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ASSESSMENT OF THE STATE OF DISRUPTIONS IN THE POWER SUPPLY SYSTEM OF A MOBILE COMMUNICATION BASE STATION

Abstract: This study provides an in-depth analysis of power supply interruptions at mobile communication base stations (BS) operated by the Khorezm branch of Uzbekistan's Uzmobile national mobile operator. The primary objective of this analysis is to evaluate the duration of power supply interruptions and their impact on the operational performance of base stations. In the case of the Khorezm region, data on power supply interruptions collected over one year from all districts were examined. According to statistical data, 13 base stations with the highest number of interruptions were selected for detailed analysis. The frequency, duration, and causes of these interruptions were studied to assess the reliability of the power supply system. The assessment results revealed distinct characteristics of power interruptions across different areas of the region. Special attention was given to evaluating the reliability of base stations from the perspective of power supply stability. The stability of the power supply system was used as the primary criterion in the analysis. The resilience of base stations to interruptions and the efficiency of their service were compared based on the frequency and duration of power outages. Additionally, the geographic location of the stations, the reliability of their connection to the electric grid, and other external factors were analyzed. The analysis identified significant differences in the intensity of power interruptions between districts in the Khorezm region. In some areas, the high frequency of interruptions was attributed to issues within the local energy infrastructure or natural conditions. Furthermore, the data enabled an assessment of how power supply interruptions affect the uninterrupted operation of base stations. This study draws important conclusions regarding the reliability of mobile communication infrastructure components, particularly base stations, in the Khorezm region. The findings emphasize the need for further research into eliminating energy supply issues, improving the efficiency of base stations, and enhancing the quality and continuity of communication services. The results of the analysis pave the way for developing technical and technological solutions to improve the reliability of base stations. Specifically, the implementation of alternative energy sources, such as supercapacitor banks or backup batteries, is recommended to provide rapid responses to power interruptions. Additionally, the advancement of monitoring and automated control systems is identified as an effective means to ensure the stability of base stations. This research serves as a crucial scientific and practical foundation for devising measures to improve the reliability of power supply systems in mobile communication networks.

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Keywords: GSM, LTE, NR, base station, continuous energy, reliability, reliability probability, Weibull parameter, linear regression.

Introduction

Currently, four telecommunication operators are active in the Republic of Uzbekistan, providing services to subscribers. In particular, in the Khorezm region, a relatively sparsely populated region of the Republic, communication operators provide communication using GSM (2G, 3G), LTE (Long term evolution – 4G), and NR (New radio – 5G) technologies [1]. To provide high-quality and high-speed services to subscribers in the regions, it is necessary to use high-band frequencies and ensure that their service distance is short. Therefore, it will be necessary to increase the number of base stations to fully cover regions such as the Khorezm region with mobile communications[2], [3]. At the same time, the most important factor for providing high-quality and uninterrupted service through the mobile communication system is the uninterrupted supply of energy to the BS. Currently, various studies are being conducted in this regard in countries with developed communication technologies, and effective results are being achieved [4], [5].

In recent years, Uzbekistan has experienced significant growth in the telecommunications sector. The number of mobile subscribers has surpassed 34.2 million, of which 28.8 million are individual subscribers. The country's mobile penetration rate has reached 79% [6]. Figure 1 presents the number of mobile subscribers per 100 inhabitants as of January 1, 2024.

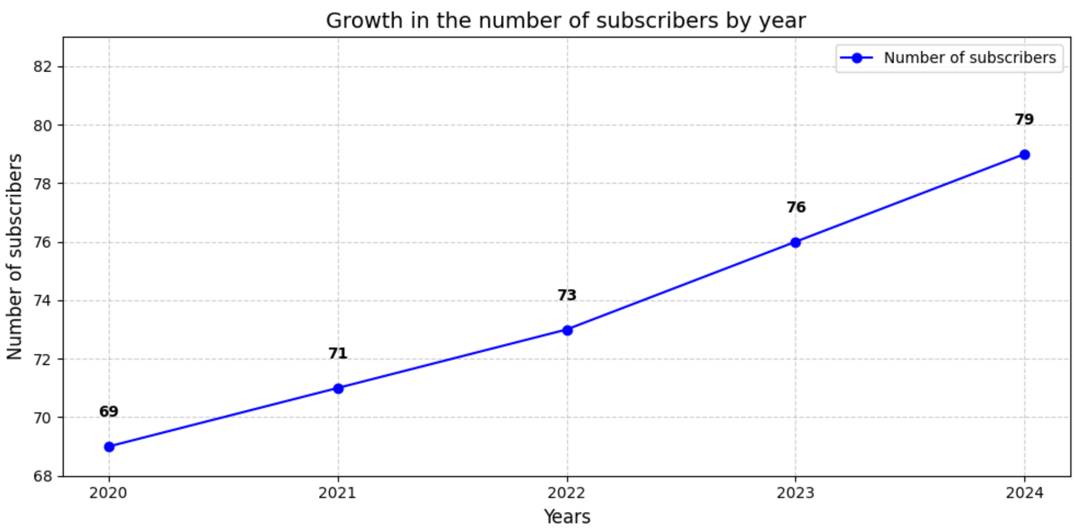

Figure 1. Number of subscribers per 100 permanent residents by year [6].

To provide high quality and reliable services to a significantly increasing number of users, mobile operators need to expand their networks, that is, increase the number of base stations to fully cover the territory. In addition, they must ensure the reliability of the BS [7], [8]. When expanding the mobile network, additional power infrastructure should be considered to ensure network reliability and minimize the impact of power outages [9], [10]. In addition, by predicting energy consumption, it is possible to minimize outages and plan electricity supply sources in advance [11], [12].

By increasing the number of BSs in the regions, it is possible to provide users with uninterrupted communication. As of August 2023, the number of BSs in the Republic of Uzbekistan will be more than 53.6 thousand. The provision of mobile communications by the Uzmobile mobile operator in the Khorezm region can be seen in Fig. 2 [13].

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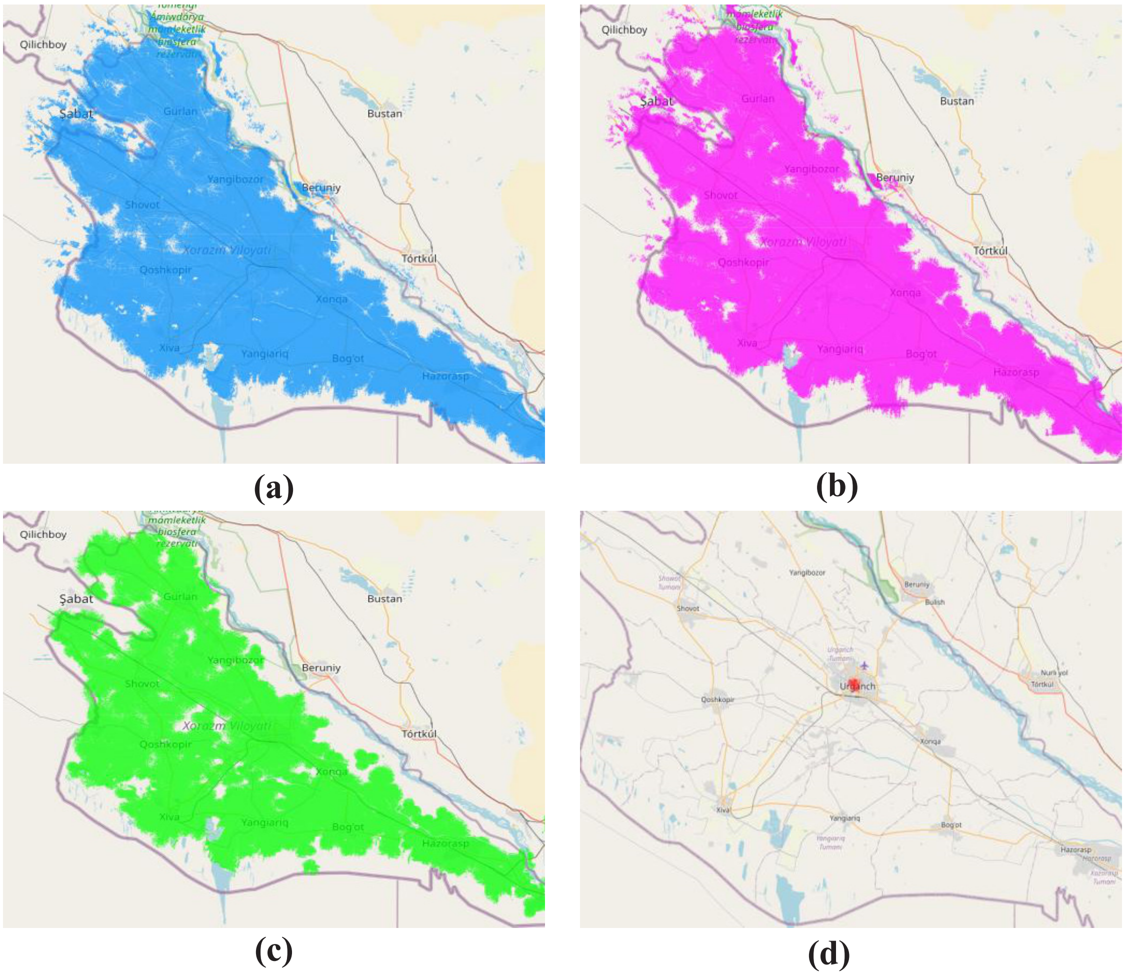

Figure 2. Khorezm region is provided with mobile communications by the mobile operator Uzmobile: a) 2G voice and internet, b) 3G voice and internet, c) 4G, d) 5G.

Ensuring that all mobile communication stations are provided with constant and reliable electricity is becoming a pressing issue [14], [15], [16]. However, power outages in some regions and rural areas are causing disruptions in the mobile communications network. This, in turn, causes disruptions in communication networks and a decrease in the quality of service. Therefore, the need for stable and uninterrupted power supply sources to ensure the uninterrupted operation of power plants is increasing [1], [5], [17]. Traditional energy sources include grid-connected electricity, backup generators, and renewable energy sources. However, modern scientific and technological approaches are causing significant changes in the field of energy storage and distribution. In studies [1], [5], batteries and renewable energy sources are proposed as primary solutions for ensuring the power supply of mobile communication base stations. In studies [8] and [9], supercapacitors are introduced as auxiliary components of power supply systems, contributing to the stabilization of power fluctuations and demonstrating high efficiency in mitigating short-term outages. These technologies allow for stable energy supply during power outages, rapid energy redistribution, and optimization of consumption. Efficient energy management technologies facilitate the dynamic management of energy flows and reserves. Optimizing energy distribution and flow, quick implementation of transition to backup sources, implementation of real-time monitoring systems, etc., are of great importance in ensuring stable and continuous operation of mobile BS [3], [4], [8], [9]. At the same time, modern monitoring systems are increasingly enabling the monitoring, maintenance, and rapid resolution of power supply systems.

Fig. 3 depicts the structural scheme of the electrical energy supply of the mobile communications BS [18], [19].

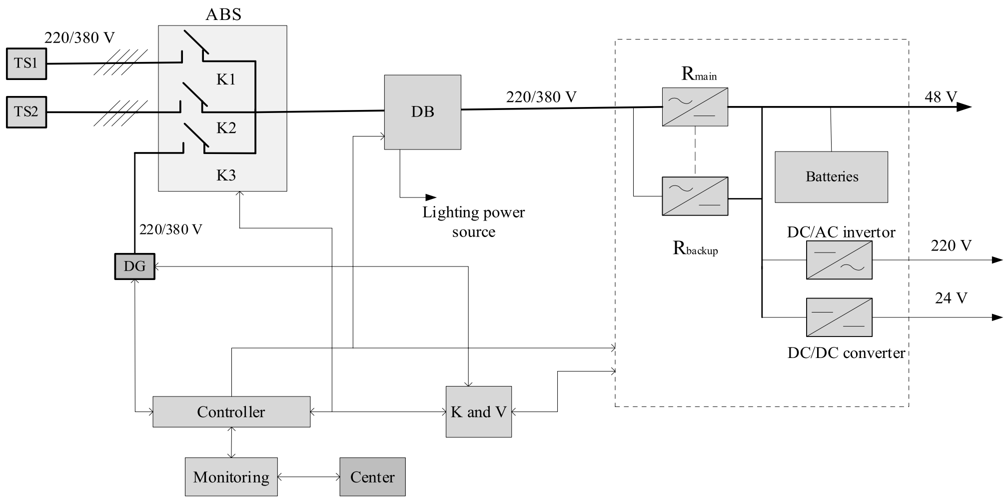

Figure 3. Structural diagram of the power supply of a mobile communication substation.

Methods and Materials

The research analyzed data on the state of power supply sources of mobile communication stations in the Khorezm branch of the national mobile operator of the Republic of Uzbekistan, Uzmobile, during a year. To ensure the uninterrupted power supply of the studied base stations, four series-connected lead-acid battery units with a voltage of 12 V and a capacity of 200 Ah are utilized, along with local electrical grids serving as the primary energy source. In the event of a power outage in the primary energy supply sources of base stations, batteries ensure an uninterrupted power supply. Under ideal conditions, the batteries can sustain the base station for up to 2 hours; however, this duration varies depending on the station's load. Moreover, due to battery aging, many units fail to provide the required power for the full 2-hour period. If a power outage in the primary energy supply persists for an extended period, the base station will experience failure once the batteries are fully discharged. Additionally, other factors may also contribute to disruptions in base station operation. Power supply interruptions in mobile communication base stations can be classified into several categories. The main causes of power-related failures in mobile communication base stations include:

- outages in local electrical grids;
- failures in automatic switching mechanisms;
- malfunctions in battery systems;
- faults in hybrid power systems;
- disruptions in rectifiers.

As a result of the analysis, 13 BSs with the highest number and duration of outages were selected from each district of the Khorezm region and their reliability was assessed. Several factors have contributed to disruptions in the primary power supply, including short circuits in low-voltage overhead lines, wire breakages between line supports, insulator damage on poles, and fluctuations in line voltage, either decreasing or increasing beyond normal levels.

During this research we will:

- Identify the 13 BSs with the most outages based on the analyzed data;
- Determine the probability of failure of each BS;
- Determine and graphically represent the parameter of the Weibull distribution;
- Determine the reliability of each BS and compare the results;
- Calculation of the overall reliability of BS;

The results of this research work will lead to more efficient, better monitoring, management, and maintenance of BS. If the reliability and performance of the BS are assessed and monitored, this will lead to improved system performance and maintenance [20], [21]. As a result of the analyses conducted, it was determined that one of the most commonly used probability distributions in assessing the reliability of BS is the Weibull distribution, and it was used to assess the reliability of BSs [22], [23].

The use of probability distributions is essential for effective monitoring, management, and maintenance of BSs. Improvements in system performance and maintenance can be achieved through continuous assessment of the reliability of BSs. The Weibull distribution is mainly used to model the rate of increase and decrease in the number of failures, and the failure rate is as follows:

$$\lambda(t)=\beta_0\cdot t^{\beta} \tag{1}$$

where $\lambda(t)$ the failure rate or risk level is $\beta_0>0$, the failure rate increases when $\beta_0>0$, and decreases when $\beta_0>0, \beta<0$.

$$P(t)=e^{-(\frac{t}{T})^{\beta}} \tag{2}$$

where $P(t)$ is the reliability function or reliability probability.

There are three different types of Weibull distributions. If $\beta=1$ exists, then the failures are random and a constant failure rate can be accepted where there is a failure rate.

If $\beta>1$, then the failure rate increases. Failures can occur due to physical wear, operation with high loads, corrosion, erosion, and other reasons. If $\beta<1$, then the rejection intensity decreases.

$$\lambda(t)=1/\beta \tag{3}$$

The causes of failures can be poor control, manufacturing defects, poor workmanship, etc. $F(t_i)$ – the probability of rejection is calculated according to expression (4) [21].

$$F(t_i)=1-\frac{n_i}{T} \tag{4}$$

where t_i is the fault duration (hours);

$\boldsymbol{n}$ – total number of failures, $\boldsymbol{i}$ – number of analyzed failures.

$$y_i=lnln\left(\frac{1}{F(t_i)}\right) \tag{5}$$

$$x_i=\ln t_i, \tag{6}$$

where x_i is the instantaneous time value (coordinate values on the horizontal axis) and y_i is the instantaneous rejection probability (coordinate values on the vertical axis) [24], [25]. Our basic approach to probability plots is to fit the shape to a linear regression line [26, [27], [28].

$$y=\beta_0+\beta x \tag{7}$$

Here β_0 and β are calculated as follows:

$$\beta=\frac{\sum_{i=1}^{i=n}(y_i-\bar{y})(x_i-\bar{x})}{\sum_{i=1}^{i=n}(x_i-\bar{x})^2} \tag{8}$$

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$$\beta_0 = y - \beta x \tag{9}$$

If the failure times follow the predicted distribution, the data will be plotted as a straight line and the fitted regression line will have a high index.

To conduct research on the Weibull distribution, the BSs with the most outages and the most users, operating under different technologies and under different conditions, were selected from all districts of the Khorezm region. The study shows that power interruptions at mobile communication base stations occur randomly rather than following a fixed pattern. Over a year, data revealed that outages varied by location and time, influenced by grid instability, seasonal changes, and technical issues. Some stations experienced multiple failures in a short period, while others had long uninterrupted operations. Information on the status and duration of outages at BSs is presented in Table 1 and Figure 4.

Table 1. Information on outages in selected BSs during the study

№	BS name	Designation of BS	Number of failures during the learning period	Duration of interruptions
1	Base station 1	BS1	516	392:15:00
2	Base station 2	BS2	524	327:59:00
3	Base station 3	BS3	789	272:15:00
4	Base station 4	BS4	102	50:49:00
5	Base station 5	BS5	296	128:34:00
6	Base station 6	BS6	554	218:30:00
7	Base station 7	BS7	425	165:25:00
8	Base station 8	BS8	261	161:29:00
9	Base station 9	BS9	82	93:38:00
10	Base station 10	BS10	507	397:05:00
11	Base station 11	BS11	144	126:06:00
12	Base station 12	BS12	833	371:52:00
13	Base station 13	BS13	612	312:46:00

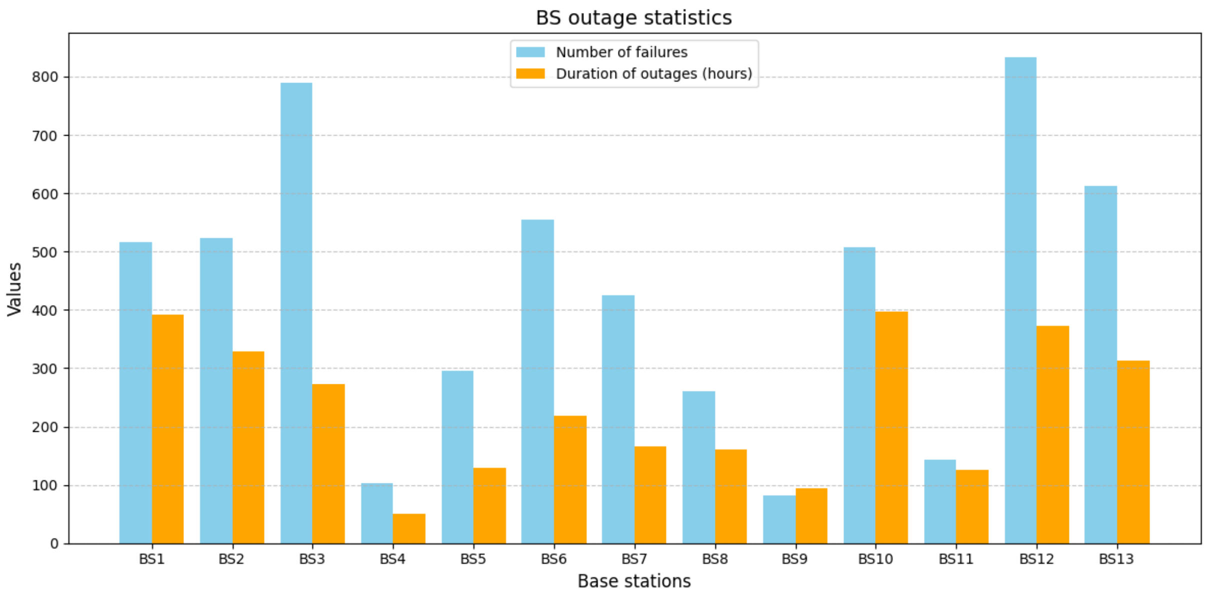

Figure 4. Number and duration of outages in BS.

Results

Calculations are performed to evaluate and determine the reliability of BS. The calculations will be performed by using the above formulas based on one year of statistical data from which the books have been analyzed. The following variables are used in the calculation: T – the analyzed period in hours, for us this value is $T=24 \cdot 365=8760$ hours and this value is the same for all BSs, t_i – failure time; i – the number of cases considered. In our study, 13 BSs with the highest outage times were selected, i.e. 1 from each region (district) of the Khorezm region, $\boldsymbol{n}$ is the total number of failures in the BS; $F(t_i)$ is the rejection probability. The accounts are calculated according to the situation in BS1 using the formulas in (4):

$$F(t_i)=1-\frac{n_i}{t}=1-\frac{516}{8760}=0,941$$

We calculate y_i and x_i according to the formula in (5) and (6):

$$y_i=lnln\left(\frac{1}{F(t_i)}\right)=lnln\left(\frac{1}{0,941}\right)=-2,802$$

$$x_i=\ln(t_i)=\ln(392,25)=5,972$$

Same calculations are performed for the remaining cases in the sequence and summarize the results in Table 2. Based on the data in Table 2, we calculate the parameters to find the linear regression function and summarize them in Table 3.

Here, $\bar{y}$ is the average value of the y's calculated using the formula, $\bar{x}$ is the average value of the x's.

Table 2. Results of calculations based on data from BS.

Designation of BS	Number of failures during the learning period (n)	Duration of outages (t_i)	$F(t_i)=1-\frac{n_i}{t}$	$x_i=\ln(t_i)$	$y_i=lnln\left(\frac{1}{F(t_i)}\right)$
BS1	516	392,25	0,941	5,972	-2,802
BS2	524	327,98	0,940	5,790	-2,786
BS3	789	272,25	0,910	5,606	-2,360
BS4	102	50,82	0,988	3,912	-4,447
BS5	296	128,57	0,966	4,852	-3,370
BS6	554	218,5	0,937	5,384	-2,728
BS7	425	165,25	0,951	5,106	-3,001
BS8	261	161,49	0,970	5,081	-3,498
BS9	82	93,63	0,991	4,533	-4,667
BS10	507	397,08	0,942	5,984	-2,820
BS11	144	126,09	0,984	4,836	-4,100
BS12	833	371,87	0,905	5,916	-2,303
BS13	612	312,77	0,930	5,743	-2,625

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Table 3. Calculation of parameters for finding a linear regression function.

i	x_i	y_i	$y_i-\bar{y}$	$x_i-\bar{x}$	$(y_i-\bar{y})(x_i-\bar{x})$	$(x_i-\bar{x})^2$
1	5,972	-2,802	0,391	0,686	0,268	0,470
2	5,793	-2,786	0,407	0,504	0,205	0,254
3	5,607	-2,360	0,833	0,320	0,266	0,102
4	3,928	-4,447	-1,254	-1,374	1,723	1,888
5	4,856	-3,370	-0,177	-0,434	0,077	0,188
6	5,387	-2,728	0,465	0,098	0,046	0,010
7	5,107	-3,001	0,192	-0,180	-0,035	0,032
8	5,084	-3,498	-0,305	-0,205	0,062	0,042
9	4,539	-4,667	-1,474	-0,753	1,110	0,568
10	5,984	-2,820	0,373	0,698	0,260	0,487
11	4,837	-4,100	-0,907	-0,450	0,408	0,202
12	5,919	-2,303	0,890	0,630	0,561	0,397
13	5,745	-2,625	0,568	0,457	0,259	0,209

To determine the reliability of BSs based on the specified distribution, we calculate the Weibull parameters. For this, we use a linear regression model. And it is calculated as follows based on the formulas in (9) and (10) using Table 2 and Table 3:

$$\beta=\frac{\sum_{i=1}^{i=n}(y_i-\bar{y})(x_i-\bar{x})}{\sum_{i=1}^{i=n}(x_i=\bar{x})^2}=\frac{5,187}{4,799}=1,081$$

$$\beta_0=\bar{y}-\beta\bar{x}=-3,193-1,081\times5,289= -8,908$$

In this case, the linear regression function looks like this (Fig. 5):

$$y=-8,908+1,081x$$

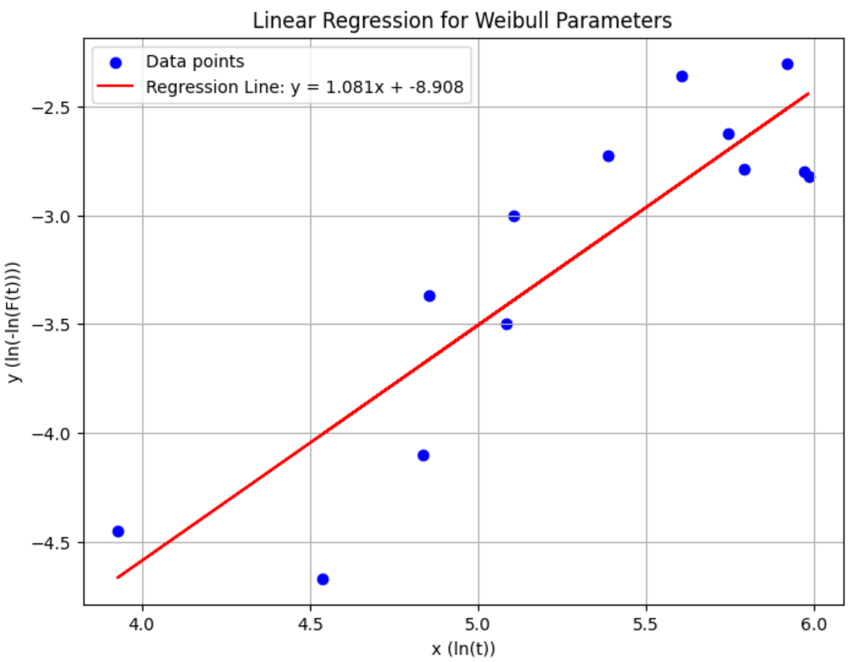

Figure 5. Linear regression plot for Weibull parameters.

Now the reliability is calculated based on the results obtained from the equations found from the linear regression model. Calculations are performed using formula (2). Here is a constant value of $e=2{,}71, \beta=1{,}081$ is the shape parameter for the Weibull distribution found using the linear regression model, T is the period under analysis (in hours), in our case this value is equal to $T=8760$ hours, this value is the same for all BSs, t is the duration of the outages, for the first case $t=392{,}25$. Reliability probability for BS1 is calculated:

$$P(t)=e^{-\left(\frac{t}{T}\right)^{\beta}}=e^{-\left(\frac{392{,}25}{8760}\right)^{1{,}081}}=0{,}966$$

Calculations for the remaining BSs are performed using the above formulas and summarize the results in Table 4. Based on Table 4, the reliability probability of BSs was assessed.

Table 4. Reliability indicators of selected BS.

Designation of BS	**Duration of outages** (t_i)	**Reliability of BSs** P(t)
BS1	392,25	0,966
BS2	327,98	0,972
BS3	272,25	0,977
BS4	50,82	0,996
BS5	128,57	0,990
BS6	218,5	0,982
BS7	165,25	0,986
BS8	161,49	0,987
BS9	93,63	0,993
BS10	397,08	0,965
BS11	126,09	0,990
BS12	371,87	0,968
BS13	312,77	0,973

According to the analysis results, the highest number of power supply interruptions were observed at TS12 and TS3, with 833 and 789 recorded failures, respectively. Despite the high frequency of outages, their reliability coefficients remained relatively stable (TS12 – 0.968, TS3 – 0.977), indicating the effectiveness of the power restoration system. In contrast, TS4 exhibited the highest reliability (0.996), with only 102 recorded failures and a total outage duration of 50 hours and 49 minutes, suggesting that its backup power sources function efficiently. On the other hand, TS10 had the lowest reliability coefficient (0.965), experiencing 507 power supply failures and a total outage duration of 397 hours and 5 minutes. This indicates that TS10's backup power system is either insufficiently effective or that the power restoration process is slow. Similarly, TS1 demonstrated relatively low reliability (0.966), with 516 recorded failures and a cumulative power outage duration of 392 hours and 15 minutes. These findings highlight the necessity of improving backup power systems and enhancing energy management strategies in stations with lower reliability. Additionally, stations such as TS9 and TS4 exhibited relatively high reliability, characterized by fewer and shorter-duration power outages.

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Discussion

The efficient and uninterrupted operation of mobile communication BSs is an important factor for a modern telecommunications infrastructure. Power supply systems are one of the main supporting mechanisms of these stations, and their reliability and stability determine the quality of mobile communication services. By analyzing the 13 BSs with the most selected outages, it was found that $\beta > 1$, which increases the outage level. This creates the need to develop solutions such as new energy supplies and backup energy sources during power outages. Outages are mainly caused by several factors, such as short circuits in low-voltage overhead power lines, broken wires between supports on the line, broken insulators on poles, and voltage drops or surges on the line.

The results of the reliability analysis of all BSs show that BS4 had a high probability of reliability by analyzing one year of data. In this study, the reliability of BSs was assessed. The mathematical expressions for calculating reliability also include a linear regression model for calculating the Weibull parameter. The reliability of each selected BS was calculated. According to the results obtained, BS4 was found to have the highest reliability and BS10 to have the lowest reliability.

Conclusion

The efficient and uninterrupted operation of mobile communication BS is crucial for modern telecommunication infrastructure. The power supply systems of these stations serve as a fundamental support mechanism, and their reliability and stability are key indicators that determine the quality of mobile communication services. In a study conducted in the Khorezm region, 13 BSs with the highest number of interruptions were analyzed. During this analysis, it was determined that $\beta > 1$, indicating an increasing intensity of interruptions. This situation highlights the need to implement alternative solutions to ensure the continuity of power supply, such as backup energy sources or new energy systems.

According to the study's results, the main causes of interruptions were identified as technical malfunctions in power transmission lines. Specifically, issues such as short circuits in low-voltage overhead power lines, broken wires between pylons, damaged insulators, and voltage fluctuations – either surges or drops – were among the primary problems. These technical faults significantly affect the uninterrupted operation of base stations. The analysis also evaluated the reliability metrics of each BS using mathematical models, including the Weibull distribution parameters calculated through linear regression methods. The results revealed that BS4 exhibited the highest reliability, indicating relatively stable power supply conditions. In contrast, BS10 demonstrated the lowest reliability, suggesting a higher susceptibility to malfunctions in power transmission lines. The findings of this study provide a solid scientific foundation for improving the reliability of mobile communication systems and ensuring the stability of power supply. Future efforts to widely implement backup energy sources and automate monitoring systems hold the potential to enhance the reliability of BSs. Such measures will play a significant role in maintaining uninterrupted and high-quality mobile communication services.

There are several approaches to making mobile power supply systems more reliable. While relying on local power grids as primary energy sources is often effective, there is a growing need for backup energy sources that provide independence from the grid. Backup power sources such as diesel generators, renewable energy sources (solar panels and wind generators), and new energy storage technologies (batteries, supercapacitors) play an important role in increasing the stability of telecommunications networks.

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