On Digital Signaling for Moscow City Railways

Donat Shneps-Shneppe

***Abstract*— The article considers possible communication networks for Moscow City Railways. This fast-growing railway system requires both the modernization of existing communication network on existing lines, and the use of modern train communication systems on the under construction railway branches of the Moscow agglomeration. Communication systems are compared by technical parameters (transmission bandwidth, spectrum utilization density, number of tasks to be solved, etc.), and by technical and economic indicators in terms of cost and deployment time (the required number of base sites, interoperability with existing communication systems, etc.). Considered are networks of digital radio, broadband GSM, satellite mobile Internet, and others, including their combination. Digital radio DMR standard, which is the most modern and progressive compared to TETRA, is analyzed more than the others. The advantages and disadvantages of this standard in terms of its use as a separate communication system and in combination with other networks are considered on the example of a multitude of technical and economic issues that the task of providing communication on the railway system of the Moscow region poses.**

***Keywords*— Moscow City Railways, GSM-R, DMR, TETRA.**

I. INTRODUCTION

The operation of a railway system requires the integration of numerous different subsystems, such as:

- Rail line infrastructure
- Energy systems
- Signaling systems
- Communications networks
- Traffic operation and management
- Rolling stock
- Maintenance
- Telematic applications for passenger services
- Freight management

The transmission of the information from the ground equipment to the on-board equipment can be accomplished in two ways:

- By physical elements arranged along the railway line (such as beacons, or "balises", and track circuits). In these systems, the train receives information only when it physically passes over these elements.
- By radio systems. In this case, radio coverage ensures that any train located on the line receives the information transmitted by the ground or satellite equipment at any location.

Received: 05 May 2018.
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The landscape for railway telecommunications in Europe has changed drastically since the turn of the century. From 35 separate analogue systems in 2000, a single, interoperable railway communications system now exists across much of the European railway network: GSM-R. In 2016, 60 countries on five continents were using GSM-R, with more than 100,000 km of lines covered in Europe [1]. Work is underway now to lay the framework for a new standardized railway telecommunications network to replace GSM-R: the railway sector is ready to replace its existing 2G networks.

The paper is one our attempt to understand the transition from the GSM-R network to the LTE-R and 5G-R - whether it takes place at all? [2] The another alternative is to turn to DMR or/and TETRA.

The rest of the paper is the following. Section 2 is devoted to Moscow transport plans. Sections 3 and 4 are about GSM-R. In Section 5, TETRA and GSM-R technologies are compared. New standard DMR is described in Section 6. Section 7 contains TETRA and DMR comparison. The paper is concluded by discussion (Section 8) on the future of railway radio and by the recommendation to implement DMR standard for Moscow railways.

II. THE GREAT MOSCOW AGGLOMERATION CASE

Moscow metro and Wi-Fi and LTE. People can use free Wi-Fi by accessing the Moscow Transport (MT_FREE) network [3]. Several million people use the network daily. All Moscow Metro line trains, Moscow Central Circle (MCC) trains, and Aeroexpress trains now feature the Moscow Transport (MT_FREE) Wi-Fi network. Passengers can stay online during an entire trip.

People using the network only need to register once, when entering a metro or MCC train, bus, tram or trolleybus. After that, they can use the MT_FREE Wi-Fi network on various transit routes, without text-message identification.

Several million passengers use Wi-Fi networks daily. The company Maxima Telecom operates the joint Wi-Fi network created under a long-term project with the Department for Transport and Road Infrastructure Development. Operator Tele2 provided a 4G-access for a half of the Moscow Metro (as by 30 May 2017).

Moscow Central Circle and GSM-R network. The Moscow Central Circle line (Fig.1) is operated by 61

Siemens ES2G Lastochka trains and controlled by GSM-R. The line opened on 10 September 2016. 130 trains per day will circulate around the circle line, with a frequency of 5–6 minutes during the rush hours, and 10–15 minutes at other times. Within MCC project ROTEK Company has supplied more than 700 GSM-R portable stations and 1,200 specifically designed SIM-cards for use in portable and locomotive radio stations, which had installed in high-speed trains "Lastochka" of MCC.

Rotek Company in partnership with Frequentis has completed a project to equip the Moscow Ring Railway (MRR) with GSM-R dispatch communication equipment on behalf of JSC Russian Railways.

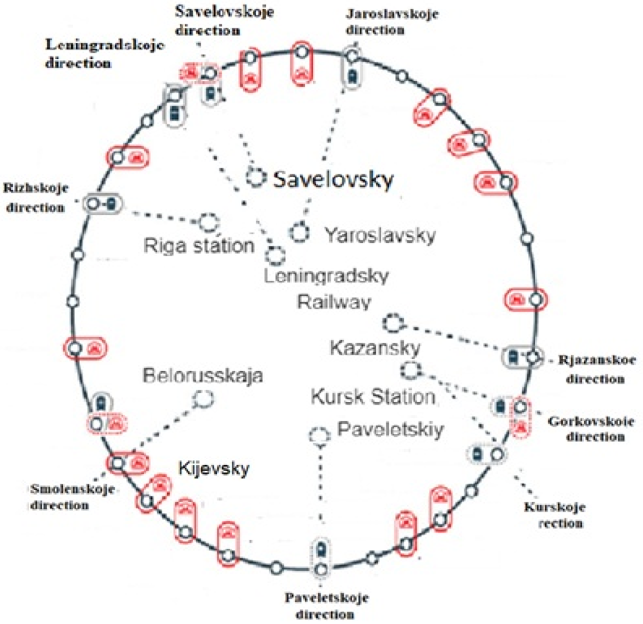

Fig. 1. Moscow Central Circle (MCC) and nine Moscow railway stations

Moscow Central Diameters. In 2017, Moscow announced plans [4] to create links between the existing radial rail routes into the city (Fig. 2). Modeling the movement of trains taking into account the development of diametrical connections of the railway lines of the Moscow node and GSM-R QoS requirements is extremely important. The possible route of one given train may lay through an urban area with complicated interference conditions and through a rural area with lack of base stations. The interoperability of different connection types, including possible frequent change of the network base layer should be considered.

Four nodes for throughput modeling, as well as two critical nodes, are shown (Fig. 2) to fulfill QoS Requirements (Table 1). By word, Banedanmark [5] has made a memo about ETCS level 2 solutions for large stations and junction areas. They state that the practical limit is approximately 25 trains per square kilometer, which could be raised to 28, when extensive network planning is done, using sectored and umbrella cells.

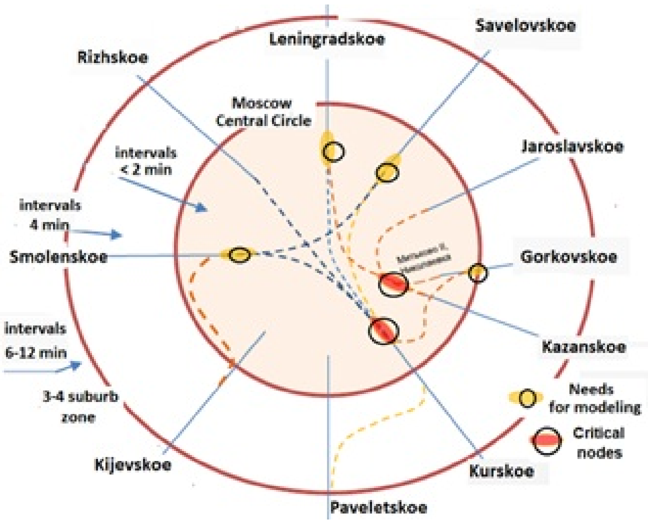

Fig. 2. Nine Moscow railway stations and the projected diametrical connections [4]

Table 1. Main GSM-R QoS requirements.

Requirements	Value
Connection establishment delay of mobile originated calls	< 8.5 s (95%), ≤ 10 s (100%)
Connection establishment error ratio	$< 10^{-2}$ (100%)
Connection loss rate	$< 10^{-2}$/h (100%)
Maximum end-to-end transfer delay (of 30 byte data block)	≤ 0.5 s (99%)
Transmission interference period	< 0.8 s (95%), < 1 s (99%)
Error-free period	> 20 s (95%), > 7 s (99%)
Network registration delay	≤ 30 s (95%), ≤ 40 s (100%)
Call-setup time	≤ 10 s (100%)
Emergency call-setup time	≤ 2 s (100%)
Duration of transmission failures	< 1 s (99%)

Fig. 3.1. On the prospects of intra-urban rail routes (ground metro): the line Odintsovo–Lobnja [4]

Fig. 3.2. Moscow Central Diameters [4]

At least five such routes are to be developed, with existing lines upgraded and large diameter tunnels bored where required (Fig. 3). The first phase would cover two ground routes, branded Moscow Central Diameters. End-to-end journey times would be about 1 hour on both routes, with services running every 6 minutes, compared with less frequent and less regular services on the current lines [4, 15, 16].

III. GSM-R BASICS

ERTMS System overview [6]. The definition of European Rail Traffic Management System (ERTMS) was the result of the European efforts to promote interoperability. ERTMS includes three levels.

– ETCS level 1: the location of the train is determined by traditional means (i.e., no beacons are used for locating the train), whereas communications between fixed safety infrastructure and trains are performed by means of beacons (transponders placed between the rails of a railway track). GSM-R is only used for voice communications.

– ETCS level 2: the communications between trains and the railway infrastructure are continuous and supported by GSM-R technology. The location of the train is estimated by means of fixed beacons.

– ETCS level 3: the integrity of the train elements is checked at the train, thus no devices are required in the track. Fixed beacons are used to locate the train.

Among them, ERTMS levels 2 and 3 employ GSM-R as the basis that supports communications. In Europe, a 4MHz bandwidth is reserved for such communications. The main elements of ERTMS are:

- EURORADIO GSM-R: radio infrastructure.
- EUROBALISE: beacons allowing for locating the trains accurately.
- EUROCAB: on-board management system that includes European Vital Computer, Driver-Machine Interface, and measurement devices such as odometers.

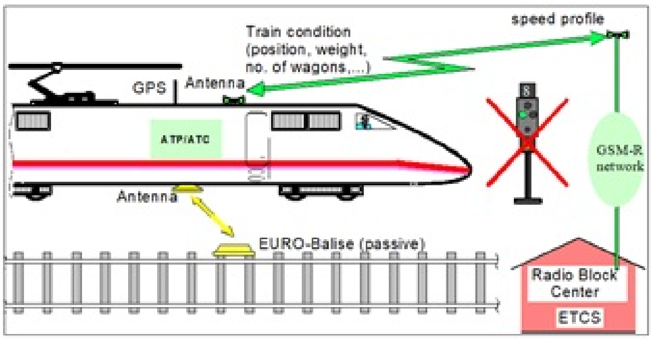

Fig. 4. European Train Control System ETCS[6]

The interface between the fixed part of ETCS is the RBC (Radio Block Centre) and for GSM-R the MSC (Mobile Switching Centre). This interface is using the protocol ISDN 30B+D that consists of 30 64kb/s B-connections plus a 16kb/s D-channel for signaling purposes. Together this makes up a 2 Mb/s connection. Between the MSC and the more outspread part of the GSM-R system, the BSC (Base Station Controller), two 2Mb/s systems is used for redundancy sake. The same applies for the connection between the BSC and the BTS (Base Transceiver System), but for security reasons the BTS is connected in a loop, always having two possible connections. The transmission media can be optofibre cable, coaxial cables or radio links, the latter often used in rural conditions.

Radio channels and available frequencies. Dedicated frequencies are reserved for the use of GSM-R for operational communications by railway companies. For uplink communication 4 MHz is reserved in the 876 – 880 MHz band, and for downlink 4 MHz in the 921 – 925 MHz band. As these frequencies are agreed on a European basis, they allow border crossing and international traffic. The 4 MHz for GSM-R makes 19 frequency channels of 200 kHz each available. One of the frequency channels is used as a guard band.

Each 200 kHz frequency channel has 8 timeslots available to be used as data or voice channels, whereof one is used as the common control channel for the radio system (this concept is called Common Channel Signaling and is used for the internal control of the radio transmission system), and the remaining 7 are used for voice or data communication. One control channel can be used for two frequency channels, making 7 + 8 =15 timeslots/channels available for communication.

Using circuit switching, there is 19 frequencies available. Each frequency contains 7 timeslots for communication, making a total 19 x 7 = 133 channels for communication. If using the concept of one control channel for two frequencies, this makes a total of 142 available. These channels shall be used for both voice and ETCS data communication.

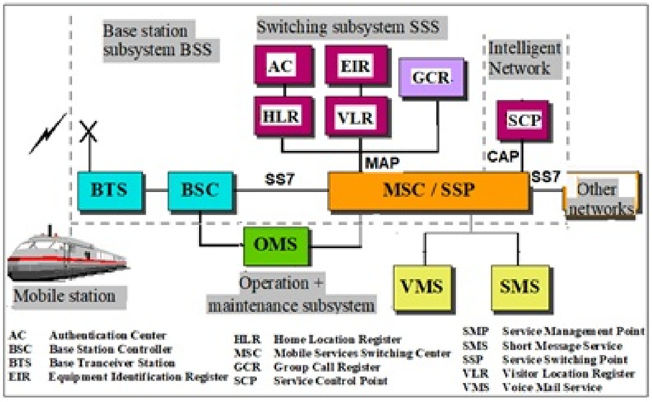

Fig. 5. Full GSM-system architecture

Table 2. GSM-R Services [6]

Service Group	Type of Service	Cab	Shunting
Voice-Call	Point-to-point	MI	M
	Public emergency	M	M
	Broadcast	M	M
	Group	MI	M
	Multi-party	MI	M
Data	Text message	MI	M
	General data applications	M	O
Specific features	Functional addressing (FA)	MI	M
	Location dependent addressing (LDA)	MI	O
	Shunting mode	MI	M
	Multiple driver communications within the same train	MI	NA
	Railway emergency calls	MI	M

Note: Mandatory for Interoperability (MI), Mandatory for the System (M), Optional (O)

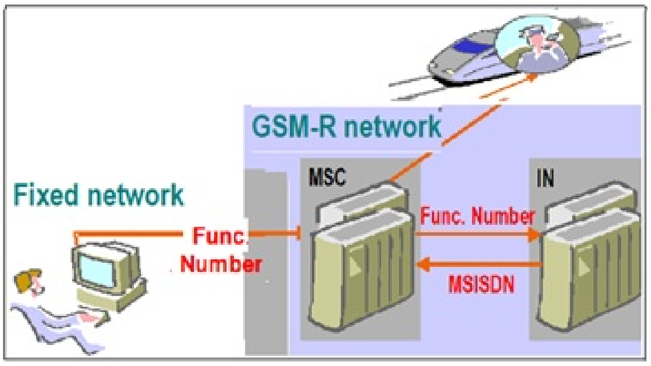

Fig. 6. Functional Addressing service scheme (supported by accistence of IN)

IV. Key Technologies for GSM-R unsolved yet

Railway has a close relationship with national economy and people's livelihood, reliability, availability, maintainability, security (RAMS) are always the key points of railway informatization construction, which are directly related to the property safety of the people. The wave propagation, wireless interference, wireless networking, encryption, and evaluation system of RAMS are the key factors, which have impact the transportation security and efficiency [7].

In general, the key technologies of GSM-R could be summarized as four aspects:

(1) The radio wave propagation simulation modeling theory and method for high-speed railway,

(2) The interference cancelation theory for GSM-R system;

(3) The key technologies of safety data transmission for high-speed railway; and

(4) The performance evaluation system for GSM-R system.

A. The radio wave propagation simulation modeling theory and method for high-speed railway

The large-scale propagation model for high-speed railway includes the different propagation models, which are suitable for different scenarios. The propagation model could optimize and modify the model according to the change of railway surrounding environment. Moreover, the propagation model could also propose and verify the correction factor, which could build the accurate radio wave propagation model database for different high-speed railway scenarios (plains, mountains, cuttings, bridges, hills, stations, tunnels, viaducts, etc.).The multipath fast fading distribution model mainly research the regularity of distribution for the multipath fast fading in high-speed railway and the field coverage margin due to multipath fast fading. Based on the small-scale fading and the distribution of multipath delay, the distribution of continuous bursters or caused by multipath fading fast is studied in the model. Moreover, the model also studies antenna technology, channel estimation and equalization, multipath diversity, and error correction coding, which is aiming to overcome the small-scale fading impact on the security of data transmission.

B. The interference cancelation theory for GSM-R system

The technology mainly studies the distribution of radio interference in high-speed railway scenario, which is taking GSM-R wireless networking and frequency planning into account. Moreover, the technology also discusses the mechanism of co-channel interference and adjacent channel interference in GSM-R system according to different radio wave propagation scenarios for high-speed railway (plains, mountains, cuttings, bridges, hills, stations, tunnels, viaducts, etc.). The technology combines the environment of high-speed railway with the interference propagation path and characteristics parameters outside of the statistical data analysis system.

The interference propagation path characteristic parameters, which is aiming to study the relationship between carrier to interference ratio and bit error rate (BER) and block error rate (BLER).

C. The key technologies of safety data transmission for high-speed railway

Nonlinear distortion handle technology of high-speed railway radio channel mainly studies the radio channel nonlinear distortion mechanism under high-speed (250 km/h - 500 km/h), complex terrain, and varying environmental characteristics. On this basis, the technology studies the influence of nonlinear distortion on train control system security data transmission according to the sparsity of train control data, which is aiming to research the feasibility of the general packet radio service for train control data transportation.

To reduce system latency, further research would study the fast synchronization of high-speed railway wireless receiver, channel estimation and equalization, and anti-Doppler frequency shift technology.

The redundancy technology in GSM-R system studies the mechanism of redundancy technology, which is aiming to establish a variety of redundancy theoretical analysis model. The technology also researches the influence of different redundancy methods (interleaving sites coverage and two base station coverages with the same site) on the network performance and service. In order to analyze the feasibility of mesh network in high-speed railway applications and establish a new train control security network model, the technology studies the application of mobile switching pool in high-speed railway.

D. *The performance evaluation system for GSM-R system*

The system mainly studies theoretical analysis model of the RAMS for GSM-R system, and deeply analyze the relationship between RAMS and network quality of service. According to the relationship between network quality of service and field coverage, radio interference, engineering design parameters (such as base station spacing, cell coverage radius, the overlapping area size, etc.), network operation, and maintenance, the system establishes the index evaluation system for GSM-R system.

The evaluation methods of GSM-R system indicators include the establishment of the index ratings and tolerance for network quality of service, field strength coverage, network operation, and maintenance. The wireless communication system RAMS indicators methods should meet the needs of reliable transmission for train control security data. Moreover, the methods also investigate the network quality service indicator of high-speed railway control data, wireless coverage level measurement, statistical analysis and measurement technology, and comprehensive evaluation method of network operation and maintenance.

V. A COMPARISON OF TETRA AND GSM-R FOR RAILWAY COMMUNICATIONS

In terms of frequency usage, TETRA is four times more efficient than GSM. TETRA offers four channels/25kHz, while GSM gives eight channels/200kHz, making TETRA systems more spectrum efficient: more channels are available, therefore there is more capacity to support significantly higher traffic levels. Having more capacity also allows for future mobile data applications to be implemented without the need for further RF equipment [8, 9].

TETRA operates in frequency bands 300 MHz and higher. GSM-R, by operating in the frequencies 876-915/921-960 MHz, requires many more base station repeaters than TETRA to obtain the same coverage. Using TETRA will lead to significant savings, not only in radio equipment, but also in civil engineering, such as buildings, shelters, and towers.

	GSM-R	TETRA
ETSI standard availability	Early 1997	Full ETSI status December 1995
Modulation	GMSK	Pi/4 DQPSK
Channel bandwidth	200 kHz providing 8 independent communication channels	25 kHz providing 4 independent communication channels
Frequency Bands (MHz)	876-880/921-925	380-400 410-430 450-470 806-821/851-866
TETRA/GSM-R CEPT SE7 Guard band in 800/900MHz for –60dBc (kHz)	300	25
Receiver sensitivity (dBm)	-104	-103
Maximum terminal speed (km/h)	500	500
Maximum propagation distance(km)	40	58
Cell handover time (ms)	Seamless	Seamless

Fig. 7. TETRA versus GSM-R [9]

Questions have been raised about the suitability of TETRA for terminals travelling at high speed – an important factor, since the average speed of trains is in excess of 200kph and speed has an effect on the TETRA radio data error rate. This is critical for high-speed rail applications where trains may run at speed of up to 350kph. The GSM-R standard specifies that the radio communication system should support speeds of up to 500kph. Simulations carried out by member companies of the TETRA community have proven that TETRA is effective at 500kph.

The typical cell size of a GSM system in a rural area is around 5 to 10 km radius, whereas TETRA cell sites range between 10 to 25 km, depending on terrain. Therefore, fewer TETRA cell sites would be required to cover a given area, typically resulting in fewer RF sites along the track and lower infrastructure costs.

Both TETRA and GSM-R will need special consideration for seamless handover when adjacent cells are busy (all traffic channels in use). However, TETRA is better provisioned to provide seamless handover continuity between cells, because ruthless pre-emption protocols already exist to disconnect lower priority users as part of the emergency call facility. This feature is very important from a safety perspective, as calls should not be dropped during data transmission and voice communication, even when trains are crossing between cells.

Voice call set-up time. GSM-R uses a public network type infrastructure that was inherited from GSM, making it extremely difficult to achieve very fast call set-up times. The set-up times currently achievable by GSM-R systems would not be acceptable in the event of an emergency. TETRA, on the other hand, was specifically designed for use in mission-critical environments, where fast response times are essential. The typical response time achieved by TETRA systems is less than 500ms-300ms within a switch, and 500ms between switches – much faster than EIRENE specifies for GSM-R.

Conclusions. The TETRA standard betters GSM-R in terms of performance, features and price – as well as having a more clearly defined future. Flexible and open, the standard allows software application interfaces to be written to address the highly specific requirements of the railway sector.

Although the GSM-R standard was designed to meet the requirements of the railway industry, TETRA is arguably a better standard for railway operators to adopt, offering:

- Better spectrum efficiency
- Better coverage
- Lower cost
- Public safety and mission-critical features
- More manufacturer support
- Clearer future plans and evolution of the standard

VI. DMR — A NEW RADIO STANDARD

In April 2015 the first release of standard DMR – ETSI TS 102361 was published, describing radio-interface (part 1), as well as the voice and base functional features of the standard (part 2). In January 2006 the third part of DMR standard was added, describing packet data transmission protocol. As a base technology of DMR, the mechanism of TDMA (Time Division Multiple Access – multi-station access with time division of the channels) is applied, what allows the deployment of two transmission time intervals on one carrier frequency with 12.5 kHz frequency grid [10].

DMR radio-interface. Two independent logical channels are put into one frequency channel (12.5 kHz). The operation of the DMR standard is expected not only in classical bands 136-174 MHz and 403-470 Mhz, but also in 450-527 MHz. Radio-interface structure of DMR standard is illustrated on Fig. 8.

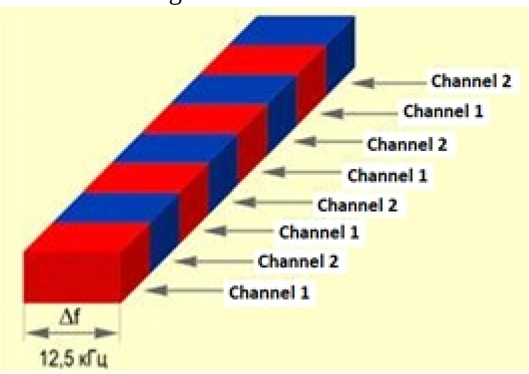

Fig. 8. DMR radio-interface structure

It should be taken into consideration, that from the planning perspective, if using the system without a repeater (in a direct connection mode) only one logical channel of two available is involved currently. In this case, profit of the direct connection mode against analogue connection in the part of channel capacity is not gained.

It is suggested to use DMR standard in two modes: (1) Direct mode – simplex communication, (2) Repeater mode (shown on Fig. 9) – using the technology of two-frequency simplex with duplex frequency division, FDD (Frequency Division Duplex). Two independent voice connections are possible in this mode.

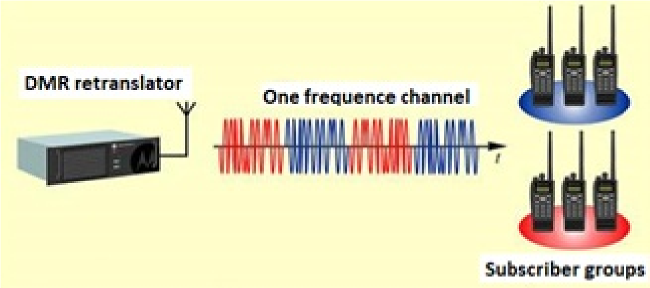

Fig 9. Repeater mode. Two independent connections are established by the use of both logical channels.

Voice transmission quality. Vocoder with ACELP algorithm (linear prediction with feeding from algebraic codebook) is especially suitable to be used in high acoustic interference situation. Forward Error Correction (FEC) technology is used for error detection and correction in channel coding.

Comparison diagram of analogue and DMR technology in the part of connection quality is shown in Fig. 10. Speaking about connection range it is worth mentioning, that obtained results depend on existence of obstacles and on electromagnetic interference conditions.

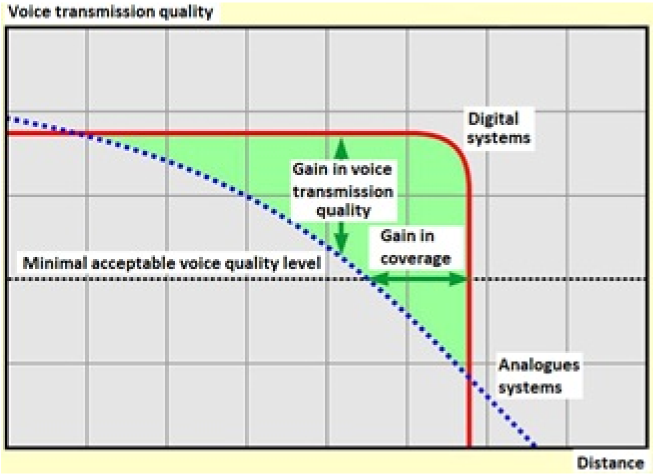

Fig. 10. Voice transmission quality

DMR key features. DMR standard is permanently developing, bringing together functional set not typical for a conventional radio-communication sector. Key features of digital DMR standard are:

- Digital processing of the signal
- Control of the battery
- Priority of the emergency call
- Upgraded hands-free mode
- On-board GSM module for applications with

location control
- Remote control
- Optional encryption
- Duplex call (in a project)
- Simultaneous transmission of voice and data (including packet transmission)
- Analogue mode, which is especially in demand in gradual replacement of technologies

DMR call types:
- Individual call station-to-station
- Group call station-to-group of stations
- Group call station-to-all stations
- Packet data transmission with channel bitrate 2 kb/s

The advanced efficiency of frequency resource usage. For most users of two-way radio connection systems, the main advantage of digital standards is a more efficient usage of available licensed frequency channels. Air is becoming more and more loaded, and the old structures of licensed channels, originally designed to serve a small number of users, are no longer able to cope with the increased level of traffic. To increase the efficiency of frequency resource usage, the DMR (ETSI) protocol uses the proven TDMA method in a 12.5 kHz channel, divided into two time slots. This allows us to maintain the well-known performance characteristics of the 12.5 kHz band and at the same time allows universal communication, depending on the current needs, to connect significantly more subscribers through the licensed channels. For example, two slots in one channel can be used to transmit two separate calls. You can also select one of the intervals for calls, and in the second one you can simultaneously transmit data or priority traffic.

VII. A TETRA and DMR Comparison

People perceive the term digital as more advanced and better than analog, because digital presents a number of attractive advantages to users. Two digital technologies — TETRA and Digital Mobile Radio (DMR) — offer different benefits, but which is the right choice for your system? When a user decides to upgrade a mobile radio system, many factors should be considered. TETRA often presents high infrastructure costs. Are these costs appropriate for the given benefits compared with the emerging DMR solution? Understanding some of the key points that characterize each of the digital technologies will help you make the best decision [11].

History of the Standards. TETRA standards development started in the European Telecommunications Standards Institute (ETSI) in the mid-1980s by a group of radio manufacturers. The initial requirement was a digital standard to replace the MPT 1327 analog trunked networks and to introduce a number of new features. The primary market segment intended for TETRA was the public access mobile radio (PAMR) market, where operators charge users service fees for trunked radio services. In the 1980s, many European countries had a strong interest in national PAMR systems for private dispatch communications and telephony. The standard specifications were written following the main needs of a PAMR system to maximize traffic capability.

ETSI chose a TDMA access and modulation schema to decrease the cell dimension and to increase traffic density. More traffic equals more business. ETSI spent several years specifying the standard because of the high complexity of the initial requirements — efficient linear modulation, vocoder selection, powerful protocols, field experimental tests, and others.

During the same time, GSM networks expanded their coverage outside towns with reasonable and decreasing costs. As a result, an important part of the mobile radio market intended for TETRA was devoured by GSM technology. The huge effort needed to develop TETRA, together with the market contraction, produced economic disasters for many companies involved in TETRA’s development. The surviving companies identified a new market segment to help pay for the investments — public-safety services. The manufacturers, with the contribution of some European governments, oriented their efforts to the more profitable security market. TETRA is the most popular solution for public safety in Europe, although the costs and economic crisis have slowed implementation in some countries.

DMR’s history is shorter and more recent. The DMR standard was published by ETSI in 2006 and optimized at the end of 2007. DMR was developed to substitute analog two-way radio systems with a pin-to-pin digital solution, meaning the digital system should perform the same coverage and application schema — repeater, multisite network, simulcast, and trunking — as the previous analog network. Motorola played an essential role in the specification activities and was the first actor in this new segment of the professional mobile radio (PMR) market. Less effort was needed to develop a DMR radio, because DMR is a less complex technology than TETRA.

The TELTRONIC communications solution based on TETRA technology provides an alternative means for data transmission instead of GSM-R and other radio systems employed in various train protection systems [11]. One basic feature of the TETRA solution is the use of standard Ethernet/IP interfaces, for both on-board equipment as well as ground-based systems, which thereby facilitates the end-to-end interchange of information between railway signaling applications.

The solution also provides for a unified multiservice system for all communications requirements, resulting in lower deployment costs compared to GSM-R systems

Frequency bands and spectral efficiency. TETRA operates between the 300 MHz and 800 MHz frequency bands, meanwhile GSM-R operates in 900 MHz and 1800 MHz. As radio propagation losses are directly proportional to the square of the frequency, GSM-R requires many more repeater stations than does TETRA to obtain the same coverage. Choosing TETRA therefore results not only in a savings for radio communications equipment, but also in civil engineering and site preparation costs (fewer towers, equipment shelters, etc.).

TETRA is four times more spectrally efficient than GSM-R, providing four channels within a bandwidth of 25 KHz, compared to eight channels over 200 KHz for GSM-R. Consequently, use of the radio spectrum, a natural resource that is limited in availability today, is greater optimized with TETRA.

Profile of use. GSM is a standard developed by ETSI for mobile telephone systems, in which frequency reuse is a key factor (even to the extent that propagations losses can be considered as an advantage), and where overall infrastructure cost is of lesser relevance since it is supported through the use of millions of subscribers.

GSM-R, which is an adaptation of GSM that include group call capability and a degree of protection for data transmission, is therefore obviously not cost-efficient for low user density systems such as for railways. TETRA can fulfill all of the communication needs identified for a railway environment in a single communications network.

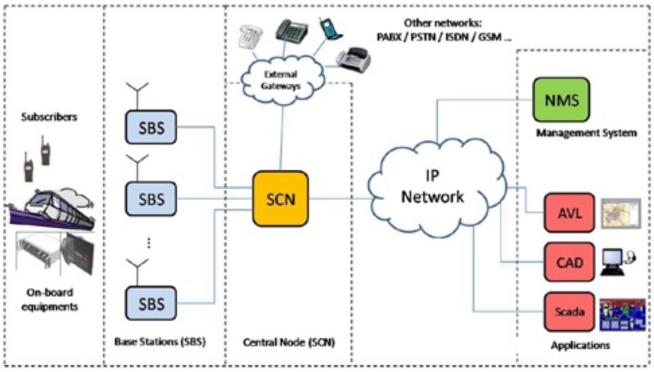

Fig. 11. TETRA architecture [12]

Digital Mobile Radio (DMR) is an open digital mobile radio standard defined in the European Telecommunications Standards Institute (ETSI) Standard and mainly used in commercial products around the world. DMR was designed with three tiers. DMR tiers I and II (conventional) and DMR III (trunked). The primary goal of the standard is to specify an entry-level, digital radio system with low complexity, low cost, and interoperability across brands, mostly intended for non-mission-critical users as for instance retail, businesses or sporting event.

On the other hand, Terrestrial Trunked Radio (TETRA), a European standard for a trunked radio system, is a professional mobile radio specification. TETRA was specifically designed for use by government agencies, emergency services (police forces, fire departments, ambulance) for public safety networks, rail transport staff for train radios, transport services, and the military. It is also a European Telecommunications Standards Institute (ETSI) standard. Both communications solutions provide an alternative means for data transmission to GSM-R, Wi-Fi, and the other radio systems employed in various train protection systems.

	TETRA	DMR Tier III
VOICE SERVICES		
Individual call, full duplex	Yes	No
Individual call, half duplex	Yes	Yes
Group call	Yes	Yes
Emergency call	Yes	Yes
Broadcast call	Yes	Yes
Pre-emptive priority call	Yes	No
All call	Yes	Yes
Telephone call, full duplex	Yes	No
Telephone call, half duplex	Yes	Yes
Roaming	Yes	Yes
Handover (restoration of ongoing calls after roaming)	Yes	No
DATA SERVICES		
Status messages	Yes	Yes
Short data messages (text messages)	Yes	Yes
Short data read and delivery receipt	Yes	No
Simultaneous voice and data	Yes	No
Packet mode data monoslot	Yes	Yes
Packet mode data multislot	Yes	No
Circuit mode data monoslot	Yes	No
Circuit mode data multislot	Yes	No
Maximum data rate, circuit mode data (gross rate)	28.8 Kbps	Not applicable
Maximum data rate, packet mode data (gross rate) (*)	14.4 Kbps (multislot)	2.4 Kbps (monoslot)
Secondary control channels for enhanced zone capacity	Yes (up to 4 control channels)	No
SECURITY SERVICES		
Authentication of terminals	Yes	Yes
Mutual authentication	Yes	No
Air interface encryption	Yes	No
End to End encryption	Yes	Yes
Temporary disabling of terminals	Yes	Yes
Enabling of terminals	Yes	Yes
Permanent disabling of terminals	Yes	Yes
ADVANCED SERVICES		
Late entry	Yes	Yes
Dynamic group number assignment (DGNA)	Yes	Yes
Call forwarding	Yes	No
Call authorized by dispatcher	Yes	No
Ambience listening	Yes	Yes

Fig 12. Comparison of the radio services and general features [12]

Bandwidth. As TETRA is a 4-TDMA technology, it provides up to 4 communication channels fitting into a 25 KHz physical channel. However, DMR being a 2-TDMA technology provides 2 communications channels fitting into a 12.5 KHz physical channel. This means that both TETRA and DMR radio technologies deliver the same spectral efficiency of 6.25 KHz per communication channel, although relevant differences arise when comparing the rates in data transmission, as shown in the table above. Maximum bandwidth provided by TETRA is 28.8 Kbps by using the circuit mode data service, whereas maximum DMR bandwidth is 2.4 Kbps by using the packet mode data service (gross rate). It is worth remarking that TETRA can offer up to 14.4 Kbps if using packet mode data service (gross rate), and DMR lacks circuit mode data service.

VIII. DISCUSSION: THE FUTURE OF RAILWAY RADIO

Work is underway now to lay the framework for a new standardized railway telecommunications network to replace GSM-R beginning in 2021 or 2022 (Fig. 13). But… a great deal of uncertainty persists over the technology that this new network will use and whether the railway sector is ready to replace its existing 2G networks [2].

There is a problem. GSM-R is a second-generation telecommunications system, which means it is a long way behind today's 4G technology, let alone 5G, which is expected to emerge around 2020. And while providers have committed to maintaining GSM-R up to 2030, beyond this it will become increasingly difficult, and expensive, for infrastructure managers to retain the same quality of service. In response, work is now underway to prepare the industry for the transition to a new radio system and associated technologies. Stable 5G products below and above 6 GHz may be available by the time of migration from GSM-R to the next standard radio system.

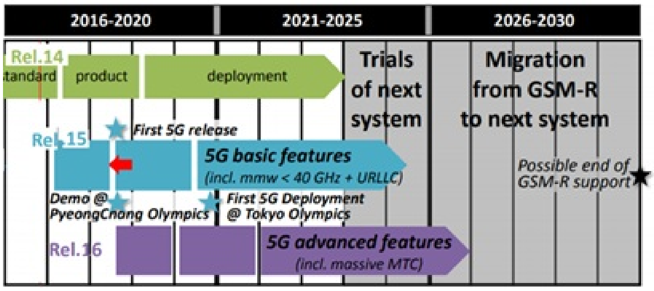

Fig. 13. Roadmap of 5G Deployments [2]

Biggest challenge. Nevertheless, it is spectrum allocation rather than radio technology, which is described as the biggest challenge facing the deployment of this new technology and the future of railway communications. GSM-R is currently located within the 4MHz of the R-GSM band. However, there is evidence that coexistence of GSM-R and a future system within this band is not possible without a substantial degradation of the level of service.

A 2016 study by LS Telcom considered whether LTE/LTE Advanced, as the only practical candidate currently available, could be used effectively on the same band as GSM-R. It found that it is not possible to introduce LTE in the GSM-R band without a number of technical mitigating measures while there is insufficient capacity to allow coexistence without some degradation. The study also concluded that LTE would provide extra data capacity but potentially reduce the capacity of GSM-R. In addition, in areas of high traffic density or border areas, the capacity for both services would be severely reduced.

To counter these problems, railways may be forced to explore the use of a different frequency for the new system, with the frequencies both below and above 1GHz available as possible alternatives. However, this could drastically increase costs due to the requirements to install new infrastructure compatible with an alternative frequency.

For GSM-R, Kapsch, Huawei, and Nokia have supplied the industry, while Ericsson is currently addressing the market with its LTE solution. Mr. Thomas Chatelet, project officer in the ERTMS Unit at the Agency (the European Agency for Railways), says that for the next generation, it is expected that these vendors will continue to lead the way, but with opportunities for others, including current signaling suppliers, to come up with their own solutions [1]. Challenge for Russia – to develop the own telecom industry (e.g. in cooperation with Huawei).

Huawei is continuing to push 4G LTE and 4.5G LTE as the preferred solution and engaged in various research and development activities [13]. Huawei will take a critical step forward with the rollout of 4G LTE on a China Railway main line in 2017. Companies already offer LTE network equipment compatible with GSM-R. The Huawei Technologies strategy consists of three steps (Fig. 14): Step 1 - Only GSM-R network, Step 2 - Parallel operation of GSM-R and LTE networks: GSM-R provides reliable (encrypted) communications for the control of trains, LTE transmits unprotected data, Step 3 - A single platform "LTE for railway" is being created.

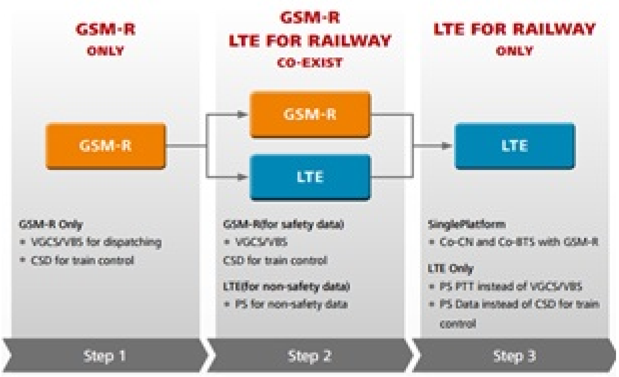

Fig. 14. Huawei Technologies strategy [13]

Is it reasonable to talk about 5G? Russia's MTS (Mobile Telephone System) has given a scathing assessment of the emerging 5G mobile standard during an investor presentation in London, decrying the lack of technological progress and the absence of any clear 5G business case [14].

Vasyl Latsanych, the chief marketing officer of Russia's biggest telco, delivered a stinging appraisal of 5G in almost every respect when asked by analysts how the eventual arrival of the technology would affect the operator's spending plans.

"There is no finalized technology, no network equipment available, no frequency allocation in any of our countries, and it is not in our plans for 2017 or 2018," he said. "There are no terminals -- and they don't seem to be coming -- and there is no business case behind it."

Complex network or LMR only. If a train route lies through large rural areas, it is reasonable to consider Satellite link as a part of the communication network for trains (Fig. 15). The use of satellite communication poses a number of questions in terms of a complex interference situation: periodic damping on the power line poles, long-term damping in tunnels and urban areas. Complex FEC and hardware-software control of the channel interleaver introduce a significant delay in the data transmission channel, which is enhanced by using a geostationary satellite with a high-altitude orbit. To control the noise-immune complex, it is necessary to predict and obtain the interference situation data through an additional system. To obtain data on periodic damping, a passive information system based on beacons can be used, warning about the presence, size, and distance between periodic sources of interference. It can be done without a warning system, relying only on the radar data on the jamming situation, or on the software error handling. But such a system will not timely adjust the noise immunity of the correcting complex, which will result in undesirable interruptions in the case of deterioration of the interference situation on the one hand, or in an unjustifiably high delay in data transmission in the event of a reduction in the amount of interference.

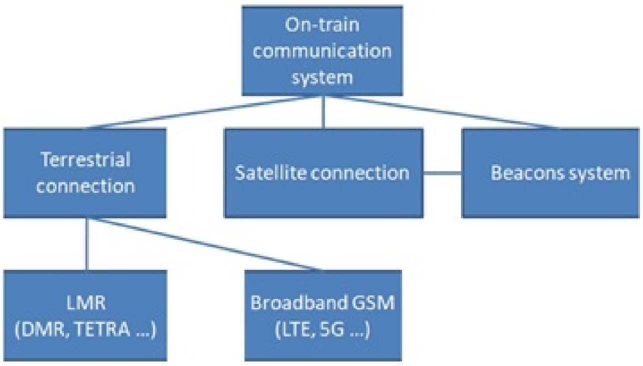

Fig. 15. Railway communications overview

In an area such as the Moscow region, the vast majority of the train's path lies in the urban or suburban area, which can be completely covered by base stations. Part of the train path can lie in the coverage area of the broadband network, in the rest, mostly suburban and partly rural area, there is a need for additional coverage of the network of radio sites. The most promising in this case is the use of the DMR network for several reasons:

- Denser use of the frequency spectrum in comparison with GSM-R
- Much less necessary number of base sites in comparison with GSM-R, 4G, not to mention 5G technologies
- In most of the frequencies used, DMR has a gain compared to TETRA in the number of required base sites (2 DMR sites versus 7 TETRA sites per coverage area)
- Economically, the transition to DMR is cheaper, as DMR has analog FM fallback mode, using analog channels in the same band.

If only one communication system for the signal network, voice calls and data transmission is to be selected for the train, DMR seems to be the most optimal universal technical solution that allows deploying the communication system with the least expenses in terms of costs and time.

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