ARCHIVES OF TRANSPORT
Volume 57, Issue 1, 2021

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.5604/01.3001.0014.7486*

STUDY OF THE POSSIBILITY OF USING TRANSMISSION IN THE LTE SYSTEM ON A SELECTED RAILWAY LINE FOR THE PURPOSE OF RUNNING RAILWAY TRAFFIC

Marcin CHRZAN[1]

[1] *Kazimierz Pulaski University of Technology and Humanities in Radom, Faculty of Transport, Electrical Engineering and Information Technology, Poland*

Abstract:

The railway and the Rail Traffic Control Systems installed on it in Poland have recently experienced rapid technological development. This is undoubtedly due to the funds that Poland receives from the European Union for the modernization of railway infrastructure. The development of modern railway infrastructure means not only stations, modern rolling stock, but also safe and reliable train control systems based on the latest telecommunications and information technologies. For a longer time, radio communication based on the GSM-R (GSM for Railways) standard is being introduced on PKP. For this purpose, dedicated infrastructure is being built in order to use this technology for railway traffic. This is associated with huge investment costs. Since the beginning of its existence, research has been conducted worldwide on the use of LTE (Long Term Evolution) technology for conducting railway traffic. For economic and technological reasons, it is necessary to study other possibilities of using modern telecommunications infrastructure not yet dedicated to railway tasks in these open networks. The article will present research on the use of open radio communication network based on LTE standard for rail traffic and passenger comfort. It will discuss the research method and selected results of measurements made on railway line no. 4. The choice of this railway line was dictated by two factors. The first one resulted from the maximum train speed, the second one is the variety of rolling stock used on this line (compartmental and non-compartmental wagons). The part of research concerning collection of measurement material was performed within the framework of completed research work PBS3/A6/29/2015. As a result of conducted in-depth literature analysis as well as performed measurements and calculations, it allowed to develop a model and software for simulating system operation in real conditions. This system allows to send railway telegrams on appropriate safety level defined in standardization documents. The research proved the possibility of using an open system in the LTE standard for the transmission of signals for railway traffic control and passengers while maintaining an appropriate level of safety. The only limitations which were indicated by the tests are improper radio interface coverage of railway lines. Appropriate planning of radio coverage of railway areas by radio communication operators (so far ignored) with proper cooperation of infrastructure manager can lead to launching efficient communication system without necessity to build specialized infrastructure for railway.

Keywords: *GSM-R, LTE, open systems, traffic control*

To cite this article:

Chrzan, M., 2021. Study of the possibility of using transmis-sion in the lte system on a selected rail-way line for the purpose of running rail-way traffic. Archives of Transport, 57(1), 91-101. DOI: https://doi.org/10.5604/01.3001.0014.7486

Contact:
1) m.chrzan@uthrad.pl [https://orcid.org/0000-0003-4181-4847] - corresponding author

1. Introduction

The introduction of microprocessor technology into the railway traffic control equipment took place at the turn of the century. However, the use of modern radio systems in rail transport is the moment when standard-based technology appeared in the world. GSM (Global System for Mobile Communications). For the needs of railways, and in particular aspects related to railway traffic control, this technology has been extended by giving it its name to the GSM-R standard. Unlike the GSM version, the frequency band in which the railway system operates has been extended and information transmission in two channels each 4 MHz wide has been introduced. FM (Frequency Modulation) systems currently used on the railways in Poland did not allow for data transmission due to their specific nature of modulation. However, some aspects of "data transmission" were used in radio-stop system. GSM-R transmission enables not only transmission in relation track - vehicle but also in relation track - track. Therefore, it has also become the basis for using it for remote wireless management of railway infrastructure.

Due to the degradation of wired infrastructure connecting the element of railway control systems, and related primarily to their destruction, the use of radio transmission medium for independent management of railway traffic control equipment is increasingly considered. An unquestionable problem when implying such solutions is the safety of transmission in such systems. It should be emphasized that safety at a certain level of transmission is already offered by the radio transmission systems themselves, which was also used in the GSM-R standard. Creation of a separate system for the needs of railways is connected with huge expenditures on designing, testing, certification and finally building and implementing such technology. Therefore, it is possible to use public open radio networks for railways, which will reduce costs because such a system relies on existing infrastructure.

A means of transmitting information that meets the requirements for safe transmission in the sense of railway traffic control systems should be developed. Therefore, a model for open radio transmission in public traffic control systems based on the public radio standard, LTE, will be presented later in this article.

The research methodology and assumptions will be presented. A measurement system will also be presented, which was used for actual measurements on the railway line based on the developed data transmission method. The obtained selected measurement results are original, as no research on the use of open data transmission for railway purposes using the LTE system has been conducted worldwide.

2. Literature review

Theoretical and practical aspects of srk systems (i.e. railway traffic control systems), including solutions applied in Poland, are presented in works (Brodzik 2019; Ciszewski et al., 2017; Jacyna et al., 2018; Mikulski and Gorzelak 2017; Zboiński and Woźnica 2010; Toruń et al., 2019; Burdzik et al., 2017, Kycko et al., 2018). This work does not, however, include solutions based on open data transmission systems.

Theoretical analysis and modelling of broadband signals, including in the LTE system, for various application areas has been presented in publications (Brazeetta et al., 2016; Baek et al., 2014; Chou et al., 2016; Gao et al., 2010, Nguyen et al., 2016).

Broadband signal propagation and related issues have been widely discussed, but no consideration has been given to rail issues under these headings.

The methodology of research as well as results and analyses of computer simulations concerning mathematical modelling of the system and transmission channel, paying attention to ensuring adequate capacity and reliability of the system and taking into account the problem of train movement were described in (Chrzan, 2018; Chrzan, 2020, Chen et al., 2017; Joshi et al., 2017, Kukulski et al., 2019).

The LTE system architecture and issues related to broadband signal transmission have been standardized in (3GPP, 2020).

The possibility of use in railway systems was not indicated there, however.

Due to the specificity of access to the technology and frequency bands used, the solutions presented above are based on the analysis of electromagnetic compatibility of existing radio systems based on frequencies specific for given regions (800, 900, 1800, 2100, 2500 MHz) (Chrzan, 2018; Chrzan, 2020). In this work, however, the consideration will concern the bands available for Polish users in railway radio communication.

Extremely important for the analysis of LTE system operation, not only in railway applications, are issues related to the use of modern antenna systems based on adaptive antenna technology, the use of SDMA (Space Division Multiple Access) or MIMO (multi-antenna systems) (Kamel et al., 2014; Parichehreh et al., 2016; Toruń et al., 2019; Bohagen et al.,2005, González-Coma et al., 2020; Hu et al., 2019).

Currently, there are no studies conducted in Poland aimed at using the LTE system on railways as a natural successor to the European system of railway radio communication based on the GSM-R standard, currently being introduced in our country. Within the framework of research works carried out at the WTEiI (Faculty of Transport, Electrical and Information Technology of the University of Technology and Humanities in Radom), an attempt was made to develop a method of safe data transmission between railway traffic control devices using fourth generation radio systems. These tests were limited to signal transmission in relation between the equipment installed on the track and LCS. However, there are no concepts and solutions for signal transmission in the track-vehicle relationship (Chrzan, 2018; Chrzan, 2020)

3. Analyses - case studies

3.1. Modelling the transmission system in a track-to-train relationship

The following assumptions were made for modelling the system of open radio transmission of telegrams between the traffic control devices and the Local Control Centre at WTEiI:

- the system includes traffic control devices with specific functionality and characteristics,
- srk devices have operating approvals and have safety certificates at a specific SIL (Safety Integrity Level) (Ciszewski et al., 2017; Idirin et al., 2011),
- radio transmission changes the transmission medium from wired to wireless, which means that the behavior of these devices should not change - their parameters are determined,
- radio transmission takes place under LOS (Line of Sight) and NLOS (Non-line-of-sight) conditions resulting from the specificity of the site,
- radio transmission takes place in open systems,
- the network load is a natural load, no influence on the network traffic generated by the measuring system - actual conditions in which the system is to operate,
- for modelling purposes, we assume the GSM-R transmission parameters with the assumption that meeting these conditions meets the transmission security conditions (Siergiejczyk and Rosiński, 2019).

3.2. The transmission model and the measurement method

In order to make measurements in the physical environment, a transmission model was built for an open system based on LTE transmission. The system in which the transmission takes place in the first stage of tests between virtual software LCS (Local Control Centre) and virtual control device, located on the train path. Within the framework of measurements, a system which is not a real time system from the Microsoft Windows operating system family was used. As a field transmitting device, a computer with Microsoft Windows 10 professional system was used along with MOXA OnCell G3470A-LTE modem (with parameters below) equipped with MIMO antenna systems (Multiple Input, Multiple Output) (Kamel et al., 2014; Parichehreh et al., 2016; Toruń et al., 2019; Bohagen et al.,2005, González-Coma et al., 2020; Hu et al., 2019).

On the receiving side there was a Windows 10 professional computer connected to the Internet via a broadband LTE network via a gateway (Fig. 1) with the following parameters (Chrzan, 2020):

- supported standards: GSM/GPRS/EDGE/LTE/ /UMTS/HSPA;
- transmission bands: LTE 2100/1800/2600/900/ /800 MHz (B1/B3/B7/B8/B20);
- UMTS/HSPA 2100/1900/850/800/900 MHz;
- transmission speed: LTE - 20 MHz bandwidth: 100 Mbps DL, 50 Mbps UL;
- HSPA - 42 Mbps DL, 5.76 Mbps UL;
- EDGE - 237 kbps DL, 237 kbps UL;
- GPRS - 85.6 kbps DL; 42.8 kbps UL;
- 4 LAN interface ports RJ-45 10/100/1000Mbps;
- cellular network antenna connectors: 2, SMA (female);
- console port: RS-232 (RJ-45);

- network protocols: ICMP, DDNS, TCP/IP, UDP, DHCP, DNS, SNMP, HTTP, HTTPS, SMTP, SNTP, ARP;
- routing/firewall: NAT, forwarding port, IP/MAC/Port filtering;
- VPN: maximum number of tunnels - 5, IPSec (DES, 3DES, AES, MD5, SHA-1, DH2, DH5), PSK/X.509/RSA;
- configuration and management options: SNMP v1/v2c/v3, Web / Serial Console, SSH, Remote SMS Control;
- number of SIM cards: 2.

The computer with the MOXA gateway served as the Local Control Center (LCS) located in the Department of Transport, Electrical Engineering and Computer Science in Radom.
The measurements were made on the railway line Warszawa Centralna - Kraków Główny running on the railway line no. 4 - Central Railway Main Line.
In order to send information, the methodology of the telegram creation and its transmission is the same as the standard for the transmission in open systems PN-EN50159:2011.
Fig.2 presents block diagram for the algorithm used to transmit datagrams.

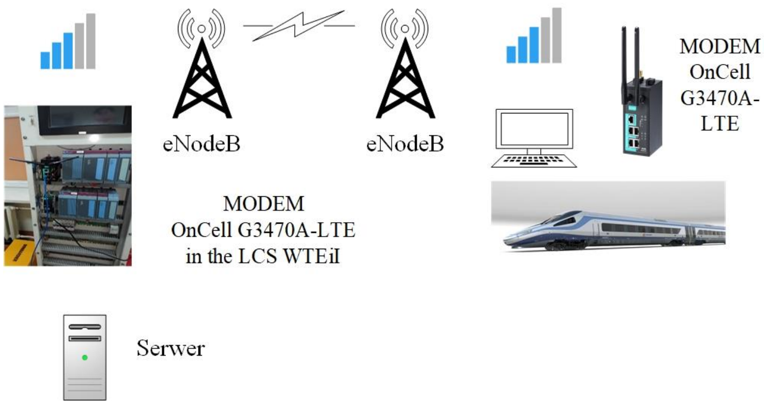


Fig. 1. Measuring system

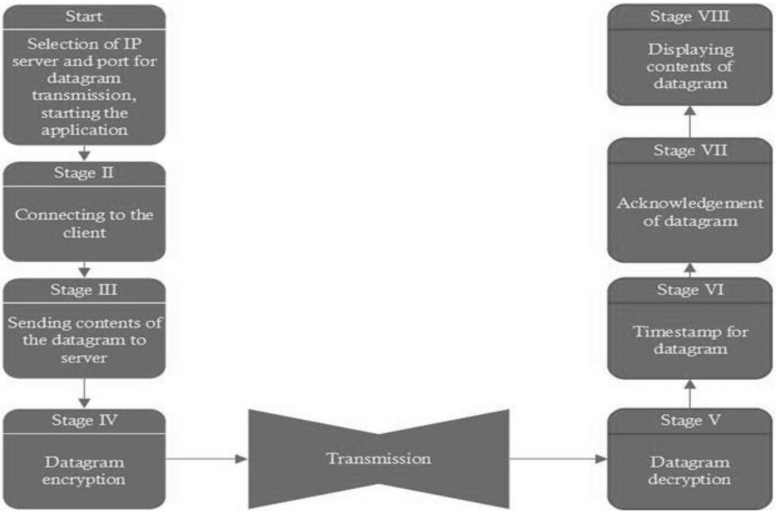


Fig. 2. The block diagram for algorithm used to transmit datagrams (Chrzan, 2018)

According to safety requirements, presented system should take into account following aspects (Chrzan, 2018):

– datagram numbering, it prevents the system from unintentional (intentional) deletion of datagram or datagram resequencing. Additionally, it allows for verification of order in which datagram arrives;
– Cyclic Redundancy Check (CRC) is used to verify plausibility and integrity of transmitting datagram. This method allows for single error detection based on the comparison of checksum appended to datagram with checksum which is calculated for datagram after receiving its contents. It should be noticed that CRC algorithm has been already embedded in Quality of Service (QoS) layer of LTE technology. In addition to that, Hybrid Automatic Repeat Request (HARQ) layer and Adaptive Modulation and Coding (AMC) layer are also responsible for correct transmission in difficult propagation conditions. Therefore, it seems to be reasonable to remove one CRC algorithm from LTE transmission. This removal allows for a decrease in datagram transmission delay and does not have the influence on safety of transmission specified in PN EN 50159:2011 standard;
– Maximum period of time in which the receiver waits for system response. It decreases datagram transmission delays;
– Advanced Encryption Standard (AES) algorithm has been used to prevent datagram transmission from hacker attacks. In the author's opinion this algorithm is sufficient for present and future systems.
– Solutions occurring in closed systems specified in EN 50128:2011, PN EN 50129:2019-01 and PN-EN 50159:2011 were adapted for open systems by authors. It results from the assumption that open systems should ensure at least the same Safety Integrity Level (SIL) as closed systems (Chrzan, 2020; Idirin et al., 2011).
– Overall system safety results from the safety of its elements. Because railway traffic control systems have a direct impact on the traffic safety, therefore they have to meet tough SIL-4 level for which, according to IEC 61508-1 norm, Tolerable Hazard Rate (THR) varies in the range of <10-9; 10-8).
– Due to impossibility of integration of presented solution with actual railway traffic control systems at this stage of research, only safety of radio communication interface has been analyzed.
– Radio communication interface under analysis uses LTE public network, what corresponds to project assumptions. Because LTE is an open system, research was conducted for actual transmission parameters and unknown system load. In authors opinion, such approach allows for plausible assessment of usefulness of system in tasks concerning railway traffic control. It results from the fact that indeterminist load of the network in fixed time interval allows us to determine actual delays and correctness of transmission. Such approach is necessary to assess the lowest possible value for parameters which should be guaranteed to ensure assumed Safety Integrity Level.
– According to PN-EN 50159:2011 standard, proposed system belongs to SIL-3 layer. Specification for SIL-3 also enumerates transmission in GSM-R, GPRS and Wi-Fi (802.11) standards. LTE technology uses packet transmission and has built-in "responsibility" for transmission correction so that LTE can be regarded as single channel transmission for which THR varies in the rage of <10-9; 10-8). Therefore, in authors opinion, proposed system based on LTE technology satisfies SIL-4 standard requirements (Toruń et al., 2019).

The measurement was based on sending an encrypted message from the device simulating the srk device installed on the line to the local control centre. Random messages were transmitted in sizes 16B, 32B, 64B, 128B, 256B, 512B, 1024B, 2048B, 4096B, 6144B, 8192B and 10240B. The measurements were related to the delay of message transmission in a set period of time, which was 900 s. The total time needed to transmit a message consisted of such factors as: time of encoding the message, time of transmitting the message through the cellular network and time of decoding the message.

The following algorithms were used to encrypt random railway messages of different sizes:

– AES CBC (Advanced Encryption Standard – Cipher Block Chaining)
– AES ECB (Advanced Encryption Standard – Electronic Codebook)

- DES CBC (Data Encryption Standard – Cipher Block Chaining)
- DES ECB (Data Encryption Standard – Electronic Codebook)
- RSA (Rivest–Shamir–Adleman) o długości klucza 1024 i 2048 bitów

The designed measuring program includes two modules: Server (being an LCS simulator) - and Client (being a transmission receiver). The Server program allows to connect with the Client program after establishing common transmission parameters such as: IP address, TCP protocol port number, and determining the method of the signal encoding. In case of RSA transmission with the use of a key - the server program allows to generate the key on the basis of the entered password. The server program receives the transmitted telegram, decrypts it, checks its integrity and sends the receipt confirmation to the Client. The program which initiates the exchange of transmission with a specific data encryption is the Client's program. Additionally, it enables sending a fixed message (telegram) of a specified length cyclically, at a specified time, sending a variable message, generated separately to each connection with the server, of a fixed length, generated cyclically, at a specified time, sending a single message of a specified length.

The telegram sent from the client to the server is constructed in such a way as to meet the safety requirements for open and closed transmission systems contained in the PN-EN50159:2011 standard, which is related to the used hardware and software working on it. Ensuring an appropriate safety level of telegram transmission should be carried out in a way that enables detection of signal transmission errors from the sender to the recipient, and in case of transmission interruption above a specified time, the system should cause a transition to a state ensuring safety. The results were saved to a file in excel spreadsheet format Fig. 3.

Because of the high non-stationarity of the propagation medium, which is the LTE system, a single measurement result is unreliable or repeatable. In such a case, the measurements were classified in terms of the probability of exceeding a certain delay of the received signal. The value of this probability is in the range 1-99%, however, typical values of this parameter are: 1%, 10%, 50%, 90% and 99%. For the purpose of the study, which is the study of delays, medians were used, i.e. middle values of an ordered subset of measurement results, whose probability of exceeding by other results from this subset is 50% (Brazeetta et al., 2016). In practice it is connected with determining the median P_{OP}^{i} value of the measurement signal delay at the receiver's input for the *i*-th subset of measurement data, created from *n* measurement results, collected on the route with the length of 40 λ according to the relation below:

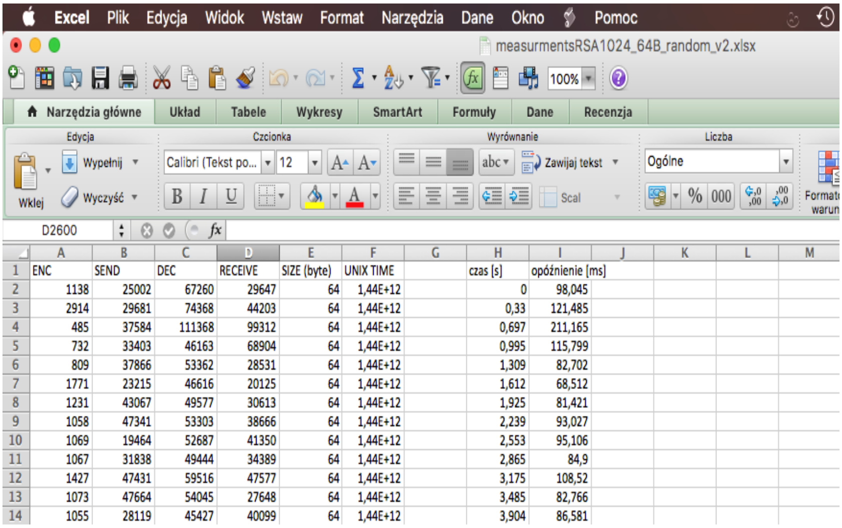
$$P_{OP}^{i}=\begin{cases} P^{i}_{OP,\frac{n+1}{2}} & ,for\ not\ even \\ \frac{1}{2}\left(P^{i}_{OP,\frac{n}{2}}+P^{i}_{OP,\frac{n}{2}+1}\right) & ,for\ n\ even \end{cases} \quad (1)$$

is an orderly subset of *n* of signal delay measurement results at the receiver's input and *n* is the number of measurements taken on the *i*-th (*i*=1,2,3...) section of the propagation path tested.

The process of median determination was carried out in real time, during the measurement tests on the section of the railway line No 4, but according to the designed algorithm of the program described in Figure 2 only determined median values of the measured signal are recorded. The designed program also allows to record all the results at specific measurement points and to determine the median values after the tests (excel sheet). The results obtained with the use of both methods can be used to model the attenuation of the tested propagation environment and signal arrival delay on selected sections of railway line No. 4.

On the basis of the algorithm presented above and relation (1), all files with the results of field tests were integrated into one and data concerning the suspension height of transmitting and receiving antennas, frequency of the tested signal and observation data concerning propagation conditions prevailing on the Central Rail Line during particular measurement series were supplemented.

Using the knowledge of characteristic points' coordinates (geographical coordinates of the position of traffic control devices) and the commonly known relation to the value of the angle between two straights on the plane, the angle of radio waves' arrival to the receiver in relation to the axis of the main communication line was calculated for each propagation case.



	A	B	C	D	E	F	G	H	I
1	ENC	SEND	DEC	RECEIVE	SIZE (byte)	UNIX TIME		czas [s]	opóźnienie [ms]
2	1138	25002	67260	29647	64	1,44E+12		0	98,045
3	2914	29681	74368	44203	64	1,44E+12		0,33	121,485
4	485	37584	111368	99312	64	1,44E+12		0,697	211,165
5	732	33403	46163	68904	64	1,44E+12		0,995	115,799
6	809	37866	53362	28531	64	1,44E+12		1,309	82,702
7	1771	23215	46616	20125	64	1,44E+12		1,612	68,512
8	1231	43067	49577	30613	64	1,44E+12		1,925	81,421
9	1058	47341	53303	38666	64	1,44E+12		2,239	93,027
10	1069	19464	52687	41350	64	1,44E+12		2,553	95,106
11	1067	31838	49444	34389	64	1,44E+12		2,865	84,9
12	1427	47431	59516	47577	64	1,44E+12		3,175	108,52
13	1073	47664	54045	27648	64	1,44E+12		3,485	82,766
14	1055	28119	45427	40099	64	1,44E+12		3,904	86,581

Fig. 3. Recording of telegram data communication parameters

In the next part it has been assumed that the same transmitting and receiving modems are used, the transmitting antennas are in a radio channel with the same parameters, so it can be assumed that the resulting antenna disappearances are correlated. For transmitting and receiving devices *m* correlated distribution of Rice'a in antenna *n* can be expressed as a relation:

$$h_{nm}(t) = \sqrt{\frac{K_m}{1+K_m}} e^{j\theta_{nm}} + \sqrt{\frac{K_m}{1+K_m}} b_{nm}(t) \qquad (2)$$

where K_m parameter *K* Rice'a the physical channel from the base station to srk *m* devices, and the angle θ_{nm} assumed in formula (2) is determined as follows (Baek et al., 2014; Chou et al., 2016):

$$\theta_{nm} = \frac{2\pi d f_c \cos\Theta_m}{c} \qquad (3)$$

where the distance d between two antenna elements is no more than the wavelength, Θ_m means the angle between the direct signal path and the position on the railway line of the srk equipment.

In equation (2), the component $\sqrt{\frac{K_m}{1+K_m}} b_{nm}(t)$ is modelled by $b_{nm}(t)$, which is an independent composite random variable of Gauss with zero expected value and variance of 1: $b_{nm} \sim CN(0,1)$.

In the case of a railway communication, it should be assumed that the DOA (degree of arrival) depends on the position of the srk equipment relative to the eNodeB base station and can be designated as (Nguyen et al., 2016):

$$\Theta_m = \begin{cases} arctg\left(\frac{\sqrt{R^2-d_{min}^2}-d_m}{d_{min}}\right), \\ \quad if\colon 0 \le d_m \le \sqrt{R^2-d_{min}^2} \\ \pi - arctg\left(\frac{d_m-\sqrt{R^2-d_{min}^2}}{d_{min}}\right), \\ \quad if\colon \sqrt{R^2-d_{min}^2} < d_m \le 2\sqrt{R^2-d_{min}^2} \end{cases} \qquad (4)$$

where d_m is the distance to the transmitting and receiving equipment.

When exchanging information in the LTE system between the base station and the srk devices in the field in time slot *t* the same block of data symbols $x(t)$ is multiplied by the composite number $\sqrt{\alpha_n(t) exp(j\phi_n(t))}$ in the *n*-antenna and broadcast, as appropriate, from all the antennas, for $n = 1,\dots,$ N tak, że $\sum_{n=1}^{N} \alpha_n(t) = 1$ while maintaining total transmitting power. The received signal model from all N_t transmitting antennas to the transmitter-receiver m is described by the relation:

$$y_m(t) = \\ = \left(\sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j\phi_n(t)\big) h_{nm}(t)\right) x(t) \\ + \eta_m(t) \quad (5)$$

where $\eta_m(t)$ is Gauss's additive white noise in $\eta_m(t) \sim CN(0, \sigma^2 I_T)$.
Therefore, the overall channel gain for transmitter-receiver m is:

$$\tilde{h}_m(t) = \sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j\phi_n(t)\big) h_{nm}(t) \quad (6)$$

For a correlated distribution of the Rice'a channel, dependency (6) can be transformed further as:

$$\tilde{h}_m(t) = \sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j\phi_n(t)\big) h_{nm}(t) = \\ = \sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j\phi_n(t)\big) \cdot \\ \cdot \left(\sqrt{\frac{K_m}{1+K_m}} exp(j\theta_{nm}) + \sqrt{\frac{1}{1+K_m}} b_{nm}(t)\right) = \\ = \sqrt{\frac{K_k}{1+K_k}} \sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j(\phi_n(t) + \theta_{nm})\big) + \\ + \sqrt{\frac{1}{1+K_k}} \sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j\phi_n(t)\big) b_{nm}(t) \quad (7)$$

For $B_m(t) = \sqrt{\frac{1}{1+K_m}} \sum_{n=1}^{N} \sqrt{\alpha_n(t)}\, exp\big(j\phi_n(t)\big) b_{nm}(t)$ then it can be shown that $B_m(t)$ is the Gauss combined random variable from $B_k(t) \sim CN(0, \sigma_m^2)$, where $\sigma_m^2 = \frac{1}{1+K_m}$. Let $H_m(t)$ is the amplitude $\tilde{h}_m(t)$:

$$H_m(t) = \left|\tilde{h}_m(t)\right| = \\ = \left|\sqrt{\frac{K_m}{1+K_m}} \sum_{n=1}^{N_t} \sqrt{\alpha_n(t)} exp\big(j(\phi_n(t) + \theta_{nm})\big) + \\ + B_m(t)\right| \quad (8)$$

In accordance with (Baek et al., 2014; Chou et al., 2016) $\sqrt{\alpha_n(t)} = \frac{1}{\sqrt{N}}$ and in combination with relation (3) to maximize the size of the entire channel, a phase can be defined as:

$$\phi_n(t) = -\frac{2\pi n d f_c \cos\psi_m}{c} \quad (9)$$

where $\psi_m \sim U(0, 2\pi)$.
For Rice's determined K-factor to maximize the total gain of the user channel m, equation (7) should meet the condition $\phi_n(t) = -\theta_{nm}$. For this requirement an optimal signal beam formation is realized, which in the literature is also called a coherent beam formation (Brazeetta et al., 2016; Baek et al., 2014; Chou et al., 2016).
No mechanisms were used at the measuring terminals to ensure that domestic roaming networks can measure services.
The average results of the measurements on the route under consideration are shown in the tables 1 and 2.

Table 1. Indicators for data transmission - downlink

		Orange	Play	Plus	T-Mobile
Mean Data Rate- upload	MDR [Mb/s]	3,43	2,78	5,02	3,21
HTTP IP-Service Setup Time	HIST [ms]	1932,00	3428,00	1191,00	3792,00
HTTP Session Failure Ratio	HSFR [%]	66,31	71,28	47,28	61,72

Table 2. Indicators for data transmission - uplink

		Orange	Play	Plus	T-Mobile
Mean Data Rate- upload	MDR [Mb/s]	0,92	1,18	1,51	0,9
HTTP IP-Service Setup Time	HIST [ms]	1741,00	1328,00	1538,00	2632,00
HTTP Session Failure Ratio	HSFR [%]	38,36	42,23	28,95	42,34

Table 3. Loss and delay rates of the packages

		Orange	Play	Plus	T-Mobile
Round Trip Time	RTT [ms]	149,11	128,24	119,12	169,43
IP packet loss ratio	IPLR [%]	15,84	15,18	7,6	14,12
IP packet delay variation	IPDV [ms]	119,28	110,12	113,72	99,21

The studies described in Tables 1-3 give rise to the thesis that appropriate spatial planning of LTE systems allows for the resignation from dedicated development of a rail-specific system such as GSM-R. It is possible to use an open LTE system for railway purposes, both for train control and signaling but also for passenger data transmission.
The results of radio signal level tests generated from the terminals are shown in Figure 4.

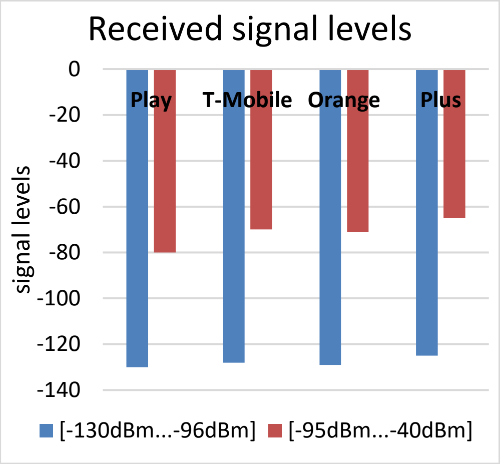


Fig. 4. Signal levels from the 4G terminals on the measurement route

On some sections of the railway line the level of signal has been decreasing, due to the fact that the communication infrastructure makes it possible to cover urban areas and roads with signal. No rolling stock was included. In the case of the propagation measurements for the LTE system in rail transport, multiway signal and vehicle interference must be included, as well as the type of material used to build the wagons. In the case of network scaling and the signal coverage of the railway lines as well, the savings are enormous (Kornaszewski et al., 2017; Chou et al., 2017). Then there is no need for dedicated communication infrastructure for the railways, because it can be replaced by an open LTE network with appropriate coding of telegrams according to PN-EN 50159:2011 standard.

4. Summary

On the basis of studies carried out on the constructed measuring stand (Fig.1) it can be stated that using the records of PN-EN 50159:2011 standard it is possible to create a system that is able to satisfy not only the needs of data transmission for railway traffic control devices but also passengers. The use of protection methods described in PN-EN 50159:2011 standard and the use of VPN channel additionally for the safety of VPN channel gives a guarantee of safety at the level required by standardization documents. Therefore, it seems necessary to start talks between the railway infrastructure manager and mobile operators in order to develop a network creation model based on existing operators. Creation of appropriate radio coverage of railway communication lines creates great opportunities to use systems open to railway needs, without compromising the existing transmission safety. It is necessary to remember the next stage of mobile networks development in the 5G direction. As an example of the implementation of 5G technology on railroads, we can give Nokia, which is working with German Rail (DB) on the world's first standalone 5G system for automatic train running in Hamburg as part of the highly automated DB S-Bahn project. It will be verified if the 5G technology is sufficiently sophisticated to be used as a transmission layer for the future traffic control system.

References

[1] 3GPP Specifications, TS 36-series, Release 99 and later., 2020. http://www.3g org/specifications/specification-numbering.

[2] BARAZZETTA, M., MICHELI, D.; DIAMANTI R., et al., 2016. *Optimization of 4G Wireless Access Network Features by Using Reverberation Chambers: Application to High-Speed Train LTE.* IEEE 46th European Microwave Conference. Book Series: European Microwave Conference, London, 719-722.

[3] BAEK, JONG HYEN, CHOI, HYEON YEONG, KIM, GON YOP; et al., 2014. *A LTE Wireless Communication Interface Test for On-board Oriented Train Control System Field Test.* IEEE 5th International Conference on Information and Communication Technology Convergence, Busan, South Korea, 690-694.

[4] BOHAGEN, F., ORTEN P., OIEN G., 2005. *Construction and Capacity Analysis of High-*

Rank Line-of-Sight MIMO Channels. Wireless Communications and Networking Conference, 2005 IEEE, 1, 432–437.

[5] BRODZIK, R., 2019. *The use and effectiveness of highway landing strip construction in Poland*. Scientific Journal of Silesian University of Technology. Series Transport, 105, 65-75.

[6] BURDZIK, R., NOWAK, B., ROZMUS, J., SŁOWIŃSKI, P., PANKIEWICZ, J., 2017. *Safety in the railway industry*. Archives of Transport, 44(4), 15-24.

[7] CISZEWSKI, T., NOWAKOWSKI, W., CHRZAN, M., 2017. *RailTopoModel and RailML – data exchange standards in railway sector*. Archives of Transport System Telematics,10(4).10-15.

[8] CHOU, SHENG-JU; CHOU, HSI-TSENG; KUO, LI-RUEI., 2016. *Potential Causes of PIM Problems in the LTE Outdoor Base Station Multi-Band Antennas.* 21st International Symposium on Antennas and Propagation, Okinawa, Japan, 1080-1081.

[9] CHEN, M.; SAAD, W.; YIN, C., 2017. *Echo State Networks for Self-Organizing Resource Allocation in LTE-U with Uplink-Downlink Decoupling*. IEEE Trans. Wirel. Commun. 2017, 16, 3–16.

[10] CHRZAN M., 2018. *Bezpieczeństwo kolejowych systemów telekomunikacyjnych*. Kazimierz Pułaski Technical University of Radom. 1st Edition. Radom.

[11] CHRZAN, M., 2020. *The Assessment of the Possibility of Using Open Systems of Radio Transmission for the Purposes of Railway Transport.* ICTE in Transportation and Logistics 2019, Springer Nature Switzerland 2020, 271-278.

[12] GAO, T., SUN, B., 2010. *A high-speed railway mobile communication system based on LTE*. Electronics and Information Engineering (ICEIE), 2010 International Conference, 1, 414-417.

[13] GONZÁLEZ-COMA, J.P.; SUÁREZ-CASAL, P.; CASTRO, P.M.; CASTEDO, L., 2020. *FDD Channel Estimation Via Covariance Estimation in Wideband Massive MIMO Systems*. Sensors 2020, 20, 930.

[14] HU, R.; TONG, J.; Xi, J.; GUO, Q.; YU, Y., 2019. *Channel Covariance Matrix Estimation via Dimension Reduction for Hybrid MIMO MmWave Communication Systems*. Sensors 2019, 19, 3368.

[15] IDIRIN, M., AIZPURUA, X., VILLARO, A., LEGARDA, J. AND JUAN MELENDEZ, MEMBER, IEEE., 2011. *Implementation Details and Safety Analysis of a Microcontroller-based SIL-4 Software Voter*. IEEE Transactions on Industrial Electronics, 58(3), 822 -829.

[16] JACYNA, M., SZCZEPAŃSKI, E., IZDEBSKI, M., JASIŃSKI, S., MACIEJEWSKI, M., 2018. *Characteristics of event recorders in automatic train control systems*. Archives of Transport, 46(2), 61-70.

[17] JOSHI, P.; COLOMBI, D.; THORS, B.; LARSSON, L.E.; TÖRNEVIK, C., 2017. *Output Power Levels of 4G User Equipment and Implications on Realistic RF EMF Exposure Assessments*. IEEE Access 2017, 5, 4545–4550.

[18] KAMEL, TOURKI.; FAHD AHMED, KHAN.; KHALID, A. QARAQE.; HONG-CHUAN, YANG.; MOHAMED-SLIM, ALOUINI., 2014. *Exact Performance Analysis of MIMO Cognitive Radio Systems Using Transmit Antenna Selection*. IEEE Journal on Selected Areas in Communications 32(3). 425-438.

[19] KORNASZEWSKI, M., CHRZAN, M., OLCZYKOWSKI, Z., 2017. *Implementation of New Solutions of Intelligent Transport Systems in Railway Transport in Poland*. In. J. Mikulski (Eds.), Smart Solutions in Today's Transport. TST 2017. Communications in Computer and Information Science, Cham Springer, 715, 282–290.

[20] KUKULSKI, J., GOŁĘBIOWSKI, P., PYZA, D., JACHIMOWSKI, R., WYCHOWAŃSKI, W., 2019. *Selected aspects of the selection of*

data sent to the vehicle in automatic rail vehicle driving systems. Scientific Journal of Silesian University of Technology. Series Transport, 103, 43-52.

[21] KYCKO, M., ZABŁOCKI, W., 2018. *Certification in control command and signalling system investment processes*. Scientific Journal of Silesian University of Technology, Series Transport 2018, 101, 119-130.

[22] MIKULSKI, J., GORZELAK, K. 2017. *Conception of modernization of a line section example in the context of a fast railway connection*. Archives of Transport, 44(4), 47-54.

[23] NGUYEN, K., BEUGIN J., BERBINEAU M., et al., 2016. *Analytical approach for evaluating LTE communication errors in train control application*. IEEE International Conference on Communication Workshop, UK, London, 2369-2374.

[24] PARICHEHREH, A., SAVAZZI, S., GORATTI, L., SPAGNOLINI, U., 2016. *Seamless LTE connectivity in high-speed trains.* Wireless Communications & Mobile Computing, 16(12), 1478-1494.

[25] SIERGIEJCZYK, M., ROSIŃSKI A., 2019. *Analysis of information transmission security in the digital railway radio communication system.* Contemporary Complex Systems and Their Dependability. Proceedings of the Thirteenth International Conference on Dependability and Complex Systems DepCoS-RELCOMEX / Zamojski Wojciech [et al.] (Eds.), Advances in Intelligent Systems and Computing, 761, 420-429.

[26] TORUŃ, A., SOKOŁOWSKA, L., JACYNA, M. 2019. *Communications-based train control system - Concept based on WiFi LAN network.* Transport Means - Proceedings of the 23-rd International Conference. Kaunas University of Technology. 911-915.

[27] ZBOIŃSKI, K., WOŹNICA, P. 2010 Optimisation of the railway transition curves' shape with use of vehicle-track dynamical model. Archives of Transport, 22(3), 387-407.