Method of Evaluation of the TETRA Standard Data Transmission Channel for Ensuring Information Security of the Railway Transport System

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***Abstract* – This paper analyzes the current situation of interval train control systems (railway interlocking) on the railway network of Kazakhstan, geared towards enhancing the effectiveness of railway transportation, the objective is to augment the capacity of rail lines, diminish operational expenses, minimize energy consumption, and mitigate wear on both tracks and rolling stock. To evaluate the data transmission channel of the TETRA standard, a test model with a long ping and a load test has been developed, and a two–stage test methodology has been proposed for the Zhetygen – Altynkol section. According to the results of the conducted experiments, it is proved that if the connection is lost for more than 60 seconds, the train automatically stops with an emergency braking command and, subject to the restoration of data transmission between the OBU (onboard unit) and the modem, the radio-blocking system works normally for cases with loss of communication and the board permits to move.**

For evaluating the influence of deploying radio communication on radio-blocking and signal strength, the Hata model within the COST231 framework was chosen. This model incorporates diverse factors contingent upon the environment, such as urban or suburban settings. The model of path loss «Loss of suburban macro-path» was chosen as a model.

***Keywords* – Digital channel, train performance control system, duration of batch transit, wireless communication network.**

1. Introduction

Being the world's largest state with no access to the open seas and an important land link of the Great Silk Road, Kazakhstan depends entirely on the development of the transport and logistics complex, which provides infrastructure links between the regions of the republic and forms the basis of transit and transport potential.

At the beginning of 2022, Kazakhstan's transport infrastructure includes 16,580 km of railways, 95,443 km of highways, 2,169 km of domestic water routes and 115 kilometers of trolleybus tracks and 76 km of tram tracks. The density of transport infrastructure per 1000 km^2 of the territory is 6.1 km of railways, 0.8 km of inland waterways and 35 km of highways, respectively [1].

Railway transport plays an important role in the economy of Kazakhstan, providing half of the total cargo turnover and transportation of most of the export and transit cargo [2].

In recent years, there has been significant positive growth trend in the share of rail transport in the overall cargo turnover.

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One of the contributing factors to this growth has been the COVID-19 pandemic, which had less of an impact on rail transportation compared to other modes of transport affected by pandemic-related restrictions. During this period, some of the cargo that was previously transported by road was shifted to rail transport.

The main export directions of Kazakhstan products are European countries, the People's Republic of China, and Central Asia. The Trans-Caspian International Trade Route is actively developing, due to the presence of port infrastructure and marine linear services.

According to the total length of 16 thousand km of railway tracks, Kazakhstan ranks 19th in the world, 31% of the mainline railway network (MRN). MRN has two or more tracks. At the same time, the load of many railway lines is close to the limits of efficient use of capacity. The proportion of sections with bottlenecks exceeds 14% of the operational length, only a quarter of the total length of the MRN is electrified. This problem is especially acute in the following sections: Moynty – Dostyk, Tobol – Kandyagash, Zharyk – Zhezkazgan, Shubarkol – Yesil, Beineu – Shetpe, where the current capacity of the MRN is insufficient to fully meet the demand for transporting goods by Kazakh shippers. With the growth of transit container traffic, an increase in the number of sections with a limiting capacity will follow [1].

Currently, there is a steady growth traffic volume on the mainline network. According to forecasts, by 2030, the need for transportation of products will increase further. Meanwhile, the capacity reserve of many sections is actually exhausted. Therefore, once again, but already in new economic, technological and organizational conditions, the task arises of determining rational, in an economic sense, methods of increasing the railway line capacity.

One of the main expectations of consumers of railway transport services is a transparent, balanced long-term and competitive tariff model that links the interests of the national infrastructure operator, carriers, cargo owners, passengers and other participants in the transportation process [1].

In addition, in order to overcome the “inertia” and technological lag of the railway industry of Kazakhstan from European countries, its further innovative evolution should be based on the principles of advanced development of the scientific, technical and technological environment.

The developed automated information infrastructure makes it possible to support the unity of systemic actions in priority areas of industry development, as well as to form and consolidate industry resources in order to effectively involve them in management, economic, and production turnover. Automated systems, information resources, information, and communication technologies are becoming instruments of modern railway policy, having the same systemic importance as financial, legal, administrative, and other instruments of the railway industry enterprise [1].

The factors affecting the safety and reliability of transport and logistics infrastructure and transportation are:

1. Critical deterioration of existing systems and equipment of railway automation, which increases the risks of threats to the life and health of passengers, the safety of transported goods, infrastructure facilities and rolling stock of railway transport, and ecological safety of the environment.

2. Improving the safety and reliability of transportation:

- the level of safety of the transportation process plays a crucial role in ensuring the sustainable operation of the transportation and logistics system, ensuring that there is no unacceptable risk to the life and health of passengers, crew, maintenance personnel, vehicles, or transported goods;
- reliability characterizes the overall efficiency of transportation and includes such components as stability, continuity, and reliability of transport services, regardless of possible changes in external conditions and factors.

The rest of this paper is organized as follows. Section 2 conducts an analysis of the current situation of interval traffic control systems on the railway network in Kazakhstan. Section 3 presents a practical solution for the communication interface linking the radio block center and the TETRA switching center is outlined. This includes the amalgamation of the radio block center with electrical centralized systems, the modernization of equipment installed on the locomotive, and the validation of algorithms for both equipment on board and stationary locations. The results of the developed model for long-ping and stress testing are presented, including measurements of channel throughput, packet transmission times, and packet loss data in the TETRA radio network obtained through experimental methods. This section also includes the results of assessing the impact of radio communication deployment on radio blockage. Finally, Section 4 summarizes the main findings of the study.

2. Materials and Methods

Currently, significant amounts of responsible confidential information are trans-mitted on the railway network of JSC National Company “Kazakhstan Temir Zholy” (JSC NC “KTZ”) using various data transmission systems.

Logistics information about the timetable and location of trains is of high commercial value. Railway automation and telemechanics systems (RATS) constitute the foundation for ensuring the safety of railway traffic. [2].

RATS encompasses a range of technical resources that facilitate the monitoring and control of both stationary tracks and mobile elements within railway transportation, ensuring a predefined level of traffic safety. In such systems, there is a notable escalation in the significance and specifications of information transmission channels. The developmental trajectory of systems for transmitting information, drawing insights from both international and local experiences, suggests the emergence of novel systems, such as digital radio channels, are necessary, in addition to traditional means like rail circuits. At the same time, the critical factors in wireless systems are the aspects of information security and noise immunity. Ensuring information security stands out as one of the paramount elements in maintaining the safety of train traffic [3].

Interval train control systems are designed to monitor and control the movement of trains on the stages and tracks, includes automatic interlocking systems (a system of automatic regulation of intervals between railway trains passing along the railway stages), semi–automatic interlocking (a system of train traffic control used on inactive sections of railways. At the semi–automatic interlocking, the entire stage between neighboring stations and/or roadblocks is indivisible, with permission to occupy the stage by only one train), radio-blocking (RB - digital train traffic control system via radio channel provides direct interaction between locomotives and dispatching systems).

It is known that the railway networks in Kazakhstan predominantly utilize analog radio communication systems with limited data transmission capabilities. Analog radio communication systems do not meet the growing needs of railways for high-quality control channels. Therefore, a strategic direction for the reform of railway radio communication is the transition to digital standards in technological radio communication.

Since the beginning of the last decade, there have been attempts to introduce digital radio communication standards such as TETRA (Terrestrial Trunked Radio), GSM-R (Group System Mobile Railway), and other promising technologies, as described in previous works [4], [5], [6], [7], [8], [9]. One of the equally important aspects is the use of advanced technologies and methods to improve the current state of automation and telemechanics, as described in [10].

The interval train control system on the railway network of Kazakhstan is equipped with interlocking systems [13], [14], [15] (Figure 1):

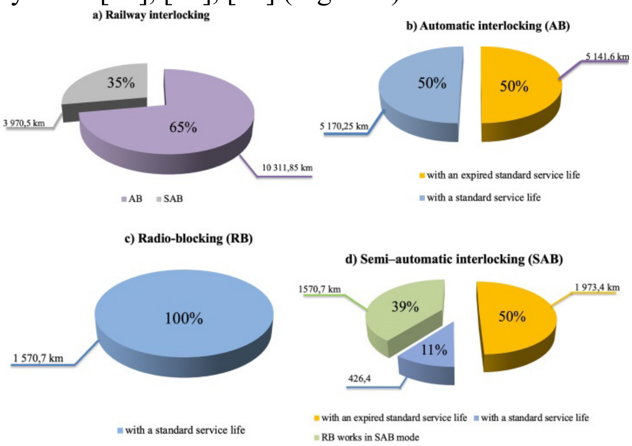

Figure 1. Analysis of current situations of interval train control systems on the railway network of Kazakhstan: a) Railway interlocking system; b) Automatic Interlocking (AB) system; c) Radio-blocking (RB) system; d) Semi-automatic interlocking (SAB) system

- 5141.6 km (50%) of lines equipped with automatic interlocking systems have a service life of more than 35 years;
- 5170.25 km (50%) of lines equipped with automatic interlocking systems have a service life of less than 35 years.
- 1570.7 km (100%) of lines equipped with radio-blocking systems.

The standard service life is 25 years, the actual 0. The system has not been put into operation for technical reasons:

- 426.4 km (11%) of lines equipped with semi–automatic interlocking systems have a service life of less than 35 years;
- 1973.4 km (50%) of lines equipped with semi–automatic interlocking systems have a service life of more than 35 years;
- 1570.7 km (39%) of lines with RB, not put into operation, operate in semi-automatic mode.

The Radio Based Train Control System (RBTC) is geared towards enhancing the efficiency of railway transport by increasing the capacity of lines, reducing operating costs and energy usage, along with wear and tear on tracks and rolling stock. The system allows [16]:

- Increase the capacity of existing lines without changing the infrastructure;
- Minimize the wayside infrastructure;
- Minimize operating costs;
- Optimize capital investments and get a quick payback;
- Apply fixed or movable block sections;
- Using Global Navigation Satellite Systems to determine the location of rolling stocks;

- The use of various communication networks (fiber optic, satellite, wired channel) for the exchange of information between stationary objects;
- Using a radio channel to exchange information with moving objects.

The on-board system (train board) sends data about the location of the train to the radio-blocking center. Track occupancy is determined by means of track circuits or axle counters [17], [18].

However, the disadvantage of radio-blocking systems is the lack of control over the integrity of the rail line. Therefore, the integrity of the rail line should be monitored using appropriate inductive devices installed on specialized mobile units.

During the construction of new lines in Kazakhstan, RBTC (Bombardier Transportation) utilizing continuous transmission of data over TETRA radio channels (Level 3 ETCS) has recently been used [19]. This system is built on new lines that have recently been put into operation. The adopted data transmission system from different manufacturers often fails and does not function reliably enough.

In the comprehensive modernization of physically and ethically obsolete RAT systems on current railway segments, it is advisable to employ second or third-level radio blocking devices incorporated into microprocessor control systems at neighboring stations [20].

Thus, radio-blocking systems are the most modern train traffic control systems on track blocking sections, but they require a careful approach in choosing a technical solution, both for the control system and for data transmission with the choice of a transport network.

2.1. Test Methods

To study the challenges related to interaction linking the radio blocking center and the TETRA switch center with electrical centralization systems at stations, upgrading the onboard equipment of the locomotive and validating the algorithms of operation of on-board and stationary equipment [21], tests were carried out on the radio based train control system, which is operated on the segment between Zhetygen and Altynkol on the mainline network's Almaty division (Figure 2).

Figure 2. Map of the Zhetygen–Altynkol section

Stationary tests were carried out at the first stage of the tests. To test the data transmission channel of the TETRA standard, a test model with a long ping and a load test has been developed, as shown in Fig. 3. As seen in Figure 4, the test model includes:

- Checking the characteristics of packet data transmission channels of the TETRA standard digital radio network;
- Point “A” (the personal computer is a OBU simulator connected via a radio modem in the locomotive), location Altynkol station;
- Point “B” (central server of the RBC post of electrical centralization at the stations), location Zhetygen station.

The TI_Server 1 hardware and the laptop at point “B” are used as terminal devices. The test is carried out 24 hours.

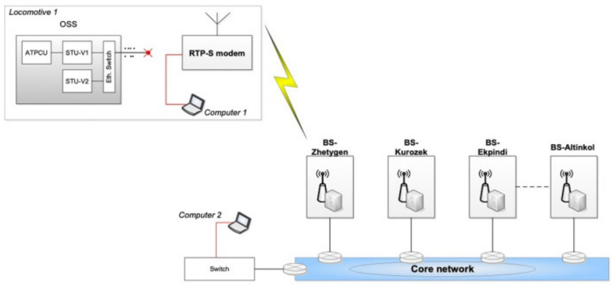

Figure 3. Scheme of experiments conduct – stage 1

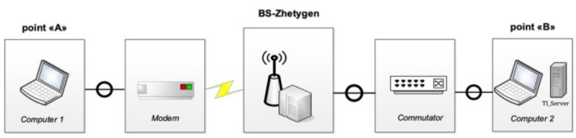

Figure 4. Test model with long ping and load test.

In this regard, the «ping» command is executed according to the scheme:

- From a laptop at point “A” ping > IP address TI-Server1 < -s 32Byte -n 86400sec;
- Point A – Personal computer (PC);
- IP address of TI-Server1- CPU;
- -s 32 bytes - standard packet size;
- -n 24 hours is the time to check the stability of the network and traffic, while the total number of sent and received IP packets must be at least 86400.

The test is performed without the use of an on-board security system with the connection of a TETRA radio modem. At the same time, before the tests, the expected results had the values given in Table 1.

Table 1. Page layout description

Parameter	Expected value
Packet loss	No more than 1%
The packet transit time	No more than 1 second in 99% of cases
The time interval between errors	7s in 99% of cases; 20s in 95% of cases

Based on the results of the 1st stage of testing, a decision is made to proceed to the 2nd stage of testing.

At the second stage, dynamic tests were carried out, which include checking the dependencies associated with the management of the railway dispatcher and mobile units with locomotives equipped with OBU and radio modems in the interaction of the RBC.

Dynamic tests were carried out while locomotives were moving simultaneously (Figure 5) [14].

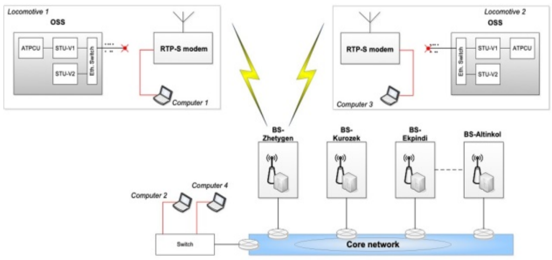

Figure 5. Conducting the second stage of the experimental scheme

Dynamic tests of the radio-blocking system were carried out according to the methodology of operational tests [22].

2.2. Experiments and Results

During the experiments, the transmission and reception of packets is provided. Modifying the packet count leads to alterations in the radio channel's load [23].

The measurement results, including data on the capacity of the channel and packet transit time; Figure 6 to Figure 10 illustrate data on packet loss in the TETRA radio network.

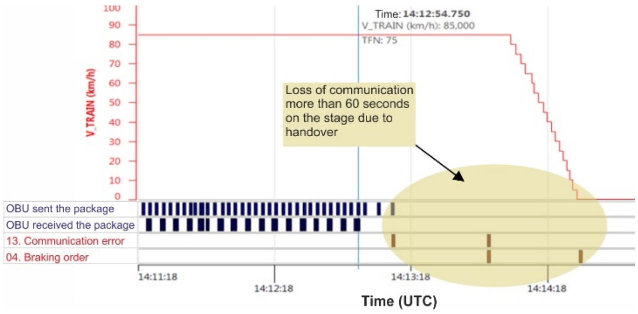

Figure 6. Graph of changes in data transmission over the radio channel with loss of communication due to handover

Figure 6 shows that there was a loss of communication lasting more than 60 seconds on the stage, as a result of which the train was stopped by the emergency braking command. The radio blocking system worked normally for cases with loss of communication. Communication failure at 30 km occurred due to the "handover". At the same time, after transmitting data twice, packet transmission is suspended for 56 seconds. After this time, the connection is restored, but the locomotive applied service braking. Therefore, the modem does not receive data for 36 seconds.

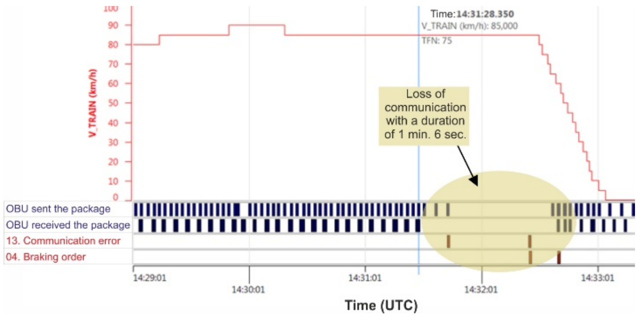

Figure 7. Graph of changes in data transmission over the radio channel in case of loss of communication with a duration of 1 min. 6 sec

Figure 7 shows that there was also a loss of communication lasting more than 60 seconds on the stage, as a result of which the train was stopped by the emergency braking command. The radio blocking system worked normally for cases with loss of communication. Communication failure occurred at 48 km then it stops transmitting data for 1 min. and 6 sec. After this time, the connection is restored, but the locomotive applied service braking. Therefore, the modem does not receive data for 26 seconds.

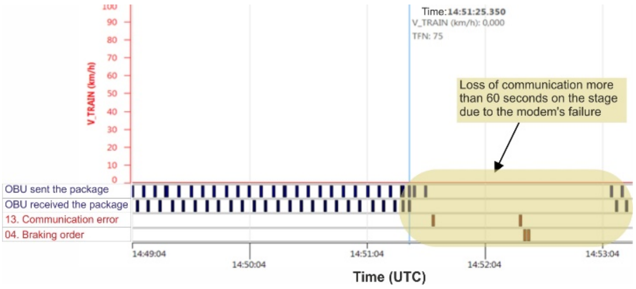

Figure 8. Graph of communication loss during packet transmission due to the modem's failure to receive incoming signals at the station

Figure 8 shows that there was a loss of communication at the station lasting more than 1 minute when the train was staying. The packets were transmitted at a frequency of 413.3 MHz. Further, data transmission is suspended for 57 seconds. After this time, the connection is restored, but the locomotive applied service braking. After 30 seconds data transmission between the OBU and the modem has been restored and the board gives permission to move. The modem does not receive data for 94 sec.

Figure 9 shows that there was a loss of communication lasting more than 60 seconds on the stage, as a result of which the train was stopped by the emergency braking command. The radio blocking system worked normally for cases with loss of communication (communication failure at 65 km).

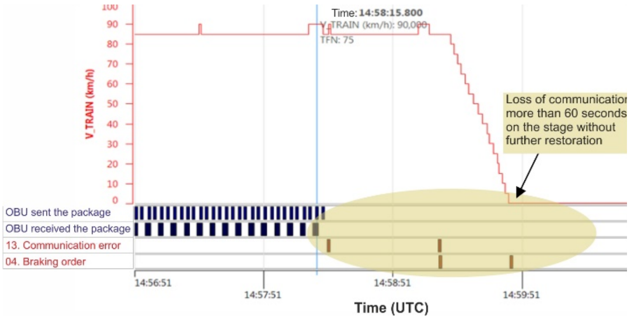

Figure 9. Schedule of changes in data transmission over the radio channel without further restoration of communication

The packets were transmitted at a frequency of 413.3 MHz. Further data transfer is suspended without further recovery.

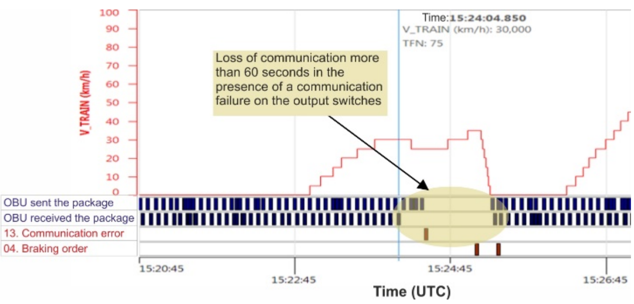

Figure 10. Graph illustrating fluctuations in data transmission across the radio channel during a communication breakdown on the output switches

Figure 10 shows that there was a loss of communication at the station lasting more than 60 seconds, as a result of which the train was stopped by the emergency braking command. Then the connection was restored and the train continued moving. The radio blocking system worked normally for cases with loss of communication.

There was a communication failure on the output switches. The packets were transmitted at a frequency of 416.975 MHz. Further, data transmission is suspended for 18 seconds. After this time, the connection is restored, but the locomotive applied service braking. Data transmission between the OBU and the modem has been restored and the board gives permission to move. The modem does not receive data for 41 seconds.

The experiments show that when the connection is lost for more than 60 seconds, the train automatically stops with the command for emergency braking. The radio blocking system works normally for cases with loss of communication. Under the condition of data transmission between the OBU and the modem, the board gives permission to move [24].

However, there remains a significant issue related to the loss of communication between the OBU and the modem, requiring a solution, namely that the modem did not receive data after the connection was restored, which led to the repeated use of the service braking of the train. To solve this issue, it is necessary to develop a base station coverage model for trunking communications.

The choice of an automatic interlocking or radio-blocking system is made on the basis of the terms of reference when performing design work on the modernization of a particular section.

The considered railway section is included in the transport corridor for transit traffic. Base stations (BS) with antennas in an open space are located along the track. The BS are situated alongside the railway with a separation from each other by a distance of 2*R, where 2*R signifies the operational range of a single base station. The speed of train is steadily along the railway track [25].

The proposed BS coverage model for trunking communication is shown in Figure 11.

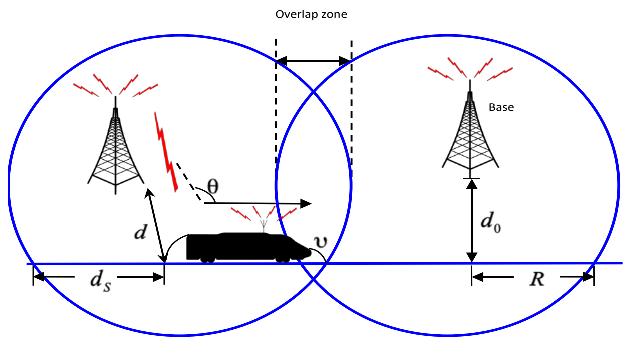

Figure 11. Base station coverage model for railway trunking communication

When the train occupies the ds position within the current cell for $0 \leq d_s \leq 2R$, the separation between the BS and the train is defined as follows

$$d = \sqrt{d_0^2 + (d_s - R)^2}, \quad (1)$$

where d_0 represents the distance from the BS to the railroad track.

The losses experienced during the propagation of signals between a BS antenna and a railway antenna through a line-of-sight path in free space are determined by the radiated frequency (f) and the speed of light (c). This relationship is mathematically expressed as:

$$L = 20\log_{10}\left(\frac{4\pi df}{c}\right), \quad (2)$$

where f represents the emitted frequency, and c denotes the speed of light.

Derived from equation (2), it is evident that the losses on the track L are dependent on both the frequency f and the distance d.

In the subsequent experiment, the BS is positioned at point 0, with a cell radius R of *1500 meters*, and the train's speed v is *100 kilometers per hour* [26].

Figure 12(a) illustrates how distance and frequency impact losses on the trackside. As depicted in the figure, the losses on the track exhibit rapid fluctuations based on the train's position. As the train advances toward the cell boundary, there is an increase in losses on the track, leading to a decline in the overall condition of the channel. Conversely, as the train approaches the center of the cell, losses on the track diminish, resulting in an improvement in the overall condition of the channel. Therefore, the cyclic alteration in the channel's condition implies that power management over time significantly influences transmission performance.

Hence, elevated mobility results in a substantial Doppler shift and propagation. In this segment, the proportion of energy in the line-of-sight path to the energy in multipath propagation is relatively high, with a relatively minor delay in multipath propagation. When the train is in motion along the railway (Figure 12), the Doppler drift f_p can be computed as

$$f_p = f_d \, cos(\theta), \quad (3)$$

where $f_d = (v/c)\, f$ represents the maximum Doppler frequency, and signifies the angle formed by the direct path of the train and the line of sight extending from the BS to the train.

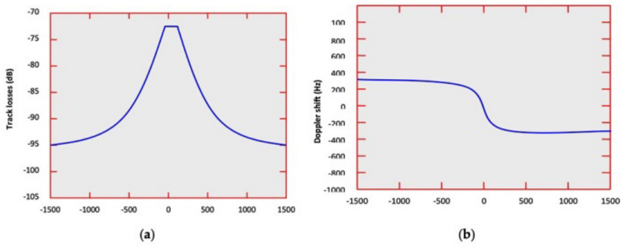

Figure 12. Track losses and Doppler drift depending on location at 450 MHz

Based on geometry information (Figure 12):

$$\cos\theta = \frac{R - d_s}{d}, \quad 0 \leq d_s \leq 2R$$

Therefore, while the BS is positioned at a considerable distance from the railway, specifically, $d_0 >> R$, f_p is quite low, as the angle θ will be roughly 90◦. Nevertheless, this will result in substantial losses on the track as per the equation (2). Hence, there exists a trade-off between track losses and f_p during the optimization of BS assignments [27].

Doppler drift along the railway at the carrier frequency of 450 MHz in Figure 12 (b) shows the:

- f_p fluctuates over time, ranging from its maximum positive value to the maximum negative value as the train traverses the cell;
- a Doppler drift occurs during the motion;
- even though f_p is minimal, as the train passes by the BS, it will experience a rapid Doppler transition;
- f_p will transition from its maximum negative value to the maximum positive value as the train enters the overlapping region between adjacent cells, as depicted in Figure 12.

2.3. The Impact of Radio Communication Deployment on Radio Blocking

When designing a TETRA network for railways, the main parameter to be determined is the quantity of BS required to ensure the essential radio coverage. A choice might be made to implement a comparatively small number of BS with powerful transmitters. Thus, the railway line will be covered with only a limited number of expansive radio cells. On the other hand, coverage for the same railway line can be achieved through a large number of base stations, with less powerful transmitters. Therefore, the coverage will be carried out by a set using radio cells of a relatively small size.

The chosen base station deployment strategy affects capacity, the relative load of traffic per cell, interference and transmission frequency, i.e. the method of coverage may affect the performance of data transmission in the radio blocking.

The communication network for the railway should ensure adequate coverage in terms of received signal power across the entire expanse of the railway on which trains equipped with a radio blocking system operate.

The sensitivity of the TETRA receiver is contingent on various factors, including the capacity, modulation and noise coefficient of the receiver. For example, assuming a capacity of 5 MHz, signal strength of 92 dBm is adequate for receiving a signal employing 16QAM modulation and 1/2 channel encoding. For a more robust modulation scheme, like QPSK, a signal with a received power of 100 dBm can be utilized – due to the achievable capacity [11]. Therefore, in the TETRA network, even if the target value of 92 dBm is not reached, the connection should still be available.

Another task that needs to be paid attention to is the study of the range of TETRA cells varying with the transmission power of the RBC. For the purposes of planning for radio coverage, a relationship must be found between the transmission power and coverage range of the cell.

P_t represents the output power of the BS transmitter. While the radio signal traverses through space, it diminishes because of diverse physical phenomena, including free-space loss, reflection, and others. This phenomenon is referred to as signal path loss. Because of path loss, the power of the received signal decreases as the receiver moves farther away from the transmitter. Hence, the radio component operates within a restricted range where the essential signal level is sustained.

To plan coverage, it is necessary to find the power of the received BS signal (P_r) depending on the transmission power (P_t) and the range from the BS (d). This will enable us to estimate the cell range by determining the distance (dr) at which the received signal (P_r) reaches $P_{min} = -92\ dBm$.

In addition to path loss, it is necessary to take into account other important factors affecting signal reception, including factors like antenna gain, losses in the cable, and margin for interference [12]. Hence, on the *dBm* scale, the received power (P_r) is the total of various contributions represented by the subsequent formula:

$$P_r = P_t + G_{\text{enb}} - L_{\text{enb}} + G_{\text{ue}} - L_{\text{ue}} - L \qquad (4)$$

here P_t represents the transmission power of the BS; G_{enb} represents the amplification of the BS transmitter antenna; L_{enb} signifies the loss in the feeder cable connected to the transmitter; G_{ue} represents the gain of the receiver antenna; L_{ue} is the aggregate in cumulative losses at the receiver, such as losses attributed to penetration; M denotes the environment for interference and attenuation; and L signifies the loss of the signal path.

The attenuation along the signal path can be approximated utilizing diverse models of signal propagation. To assess the signal strength, the Hata model within the COST231 framework was selected, incorporating different factors based on the urban and suburban environments. The model of path loss "Loss of suburban macro-path" was chosen as a model. Within this model, the attenuation along the signal path (L) is represented by the subsequent formula:

$$\begin{aligned} L = &\left[44.9 - 6.55\log_{10}(h_{\text{enb}})\right]\log_{10}\left(\frac{d}{1000}\right) + \\ &45.5 + (35.46 - 1.1h_{\text{ue}})\log_{10}(f_c) - \\ &13.82\log_{10}(h_{\text{ue}}) + 0.7h_{\text{ue}} + C \end{aligned}, \qquad (5)$$

where d is the distance (m) between BS and UE (user equipment), h_{enb} is the BS antenna height (m), h_{ue} represents the antenna height of the user equipment (UE) in meters, f_c is the carrier frequency in megahertz, and C is a constant coefficient set at 3 dB in an urban setting and 0 dB in a suburban environment.

The cell range is determined by the distance between them. It should be noted that P_r=$P_{\min}$. To find d_r, the loss of path L in (4) is replaced by the loss of path (5), which is expressed as follows:

$$\begin{aligned} P_{\min} &= P_t + G_{\text{enb}} - L_{\text{enb}} + G_{\text{ue}} - L_{\text{ue}} - M - L \\ &= P_t + G_{\text{enb}} - L_{\text{enb}} + G_{\text{ue}} - L_{\text{ue}} - M - \\ &\quad \left[44.9 - 6.55\log_{10}(h_{\text{enb}})\right]\log_{10}\left(\frac{d}{1000}\right) - \\ &\quad 45.5 + (35.46 - 1.1h_{\text{ue}})\log_{10}(f_c) - \\ &\quad 13.82\log_{10}(h_{\text{ue}}) + 0.7h_{\text{ue}} + C \end{aligned} \qquad (6)$$

By transforming the above equation, it is possible to determine the range of d_r cells:

$$d_r = 10^{3 + \frac{x}{44.9 - 6.55\log_{10}(h_{\text{enb}})}}, \qquad (7)$$

where the x in equation (7) can be define as:

$$\begin{aligned} x = &P_t + G_{\text{enb}} - L_{\text{enb}} + G_{\text{ue}} - L_{\text{ue}} - M - P_{\min} - \\ &45.5 - (35.46 - 1.1h_{\text{ue}})\log_{10}(f_c) + \\ &13.82\log_{10}(h_{\text{ue}}) - 0.7h_{\text{ue}} - C \end{aligned} \qquad (8)$$

This equation serves as the primary tool utilized for the strategic planning of radio broadcast deployment.

3. Discussion of the Results

By comparing the experimentally obtained results with prior research, it is noteworthy that the outcomes can be utilized in the formulation of a national system aimed at ensuring the information security of the primary railway network in the Kazakhstan. So, the function of applying the emergency braking command by train in case of loss of communication lasting more than 60 seconds must be taken as a basis. Under the condition of data transmission between the OBU and the modem, the radio blocking system works normally for cases with loss of communication and the board gives permission to move.

Also, the experimental data obtained allow us to determine the most vulnerable points in the OBU-modem communication system, which should be paid attention to when developing microprocessor systems based on a radio channel.

Based on the developed base station coverage model for railway trunking communication, it was revealed that for communication systems using wireless trunking, significant challenges associated with Doppler drift and rapid Doppler transition need to be addressed before practical implementation, since Doppler drift may result in synchronization challenges and the frequency of bit errors. In cases where the change in the Doppler drift is so small that it can be neglected, it is sufficient to have precise data regarding the velocity and position of the train to accurately assess and compensate for it.

Also, the obtained results of the influence of length and frequency on track losses show how track losses fluctuate based on the train's position. As the train approaches the cell's periphery, there is a rise in track losses, thereby the condition of the channel worsens, and vice versa. Thus, time-based power management has a big impact on transmission performance.

4. Conclusion

The analysis of current situations of interval train control systems on the railway network of Kazakhstan confirms that radio-based train control system is focused on enhancing the effectiveness of railway transport by increasing the capacity of lines, reducing operating costs and the consumption of energy, as well as the wear of tracks and rolling stock despite the lack of a radio blocking system as the absence of monitoring the integrity of the rail line.

For the practical solution of the issue of interactions within the radio-blocking center and the TETRA switching center, connecting the centralized electrical systems to the radio-blocking center, modernization of the onboard equipment of the locomotive, as well as verifying the algorithms of operation of stationary and onboard equipment, in Section 3 it is proposed to conduct a test procedure in two stages on the Zhetygen - Altynkol section.

To test the data transmission channel of the TETRA standard, a test model using a long ping and a load test has been developed.

It has also been determined that, for wireless tracking communication before practical implementation, significant issues related to Doppler shift and rapid Doppler transition require attention, as Doppler shift can complicate synchronization and lead to an increased bit error rate frequency. To address this, an assessment of the impact of radio communication deployment on radio blockage and signal level has been conducted, using the Hata model within the COST231 framework. This model encompasses diverse factors based on the surrounding urban and suburban environment. The chosen path loss model is the "Suburban Macro Path Loss" model.

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