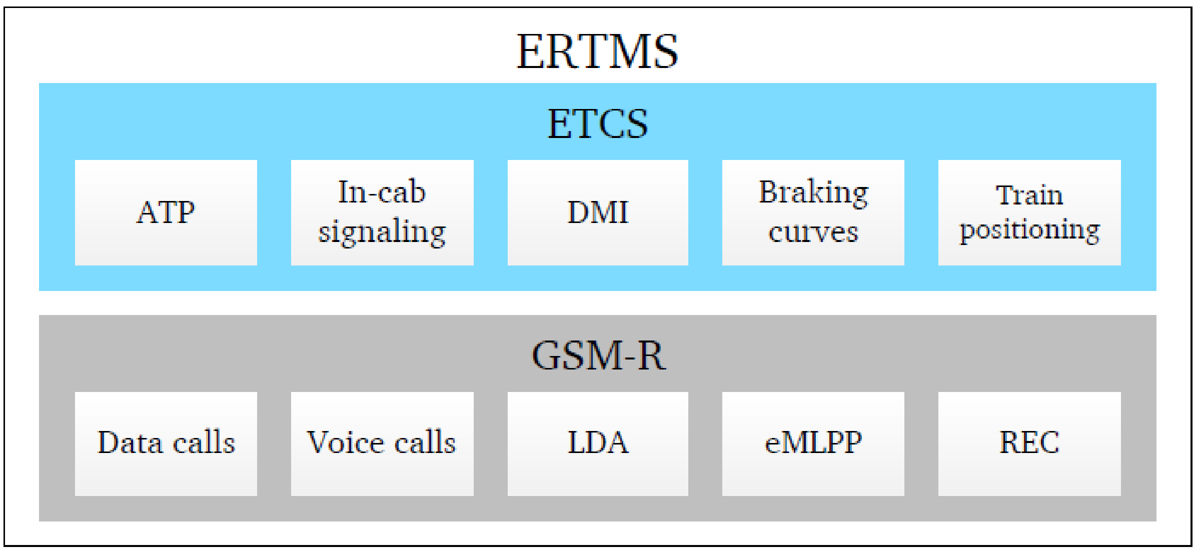


Fig: Elements of the ERTMS

EUROPEAN TRAIN CONTROL SYSTEM (ETCS): SHORTCOMINGS OF THE CLASSICAL SIGNALING

The classical railway signaling, which is shown in Figure, is usually based on the colour light signals (earlier on semaphores). The usual (simplified) operation of the system is as follows:

1. Firstly, when a train is scheduled to depart, the Traffic Management System sends a train route request to the interlocking.
2. The interlocking verifies whether the blocks (i.e. track sections) that will be included in the route are occupied or not. This is done via train detection system, such as axle counters.
3. Then, if the blocks are unoccupied, the interlocking sets the points (i.e. track switches) using point machines. Moreover, the interlocking verifies that respective signals display "stop" aspect, so other trains do not enter the route.
4. Once this is done, the appropriate signal aspect is displayed to the train driver.

This system ensures that two conflicting routes cannot be set up at the same time. Also, a "proceed" signal aspect guarantees that the route is locked, i.e. all the points are in the correct positions, all the blocks are unoccupied and all conflicting routes receive a "stop" aspect. However, the safety of the system depends

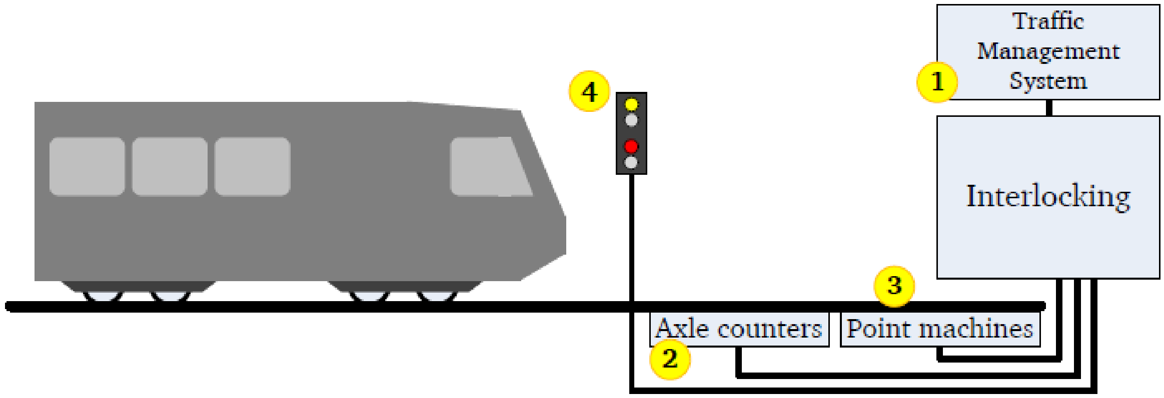


Fig: Classical railway signaling based on the colour light signals

Significantly on the human factor, i.e. on the reaction of the driver to the displayed signal aspect. The driver may, for instance, fail to notice the signal, may misinterpret the signal aspect or may underestimate the stopping distance of the train. In case of such an error, the consequences may be fatal. Moreover, both the risk and consequence of the driver error increase with the train speed. Besides the safety concerns, the colour light signals have other drawbacks:

- They carry limited information [5, p. 18]. It is impossible to inform the driver about precise speed limits, track gradients and the exact distance to the "stop" signal location.
- They are located at fixed positions [5, p. 18]. Thus, if the speed limit is increased while the train is somewhere between two signals, the driver cannot be informed about it. The train will continue running at the old speed limit until the next signal becomes visible.
- They cannot take into account the characteristics of the particular train. For example, trains have different braking capabilities and maximum running speeds. Since the system does not know what train is currently running, the speed limits must assume the worst-case braking characteristics.

In order to address these shortcomings—therefore, to increase safety, efficiency, and capacity of the railway system—railways gradually move to computer-based signaling systems, such as ETCS.

ETCS:

ETCS, which is the state-of-the-art in railway command-control and signaling, is a communication-based system that manages and supervises train movement.It should be noted that ETCS does not replace the driver, so it does not provide Automatic Train Operation (ATO). However, the system supports the driver and reacts in case of a potentially dangerous error.

ETCS APPLICATION LEVELS

ETCS has three application levels: 1, 2 and 3. All of the levels provide the in-cab signaling and ATP. However, they differ in terms of efficiency, investment cost and compatibility with the legacy signaling. Thanks to these multiple levels, the railways may adapt the system to their specific requirements and strategy. In Denmark, it has been decided to deploy ETCS Level 2 on the whole national railway network. Therefore, the research work presented in this thesis considers. ETCS Level 2. Consequently, in the following sections and chapters, ETCS Level 2 is referred to as ETCS.

ETCS replaces the way the driver receives signals (commands) from the system and it introduces elements supervising train movement. However, it does not replace the entire legacy signalling system, but builds on top of it. As shown in Figure, the interlocking, axle counters (or other track detection), point machines, and Traffic Management Systems are still necessary. However, these elements of the signalling system are out of scope of the ETCS standard and they differ from vendor to vendor.

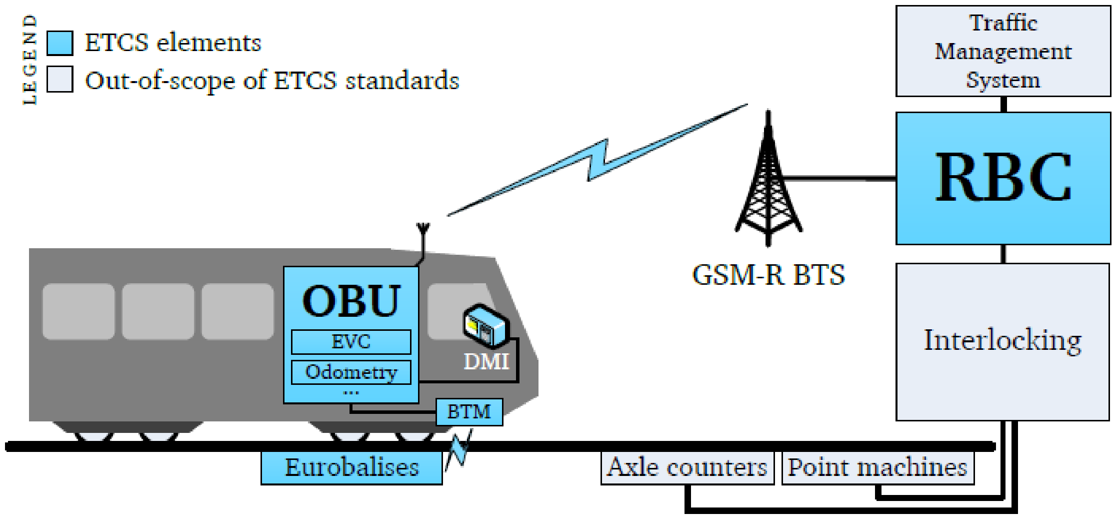


Figure 2.3: Schematic overview of ETCS Level 2 architecture

ARCHITECTURE OF THE ETCS SYSTEM

ETCS is divided into two general parts: on-board and trackside. The trackside part consists of the Radio Block Centre (RBC) and Eurobalises. The on-board part consists of the On-board Unit (OBU) and its supporting elements.

ETCS TRACKSIDE ELEMENTS

The *Radio Block Centre (RBC)* is the main element on the trackside part. It is a centralized computer that manages all trains running within its area. In Denmark, the entire railway network is planned to be divided into 36 areas, each supervised by a dedicated RBC.

As illustrated in Figure, the RBC has interfaces with the Traffic Management System, the interlocking, and the train OBU. However, only the interface with OBU is standardized. The remaining two are proprietary solutions specific to a system vendor. Using these three interfaces, the RBC gets a detailed overview of the area it is responsible for. The Traffic Management System provides the current timetables—the up-to-date operational plan for each train. The OBUs provide information about the speed and position of the trains. The interlocking is responsible for setting andlocking train routes—reserved and protected paths through the rail network.The RBC manages train movement using Movement Authorities (MAs). An

MA is a digital message containing a speed/distance envelope, i.e. a data vector defining the precise speed limits on the track section ahead of a train. Every MA includes the End of Movement Authority (EoMA), i.e. the stop location that the train is not authorized to pass until a new MA is issued.

Besides the RBC, the other trackside element is the *Eurobalise*, which is a transponder installed between the rails. While passing over an Eurobalise, a train receives a low-bitrate signal from it. In ETCS Level 2, this method is used to deliver static information, for example, about the precise position of the Eurobalise or about the RBC responsible for a particular area.

ETCS ON-BOARD ELEMENTS

The *On-board Unit (OBU)* is a set of ETCS elements installed on the train. OBU consists of the European Vital Computer (EVC), DMI, Balise Transmission Module(BTM), an odometry system, and a GSM-R radio module [4, p. 32]. The EVC contains logic of the system, while the remaining elements provide interfaces and supporting functions, as follows:

- The DMI displays all commands and information necessary for a driver (e.g. speed limits, distance to EoMA). Thus, simplifying, DMI provides the functionality that was provided by the colour light signals in the classical signaling system. However, the DMI can also receive input from the driver, e.g. during ETCS setup procedure.
- The odometry system determines the current speed of the train and its position in relation to the last Eurobalise. Thus, it is an essential feature for ATP.
- The BTM reads the information sent by the Eurobalises that are placed along the track. Each Eurobalise sends its precisely defined position, which is used to correct the likely distance measurement error of the on-board odometry system.
- The GSM-R module provides a communication interface to the RBC.

The EVC interprets the MA messages incoming from the RBC (via GSM-R)and calculates safe braking curves. The braking curve defines the maximum speed that will still allow the train to stop before EoMA. As the train is running, the EVC controls if the driver follows the commands displayed on the DMI, i.e. the OBU controls if the train runs according to the issued MA. If the train speed approaches the braking curve, the EVC issues an audible warning. Then, if the driver does not react, and the braking curve is reached, an emergency brake is applied. In this way, ETCS provides ATP functionality that minimizes the risk of a human error.

GSM-RAILWAYS (GSM-R)

GSM-R is the first mobile communication standard designed specifically for railways. It is based on the Global System for Mobile Communication (GSM) standard, which is widely used in commercial mobile telephony networks. GSM-R provides two essential railway services:

- Train-to-ground data communication for ETCS Level 2 and 3.
- Voice communication with specific features necessary for railways. The GSM-R network replaces train-to-ground radio, tunnel radio, shunting radio and maintenance radio, i.e. it is a single solution fulfilling all railway voice communication needs.

GSM-R is a network dedicated entirely to railways. This means that it is independent from other networks (e.g. commercial GSM networks) and it is not shared with entities other than railways (e.g. police or other public services). Also, GSM-R does not provide any services directly to the passengers, so their GSM terminals do not detect or connect to the GSM-R network.

RAILWAYS' CHOICE OF GSM-R

The work that eventually led to the development of GSM-R started in the late 1980s.At that time, concepts of a new communication-based signaling system started to emerge. These concepts later turned into ETCS, as described earlier.However, already in the 1980s, it was foreseeable that future railways would need new mobile communication systems. Therefore, UIC initiated a discussion on reserving some of the GSM radio spectrum for the future railway use.

Railways wanted to adopt a well-proven technology and use it for their purposes with a minimum of modifications. Two technologies were the strongest candidates: GSM and Terrestrial Trunked Radio (TETRA). GSM is a technology designed for commercial mobile telephony networks. TETRA is a network for public services, e.g. police, fire brigades, governmental institutions etc.Both technologies had their advantages and disadvantages. GSM had largesupport from the telecommunication industry and a large base of suppliers. On the other hand, TETRA could provide bigger coverage and offered various features, which were useful for railways, e.g. group calls and direct mode operation (without infrastructure). However, in 1990, TETRA was still in the standardization process. Therefore, GSM was chosen. The most important argument was that GSM had been an already proven technology with many products available on themarket.

DIFFERENCES TO THE COMMERCIAL STANDARD

GSM was designed as a network for commercial mobile telephony. Therefore, the GSM standard had to be modified before it could be used in railway environment.

There were several reasons for that:

- Railway communication network must support users (trains), who travel with speeds up to 500 km/h. Various services and applications delivered by the railway communication network have different importance and different impact on the railway safety.
- There is a need to differentiate between these services and provide them with various priorities in the network. Therefore, railway communication network must provide an efficient Quality of Service (QoS) mechanism.
- Railways require additional voice communication features, such as dynamic addressing and group calls.

GSM-Rprovides all of the features of GSM. However, there are a few notable additions introduced in GSM-R by EIRENE and MORANE projects:

- *Enhanced Multi-Level Precedence and Pre-emption (eMLPP)* is a QoS mechanism that sets different priorities to calls and connections in GSM-R. For instance, eMLPP ensures that ETCS message exchange is not interrupted by a low-priority voice call. eMLPP is a necessary mechanism in a network where transmission resources are shared between safety-critical (e.g. ETCS) and other services.
- *Functional Addressing (FA)* allows users to call certain destination without knowing a specific phone number [14]. For example, it is possible to call a train dispatcher responsible for a given area, by simply pressing a single “Dispatcher” button on a GSM-R voice terminal. Another example is calling a train driver. Instead of knowing the particular phone number used by a train, it is possible to call the driver using the train running number.
- *Location Dependent Addressing (LDA)* dynamically selects the called party based on the caller location. This feature is used mainly when a train driver wants to connect with a dispatcher. LDA automatically chooses the dispatcher responsible for the given railway area. FA and LDA greatly simplify everyday railway operation and allow placing voice calls faster.
- *Voice Group Call Service (VGCS)* and *Voice Broadcast Service (VBS)* offer the possibility to make group and broadcast calls [24]. For instance, these features may be used by a dispatcher to inform all train drivers about some disruption and the following travel delay.
- *Railway Emergency Call (REC)* is the most important GSM-R feature from the point of view of railway safety. REC is a high-priority broadcast call. It can be established from any GSM-R voice terminal using a dedicated REC button. REC pre-empts all ongoing voice calls and connects the caller with the dispatcher. All other terminals in the area automatically start to listen to the ongoing REC. Therefore, it is ensured that all railway personnel are immediately informed about the emergency situation.
- Besides the additional features, another important difference to GSM is thededicated radio frequency band in which GSM-R operates. Across Europe railways received an exclusive 4 MHz in 921 MHz radio band for GSM-R. As shown in Figure 2.4, 876–880 MHz is the uplink band, while 921–925 MHz is the downlink band. The common band used across the whole EU is one of the important elements allowing for cross-border interoperability.

In some countries GSM-R received an additional 3 MHz band: 873–876 MHz in uplink and 918–921 MHz in downlink. Thus, a total bandwidth of 7 MHz is available to GSM-R there.

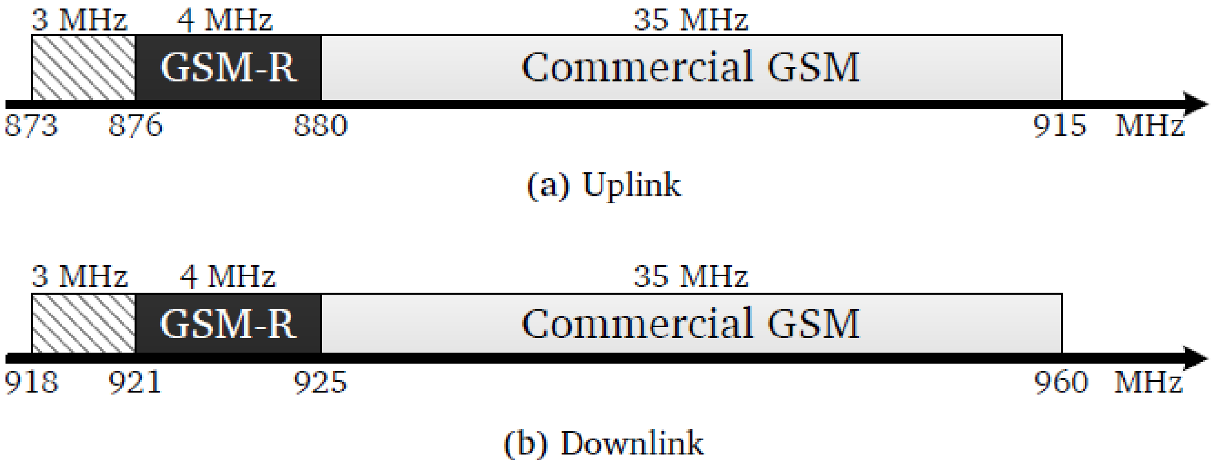


Fig: GSM-R radio frequency bands in uplink and downlink. The hatched fields represent the additional band assigned to GSM-R in some of the European countries

GSM-R PRINCIPLES AND SHORTCOMINGS

GSM-R network is divided into three main subsystems:

- *Mobile Station (MS)* is the user terminal attached wireless to the network. It may be a handheld voice terminal, a voice cab-radio or an ETCS OBU installed in a locomotive.
- *Base Station Subsystem (BSS)* is a Base Station Controller (BSC) and a number of Base Transceiver Stations (BTSs), managed by that BSC. BTS is a radio base station responsible for wireless communication with MSs.
- *Network and Switching Subsystem (NSS)* is commonly referred to as the "core network". The most important nodes in NSS are: Mobile Switching Center (MSC), Home Location Register (HLR) and Visitor Location Register (VLR).

MSC is the central element of NSS. It is responsible for management of the MSs (e.g. registration), call establishment, call routing and mobility management.

Apart from the three subsystems above, GSM-R includes servers responsible for providing railway services (e.g. REC), as well as nodes responsible for operation and maintenance tasks (Operations and Maintenance Centre). The basic architecture of
GSM-R

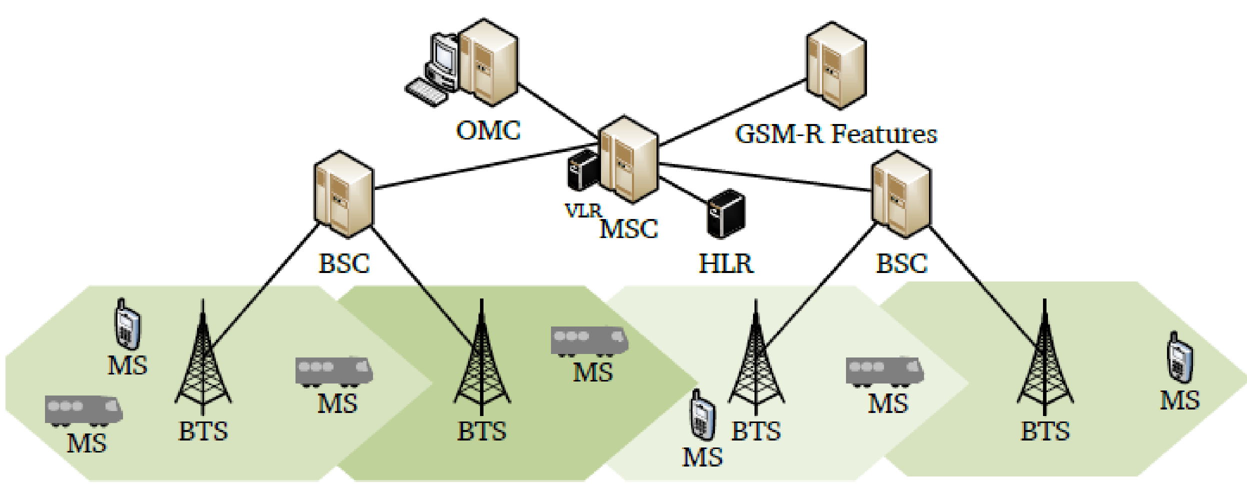


Fig: GSM-R network architecture

MAIN FEATURES OF GSM-R

GSM was designed as a mobile network for providing telephony service (data communication was significantly less important). Thus, technical solutions implemented in GSM were selected and optimized for that type of communication. The following paragraphs present the main features of GSM-R, while the next section discusses the consequences of the chosen solutions. This analysis is based on the previously published paper.

CELLULAR NETWORK

GSM-R is a cellular network, i.e. the connectivity with Mobile Stations (MSs) is delivered by a system of geographically distributed radio cells. The centre point of each cell is a BTS. From one side, the BTS provides radio coverage in its cell. On the other side, the BTS provides connectivity to the core network and the service offered there.

CIRCUIT-SWITCHED BASED TRANSMISSION

GSM-R is a circuit-switched network. Therefore, every connection in the network (call or a data connection) requires a dedicated end-to-end virtual circuit. This means that network resources are reserved exclusively for a particular connection, both on the radio and the backbone links.

FREQUENCY-DIVISION DUPLEX (FDD)

GSM-R is an FDD technology, so the uplink (from an MS to a BTS) and downlink transmission are carried on separate frequencies, as shown previously in Figure.

Hence, the 4 MHz GSM-R band consists actually of a 4 MHz band in uplink and a 4 MHz band in downlink.

The uplink and downlink resources are assigned symmetrically, in a sense that an active connection always receives equal uplink and downlink network resources.

In the following paragraphs, only one direction is discussed, but the description applies equally to both of them.

FREQUENCY CHANNELS

The 4 MHz GSM-R radio band is divided into 19 frequency channels, each being 200 kHz wide. These channels are used to separate transmissions in neighbouring cells. Hence, the frequency channels must be distributed among cells in a way ensuring that neighbouring cells do not use the same frequencies (the same channels). Each radio cell uses one or more channels depending on the expected capacity demand.

A frequency channel that is used in one cell can be reused in another cell, but only if the distance between them guarantees that the cells do not interfere with each other. Seven frequency channels are usually required to provide coverage over a wide area. On an open railway line, where only a linear coverage must be provided, four channels may be sufficient. Since the GSM-R band offers 19 channels, cells are assigned sets of channels instead of a single channel.

For instance, if seven sets are defined, then each of them includes two or three channels. Therefore, two or three frequency channels are available in each cell. An exemplary channel distribution is presented in Figure.

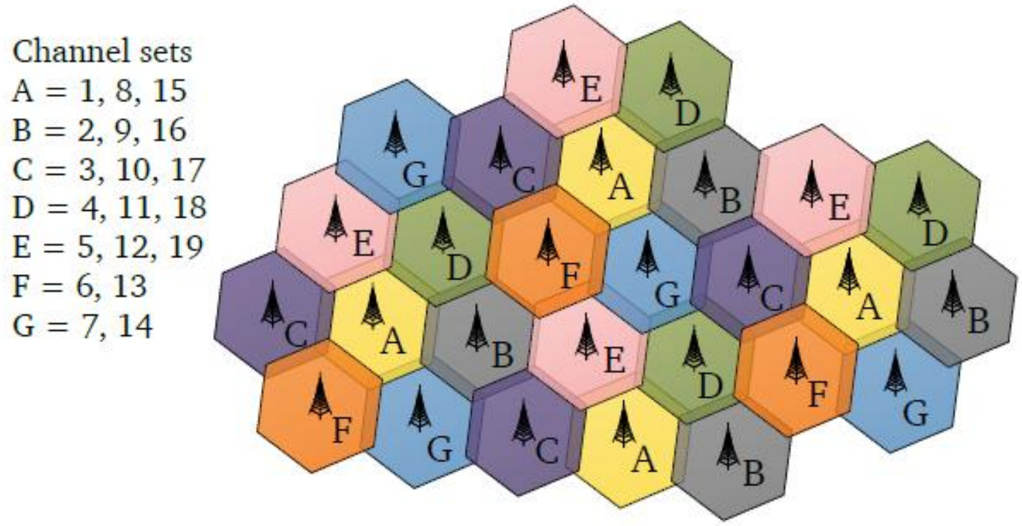


Fig: Example of frequency channel distribution with seven channel sets. Each set is marked with a letter and a distinctive color.

TIME DIVISION MULTIPLE ACCESS (TDMA)

In order to provide multiple calls (circuits) per cell, each frequency channel is shared between MSs using TDMA. GSM-R radio transmission is divided into frames.

A frame lasts 4.615 ms and consists of eight time-slots (each 0.577 ms), as shown in Figure. In each cell, at least one time-slot is reserved for network signaling

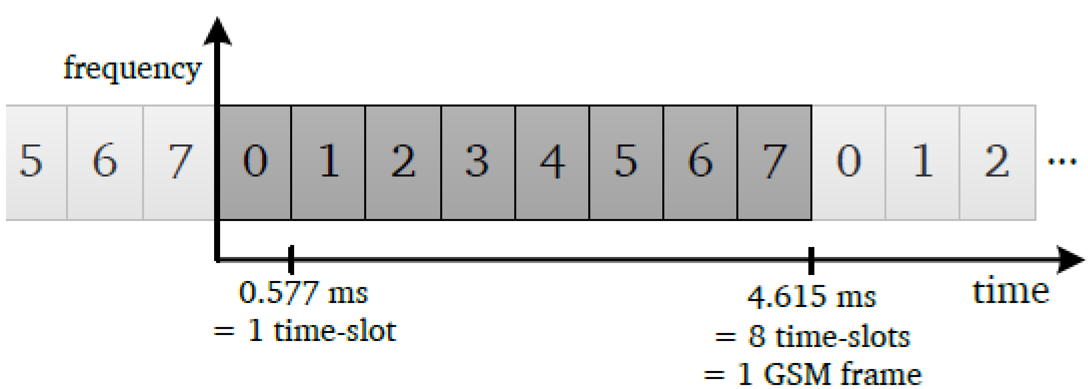
.

The remaining seven slots carry user calls/connections, i.e. the virtual circuits.

A GSM-R call occupies one TDMA time-slot in every consecutive frame. This time-slot is reserved exclusively for the call, until the call is finished. Since seven time-slots are available, seven simultaneous calls can be carried over a single frequency channel (assuming that one time-slot is used for network signaling).

Inactive MSs do not occupy any time-slots. As explained earlier, a cell usually offers up to three frequency channels and each of them carries seven connections.

Therefore, capacity of a typical cell is 23 connections, i.e. traffic channels. These capacity considerations



RADIO MODULATION

Gaussian Minimum Shift Keying (GMSK) modulation, which is used in GSM-R, was chosen due to its simplicity in hardware implementation and low interference emission. However, regardless of the radio conditions, it transmits only one bit per
symbol.

CONSEQUENCES OF THE GSM-R DESIGN CHOICES

GSM standard was designed taking into account two important assumptions that affect the performance and capabilities of GSM-R networks today:

• GSM network will be used predominantly for voice service.
• MSs will offer little computing power and limited battery life.

Nowadays, these assumptions do not hold. This is because, since the early 1990s, when GSM was designed, both the communication demands and the capabilities of electronic devices have evolved significantly.
First and foremost, data communication is now equally or even more important than voice communication. In railways, this was already true when GSM-R was being designed as a technology supporting ETCS command-control system. ETCS is based on data communication. Moreover, new communication-based applications and services are foreseen for railways. Hence, a modern railway communication network must provide good support for data transmission.

Secondly, thanks to the advances in electronics, the computational power of modern mobile terminals allows implementing much more advanced modulation and multiplexing solutions. Also, the battery life is usually less of an issue in the railway environment, because many terminals (MSs) have continuous power supply, e.g. from a locomotive.

Despite these significant changes, the GSM-R standard remained unmodified.
Some of the design choices that made GSM-R a good technology for voice communication in the 1990s became its shortcomings today:

• GSM-R does not provide packet-switched based transmission. Therefore, data communication must be delivered by Circuit-Switched Data (CSD), which cannot assign the network resources based on the actual demand. This means that data is transmitted over virtual circuits, just like voice frames. However, in opposite to voice, data communication is most often bursty. Data source sends varying amount of data at irregular intervals. Such a bursty transmission does not fit well into a fixed circuit provided by GSM-R. As a result, circuits are often underutilized and network resources are wasted.

• TDMA assigns one time-slot a frame to each connection. This fits well with voice encoders that encode speech into periodical frames. Bursty data connections, such as ETCS, could benefit from using more time-slots per frame. However, a single connection cannot get more than one time-slot, even if spare time-slots are available. Therefore, the radio resources may stay unassigned even if there is data traffic waiting for transmission.

• GSM-R resources are assigned symmetrically in uplink and downlink. However, data-based services often generate different amount of traffic in the twodirections. Hence, symmetry of GSM-R connections means that either uplink or downlink is overbooked and the network resources are wasted further.

• GMSK modulation scheme, which is used in GSM-R, is unable to take the full advantage of good radio conditions. GMSK is sufficient for voice communication, but more advanced modulations schemes would allow GSM-R to transmit at much higher bitrates. Thanks to the advances in electronics, nowadays even

handheld devices are capable of using more advanced multiplexing and modulation techniques, such as Orthogonal
Frequency-Division Multiple Access (OFDMA) and Quadrature Amplitude Modulation (QAM).

• The maximum connection bitrate offered by GSM-R is only 9.6 kbit/s.
This is a consequence of many design choices such as the modulation and multiplexing schemes. Such a low bitrate is insufficient for many modern applications, especially those based on transmission of multimedia.

• Transmission latency in GSM-R network is estimated to be in the range between 200 ms [29] and 400 ms [4, p. 162]. If the low bitrate is added to that, the GSM-R delay performance turns out to be very poor. Thus, GSM-R may not fulfil requirements of delay-sensitive applications.

• GSM-R Call setup time is in the range of about 5 s [4, p. 162]. GSM-R requirements state that the setup procedure cannot exceed 8.5 s (95% of cases) and
10 s (100% of cases) [30]. This may be sufficient for a voice call, but such a long connection setup time is unacceptable for many real-time applications.

FUTURE ALTERNATIVES

GSM-R capacity and data transmission capabilities are insufficient considering today's railway communication needs. In the future, GSM-R shortcomings will become even more problematic as demand for communication-based services will grow. Therefore, railways seek various technical and operational solutions to these shortcomings.

CONCLUSION:

We can conclude after knowing about ERTMS that there is a huge scope of evolution in the Railways when it comes to the communication systems. The technologies used are changing and evolving day by day. From Analog Communication Techniques to VoLTE, the evolution is great. There are some other technologies too which are used such as GPRS, WiMAX etc., which are used in systems. All systems have some eye catching features and some limitations. The need of the hour is to get a hybrid technology, with features of each others, so that communication on a whole gets better in future.

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