Chemical Technology, Control and Management

Volume 2021 | Issue 1 Article 11

3-29-2021

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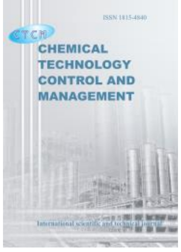
Recommended Citation

Davronbekov, Dilmurod and Matyokubov, Utkir Karimovich (2021) "CALCULATE THE RELIABILITY OF THE BTS-BSC NETWORK WITH THE RESERVED LINE CONNECTION," *Chemical Technology, Control and Management*: Vol. 2021 : Iss. 1 , Article 11.
DOI: https://doi.org/10.34920/2021.1.76-84
Available at: https://uzjournals.edu.uz/ijctcm/vol2021/iss1/11

ISSN 1815-4840, E-ISSN 2181-1105
Himičeskaâ tehnologiâ. Kontrol' i upravlenie
CHEMICAL TECHNOLOGY. CONTROL AND MANAGEMENT
2021, №1 (97) pp.76-84. https://doi.org/10.34920/2021.1.76-84
International scientific and technical journal
journal homepage: https://uzjournals.edu.uz/ijctcm/



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CALCULATE THE RELIABILITY OF THE BTS-BSC NETWORK WITH THE RESERVED LINE CONNECTION

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Abstract: *The issue of reserving communication lines between the base station and the mobile network base station controller which are considered as one system is considered. Analytical expressions have been developed for calculating the reliability of the system for various options for backing up communication lines between the base station and the base station controller. The results of research and calculations of reliability for ten different types of backup communication lines of the base station and the base station controller are presented.*
Keywords: *Base transceiver station, base station controller, reliability, intensity of failures, viability, line connection, optical cable, copper cable, radio relay line, repeater, backup, system.*

Аннотация: *Битта тизим сифатида қараладиган уяли алоқа тармоғининг таянч станцияси ва таянч станция контроллери ўртасидаги алоқа тармоқларини заҳиралаш масаласи кўриб чиқилган. Тизимнинг ишончлилигини ҳисоблаш учун таянч станция ва таянч станция контроллери ўртасидаги алоқа тармоқларини заҳиралашнинг турли хил вариантлари учун аналитик ифодалар ишлаб чиқилган. Таянч станция ва таянч станция контроллери оралиғидаги алоқа тармоқларининг ўн хил заҳира ҳолатлари учун ишончлилик бўйича тадқиқотлар ва натижалар келтирилган.*
Таянч сўзлар: *таянч станция, таянч станция контроллери, ишончлилик, рад қилиш жадаллиги, яшовчанлик, алоқа тармоғи, оптик кабель, мис кабель, радиорелели тармоқ, репитор, заҳиралаш, тизим.*

Аннотация: *Рассматривается вопрос резервирования линий связи между базовой станцией и контроллером базовой станции мобильной сети, которые рассматриваются как одна система. Разработаны аналитические выражения расчета надежности системы для различных вариантов резервирования линий связи между базовой станцией и контроллером базовой станции. Представлены результаты исследования и расчетов надежности для десяти различных видов резервной линии связи системы базовая станция - контроллер базовой станции.*
Ключевые слова: *Базовая приемопередающая станция, контроллер базовой станции, надежность, интенсивность отказов, живучесть, линейное соединение, оптический кабель, медный кабель, радиорелейная линия, репитер, резервирование, система.*

Introduction

Currently, there is a growing need of society for information and communication technologies, in particular for mobile communication services. Ensuring the continuity of the services provided during such a period is a very important issue. Particularly unacceptable is a failure that can lead to the termination of the exchange of information or the loss of important information as a result of failure of any element of the network [1-3].

Network design and power distribution methods try to reduce network failures and increase viability through the correct placement of devices with sufficient diversity and capabilities in the network topology. For example, by designing a topology and determining the capacity of connections in a backbone network, it is possible to use data exchange through another device in the network in the event of any interruption in the network. In addition, ensuring the reliability of communication lines, uninterrupted power supply in mobile communication systems during natural and man-made disasters is a very important issue [2-13, 31-33].

In the design of reliable mobile communication systems it is necessary to effectively use various software tools, systems design methods, forecasting methods, mathematical algorithms, modern technologies [14-23]. At the same time, the network must be cost-effective [24, 25-36].

Research Methods and the Received Results

When calculating the reliability of a system, it is important to know the structure of the system and the characteristics of the elements used in it. In particular, the rejection intensity values of the elements in the system are one of the key parameters. (5), (6), (7), (8), (9), (18), (19), (20), (26), (30) shows the simplified structure of the cellular communication system base station (BTS) and the base station controller (BSC) and analytical expressions are developed to calculate the reliability of the system for different communication lines. This takes into account the fact that the communication line is different.

Among all the methods of increasing the reliability provided in the design, a special place is occupied by the use of redundancy, i.e. introduction of additional means or capabilities in excess of the minimum necessary for the object to perform the specified functions. The very same method of increasing the reliability of an object by introducing redundancy is called reservation.

The special place given to this method is explained by the fact that redundancy allows the most complete solution of the problem of obtaining the required reliability of systems with relatively unreliable elements.

Figure 1 shows the simplified structural structure of the base station and the base station controller system communication line backup. Here, P_1- reliability of the base station system; P_2- reliability of the base station controller system; P_A- backup communication line reliability; P_3- the reliability of the first communication line; P_4- reliability of the second (backup) communication line.

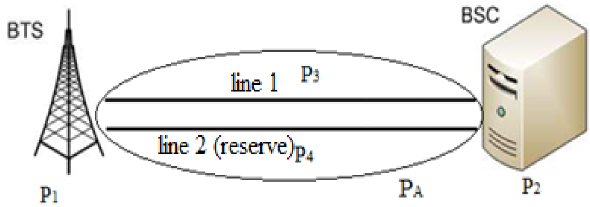

Figure 1. ***The communication line is a simplified structure of the backup BTS-BSC system.***

In parallel backup of communication lines, reliability can be calculated using the following expression:

$$P_A = 1 - (1 - P_3) \cdot (1 - P_4) \tag{1}$$

In this case, the reliability of the overall system is expressed as follows:

$$P_{Tot} = P_1 \cdot P_2 \cdot [1 - (1 - P_3) \cdot (1 - P_4)] \tag{2}$$

The exponential distribution law is the most common in practice technical model of reliability of radio-technical elements during normal operation. The probability of no-failure operation at any time interval t will be written [18-20, 27-30, 34-36]:

$$P(t) = \exp(-\lambda \cdot t),\ t > 0 \tag{3}$$

where λ – failure rate constant equal to the reciprocal.

$$\lambda = \frac{1}{T_{\mathrm{av}}} \tag{4}$$

T_{av}- average uptime.

The probability of failure-free operation of a system of n series-connected elements, the failures of which are independent and obey an exponential law

$$P(t) = \prod_{j=1}^{n} \exp\,(-j \cdot \lambda \cdot t) = exp[t \cdot \sum_{i=1}^{n} \lambda_i] \tag{5}$$

where $j \cdot \lambda$ – the failure rate of the j-th element of the system.

The reliability of system elements according to the exponential law in the development of analytical expressions is given in Table 1:

Table 1.

Expressions to calculate the reliability of system elements.

System element	$P(t)$	Determination of system element rejection intensity (λ)	Note
BTS	$P_1(t) = e^{-\lambda_1 \cdot t}$	λ_1	
BSC	$P_2(t) = e^{-\lambda_2 \cdot t}$	λ_2	
Copper cable	$P_{\text{cw}}(t) = e^{-\lambda_{\text{cw}} \cdot t}$	λ_{cw}	$\lambda_{\text{cw}} = l_1 \cdot \lambda_3$ l_1 – copper wire length
Optical cable	$P_{\text{of}}(t) = e^{-\lambda_{\text{of}} \cdot t}$	λ_{of}	$\lambda_{\text{of}} = l_2 \cdot \lambda_4$ l_2- optical fiber length
RRL	$P_{\text{rrl}}(t) = e^{-2 \cdot \lambda_{\text{rrl}} \cdot t}$	λ_{rrl}	
RRL repeaters	$P_{\text{пртр}}(t) = e^{-(2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t}$	λ_{rrlr}	N – number of repeaters

Possible cases of backing up the base station and the base station controller range communication line through a combination of copper cable, optical cable, RRL and repeater RRLs are shown in Figure 2.

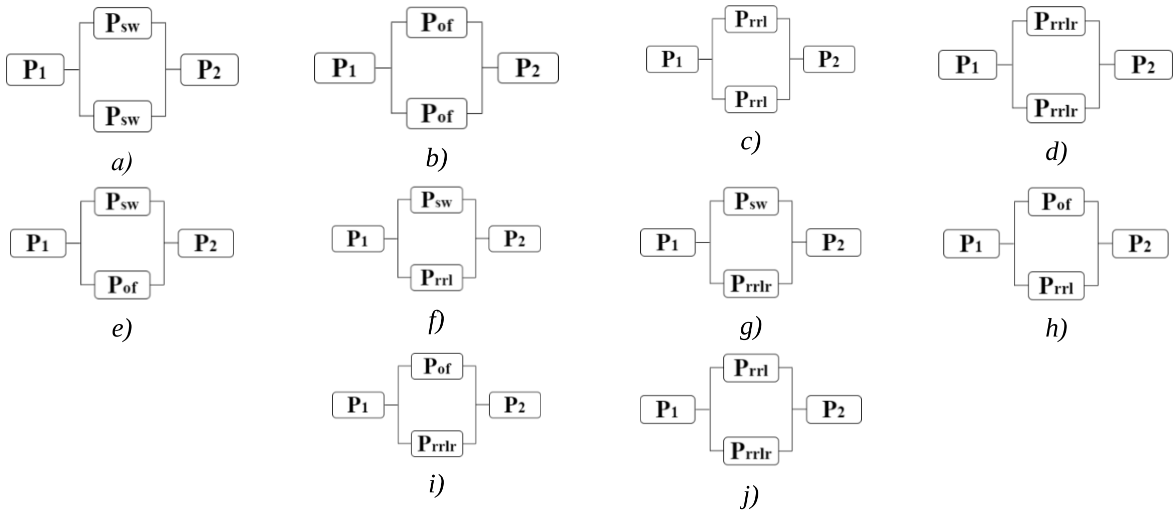

Fig.2. ***Different structures of BTS-BSC system communication line reservation:***
a) backup via copper cables, b) backup via optical cables, c) Backup via RRLs, d) backup through repeater RRLs, e) backup via copper cable and optical cable, f) backup via copper cable and RRL, g) backup via copper cable and repeater RRL, h) backup via optical cable and RRL, i) backup via optical cable and repeater RRL, j) Backup via RRL and repeater RRL.

The first case is the organization of backup of the base station and the base station controller network communication line via copper cables (Figure 2.a).

$$P_A = 1 - (1 - P_{\text{cw}}) \cdot (1 - P_{\text{cw}}) = 1 - [1 + P_{\text{cw}}^2 - 2 \cdot P_{\text{cw}}] = 2 \cdot P_{\text{cw}} - P_{\text{cw}}^2 \quad (6)$$

Here, P_A - is the reliability indicator when the communication line is arranged via copper cables.

In this case, the reliability value when the base station and the base station controller network communication line is backed up by copper cables is calculated as follows:

$$P_{Tot(\text{cw,cw})} = P_1 \cdot P_2 \cdot P_A = P_1 \cdot P_2 \cdot (2 \cdot P_{\text{cw}} - P_{\text{cw}}^2) == e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(2 \cdot e^{-\lambda_{\text{cw}} \cdot t} - e^{-2 \cdot \lambda_{\text{cw}} \cdot t}\right) =$$
$$= e^{-(\lambda_1 + \lambda_2) \cdot t} \cdot \left(2 \cdot e^{-\lambda_3 \cdot l_1 \cdot t} - e^{-2 \cdot \lambda_3 \cdot l_1 \cdot t}\right)$$

$$P_{Tot(\text{cw,cw})} = 2 \cdot e^{-(\lambda_1 + \lambda_2 + l_1 \cdot \lambda_3) \cdot t} - e^{-(\lambda_1 + \lambda_2 + 2 \cdot l_1 \cdot \lambda_3) \cdot t} \quad (7)$$

The second case is the organization of backup of the base station and the base station controller network communication line via optical cables (Figure 2.b).

$$P_B = 1 - (1 - P_{\text{of}}) \cdot (1 - P_{\text{of}}) = 1 - \left[1 + P_{\text{of}}^2 - 2 \cdot P_{\text{of}}\right] = 2 \cdot P_{\text{of}} - P_{\text{of}}^2 \quad (8)$$

Here, P_B- is the reliability index when the communication line is arranged via optical cables.

In this case, the reliability value when the base station and the base station controller network communication line is backed up by optical cables is calculated as follows:

$$P_{\text{Tot(of,of)}} = P_1 \cdot P_2 \cdot P_B = P_1 \cdot P_2 \cdot \left(2 \cdot P_{\text{of}} - P_{\text{of}}^2\right) == e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(2 \cdot e^{-\lambda_{\text{of}} \cdot t} - e^{-2 \cdot \lambda_{\text{of}} \cdot t}\right) =$$
$$= e^{-(\lambda_1+\lambda_2) \cdot t} \cdot \left(2 \cdot e^{-l_2 \cdot \lambda_4 \cdot t} - e^{-2 \cdot l_2 \cdot \lambda_4 \cdot t}\right)$$
$$P_{\text{Tot(of,of)}} = 2 \cdot e^{-(\lambda_1+\lambda_2+l_2 \cdot \lambda_4) \cdot t} - e^{-(\lambda_1+\lambda_2+2 \cdot l_2 \cdot \lambda_4) \cdot t} \quad (9)$$

The third case is the organization of backup of the base station and the base station controller network communication line via RRLs (Figure 2.c).

$$P_{\text{C}} = 1 - (1 - P_{\text{rrl}}) \cdot (1 - P_{\text{rrl}}) = 1 - \left[1 + P_{\text{rrl}}^2 - 2 \cdot P_{\text{rrl}}\right] = 2 \cdot P_{\text{rrl}} - P_{\text{rrl}}^2 \quad (10)$$

Here, P_{C}- is the reliability index when the communication line is organized by RRLs. In this case, the reliability value when the base station and the base station controller network communication line is backed up by RRLs is calculated as follows:

$$P_{\text{Tot(rrl,rrl)}} = P_1 \cdot P_2 \cdot P_{\text{C}} = P_1 \cdot P_2 \cdot \left(2 \cdot P_{\text{rrl}} - P_{\text{rrl}}^2\right) == e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(2 \cdot e^{-2 \cdot \lambda_{\text{rrl}} \cdot t} - e^{-4 \cdot \lambda_{\text{rrl}} \cdot t}\right)$$
$$P_{\text{Tot(rrl,rrl)}} = 2 \cdot e^{-(\lambda_1+\lambda_2+2 \cdot \lambda_{\text{rrl}}) \cdot t} - e^{-(\lambda_1+\lambda_2+4 \cdot \lambda_{\text{rrl}}) \cdot t} \quad (11)$$

The fourth case is the organization of backup of the base station and the base station controller network communication line through repeater RRLs (Figure 2.d).

$$P_D = 1 - (1 - P_{\text{rrlr}}) \cdot (1 - P_{\text{rrlr}}) = 1 - \left[1 + P_{\text{rrlr}}^2 - 2 \cdot P_{\text{rrlr}}\right] = 2 \cdot P_{\text{rrlr}} - P_{\text{rrlr}}^2 \quad (12)$$

Here, $P_D -$ is the reliability index when the communication line is organized by repeater RRLs. In this case, the reliability value when the base station and the base station controller network communication line is backed up by repeater RRLs is calculated as follows:

$$P_{\text{Tot(rrlr,rrlr)}} = P_1 \cdot P_2 \cdot P_D = P_1 \cdot P_2 \cdot \left(2 \cdot P_{\text{rrlr}} - P_{\text{rrlr}}^2\right) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(2 \cdot e^{-(2 \cdot \lambda_{\text{rrl}}^* + N \cdot \lambda_{\text{rrlr}}) \cdot t} - e^{-2(2 \cdot \lambda_{\text{rrl}}^* + N \cdot \lambda_{\text{rrlr}}) \cdot t}\right)$$
$$P_{\text{Tot(rrlr,rrlr)}} = 2 \cdot e^{-\left(\lambda_1+\lambda_2+2 \cdot \lambda_{\text{rrl}}^* + N \cdot \lambda_{\text{rrlr}}\right) \cdot t} + e^{-\left(\lambda_1+\lambda_2+4 \cdot \lambda_{\text{rrl}}^* + 2 \cdot N \cdot \lambda_{\text{rrlr}}\right) \cdot t} \quad (13)$$

The fifth case is the organization of backup of the base station and the base station controller network communication line via copper cable and optical cables (Figure 2.e).

$$P_{\text{E}} = 1 - (1 - P_{\text{cw}}) \cdot (1 - P_{\text{of}}) = 1 - [1 - P_{\text{of}} - P_{\text{cw}} + P_{\text{of}} \cdot P_{\text{cw}}] \quad (14)$$

Here, P_E- is an indicator of reliability when the communication line is arranged via copper cable and optical cable. In this case, the reliability value when the base station and the base station controller network communication line is backed up by copper cable and optical cable is calculated as follows.

$$P_{\text{Tot(cw,of)}} = P_1 \cdot P_2 \cdot P_{\text{E}} = P_1 \cdot P_2 \cdot [1 - (1 - P_{\text{of}} - P_{\text{cw}} + P_{\text{of}} \cdot P_{\text{cw}})]$$
$$= P_1 \cdot P_2 \cdot (P_{\text{of}} + P_{\text{cw}} - P_{\text{of}} \cdot P_{\text{cw}}) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(e^{-\lambda_{\text{of}} \cdot t} + e^{-\lambda_{\text{cw}} \cdot t} - e^{-\lambda_{\text{cw}} \cdot t} \cdot e^{-\lambda_{\text{of}} \cdot t}\right)$$
$$P_{\text{Tot(cw,of)}} = e^{-(\lambda_1+\lambda_2+l_2 \cdot \lambda_4) \cdot t} + e^{-(\lambda_1+\lambda_2+l_1 \cdot \lambda_3) \cdot t} - e^{-(\lambda_1+\lambda_2+l_1 \cdot \lambda_3+l_2 \cdot \lambda_4) \cdot t} \quad (15)$$

The sixth case is the organization of backup of the base station and the base station controller network communication line via copper cable and RRL (Figure 2.f).

$$P_F = 1 - (1 - P_{\text{cw}}) \cdot (1 - P_{\text{rrl}}) = 1 - [1 - P_{\text{rrl}} - P_{\text{cw}} + P_{\text{cw}} \cdot P_{\text{rrl}}] = P_{\text{rrl}} - P_{\text{cw}} \cdot P_{\text{rrl}} + P_{\text{cw}} \quad (16)$$

Here, P_F- is the reliability indicator when the communication line is organized via copper cable and RRL. In this case, the reliability value when the base station and the base station controller network communication line is backed up by copper cable and RRL is calculated as follows:

$$P_{\text{Tot(cw,rrl)}} = P_1 \cdot P_2 \cdot P_F = P_1 \cdot P_2 \cdot (P_{\text{rrl}} - P_{\text{cw}} \cdot P_{\text{rrl}} + P_{\text{cw}}) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(e^{-2 \cdot \lambda_{\text{rrl}} \cdot t} - e^{-\lambda_{\text{cw}} \cdot t} \cdot e^{-2 \cdot \lambda_{\text{rrl}} \cdot t} + e^{-\lambda_{\text{cw}} \cdot t}\right)$$
$$P_{\text{Tot(cw,rrl)}} = e^{-(\lambda_1+\lambda_2+2 \cdot \lambda_{\text{rrl}}) \cdot t} - e^{-(\lambda_1+\lambda_2+l_1 \cdot \lambda_3+2 \cdot \lambda_{\text{rrl}}) \cdot t} + e^{-(\lambda_1+\lambda_2+l_1 \cdot \lambda_3) \cdot t} \quad (17)$$

The seventh case is the organization of backup of the base station and the base station controller network communication line via copper cable and repeater RRL (Figure 2.g).

$$P_G = 1 - (1 - P_{\text{cw}}) \cdot (1 - P_{\text{rrlr}}) = 1 - [1 - P_{\text{rrlr}} - P_{\text{cw}} + P_{\text{cw}} \cdot P_{\text{rrlr}}] = P_{\text{rrlr}} - P_{\text{cw}} \cdot P_{\text{rrlr}} + P_{\text{cw}} \quad (18)$$

Here, P_G- is the reliability indicator when the communication line is organized via copper cable and repeater RRL. In this case, the reliability value when the base station and the base station controller network communication line is backed up via copper cable and repeater RRL is calculated as follows:

$$P_{\text{Tot(cw,rrlr)}} = P_1 \cdot P_2 \cdot P_G = P_1 \cdot P_2 \cdot (P_{\text{rrlr}} - P_{\text{cw}} \cdot P_{\text{rrlr}} + P_{\text{cw}}) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot [e^{-(2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t} - e^{-\lambda_{\text{cw}} \cdot t} - e^{-\lambda_{\text{cw}} \cdot t} \cdot e^{-(2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t}]$$
$$P_{\text{Tot(cw,rrlr)}} = e^{-(\lambda_1 + \lambda_2 + 2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t} + e^{-(\lambda_1 + \lambda_2 + l_1 \cdot \lambda_3) \cdot t} - e^{-(\lambda_1 + \lambda_2 + l_1 \cdot \lambda_3 + 2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t} \quad (19)$$

The eighth case is the organization of backup of the base station and the base station controller network communication line via optical cable and RRL (Figure 2.h).

$$P_{\text{H}} = 1 - (1 - P_{\text{of}}) \cdot (1 - P_{\text{rrl}}) = 1 - [1 - P_{\text{rrl}} - P_{\text{of}} + P_{\text{of}} \cdot P_{\text{rrl}}] = P_{\text{rrl}} - P_{\text{of}} \cdot P_{\text{rrl}} + P_{\text{of}} \quad (20)$$

Here, P_H- is the reliability indicator when the communication line is organized via optical cable and RRL. In this case, the reliability value when the base station and the base station controller network communication line is backed up via optical cable and RRL is calculated as follows:

$$P_{\text{Tot(of,rrl)}} = P_1 \cdot P_2 \cdot P_{\text{H}} = P_1 \cdot P_2 \cdot (P_{\text{rrl}} - P_{\text{of}} \cdot P_{\text{rrl}} + P_{\text{of}}) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot \left(e^{-2 \cdot \lambda_{\text{rrl}} \cdot t} + e^{-\lambda_{\text{of}} \cdot t} - e^{-\lambda_{\text{of}} \cdot t} \cdot e^{-2 \cdot \lambda_{\text{rrl}} \cdot t}\right)$$
$$P_{\text{Tot(of,rrl)}} = e^{-(\lambda_1 + \lambda_2 + 2 \cdot \lambda_{\text{rrl}}) \cdot t} + e^{-(\lambda_1 + \lambda_2 + l_2 \cdot \lambda_4) \cdot t} - e^{-(\lambda_1 + \lambda_2 + l_2 \cdot \lambda_4 + 2 \cdot \lambda_{\text{rrl}}) \cdot t} \quad (21)$$

Table 2.

Comparison of reliability results of communication lines

Backup communication line type	P_{cw}**- main line (not backed up)**	$P_{Tot(cw,cw)}$ **(reserved)**	P_{cw}**- main line (not backed up)**	$P_{Tot(of,of)}$ **(reserved)**	P_{rrl} **main line (not backed up)**	$P_{Tot(rrl,rrl)}$ **(reserved)**	P_{rrlr} **main line (not backed up)**	$P_{Tot(rrlr,rrlr)}$ **(reserved)**	P_{cw} **main line (not backed up)**	$P_{Tot(cw,of)}$ **(reserved)**
Time t = 24 hours	0,992111	0,9986187	0,992111	0,9986808	0,990446	0,9985897	0,972544	0,9979280	0,992111	0,9986808
Time t = 720 hours	0,788518	0,9181856	0,788518	0,9611738	0,749762	0,9009858	0,433788	0,6530250	0,788518	0,9611738
Time t = 8760 hours	0,055532	0,0666959	0,055532	0,6176705	0,030077	0,0365963	0,0000386	0,0000477	0,055532	0,6176697
Backup communication line type	P_{cw} **main line (not backed up)**	$P_{Tot(cw,rrl)}$ **(reserved)**	P_{cw}**- main line (not backed up)**	$P_{Tot(cw,rrlr)}$ **(reserved)**	P_{rrl} **main line (not backed up)**	$P_{Tot(of,rrl)}$ **(reserved)**	P_{rrlr} **main line (not backed up)**	$P_{Tot(of,rrlr)}$ **(reserved)**	P_{rrl} **main line (not backed up)**	$P_{Tot(rrl,rrlr)}$ **(reserved)**
Time t = 24 hours	0,992111	0,9986056	0,992111	0,9712629	0,990446	0,9986808	0,972544	0,9986808	0,990446	0,9393439
Time t = 720 hours	0,788518	0,9103076	0,788518	0,4169886	0,749762	0,9611738	0,433788	0,9611737	0,749762	0,9366043
Time t = 8760 hours	0,055532	0,0518462	0,055532	0,0000476	0,030077	0,6176697	0,0000386	0,6176697	0,030077	0,1071437

The ninth case is the organization of backup of the base station and the base station controller network communication line via optical cable and repeater RRL (Figure 2.i).

$$P_I = 1 - (1 - P_{\text{of}}) \cdot (1 - P_{\text{rrlr}}) = 1 - [1 - P_{\text{rrlr}} - P_{\text{of}} + P_{\text{of}} \cdot P_{\text{rrlr}}] = P_{\text{rrlr}} - P_{\text{of}} \cdot P_{\text{rrlr}} + P_{\text{of}} \quad (22)$$

Here, the reliability indicator is when the $P_I -$ communication line is organized via an optical cable and a repeater RRL. In this case, the reliability value when the base station and the base station controller network communication line is backed up via optical cable and repeater RRL is calculated as follows:

$$P_{\text{Tot(of,rrlr)}} = P_1 \cdot P_2 \cdot P_I = P_1 \cdot P_2 \cdot (P_{\text{rrlr}} - P_{\text{of}} \cdot P_{\text{rrlr}} + P_{\text{of}}) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot [e^{-(2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t} + e^{-\lambda_{\text{of}} \cdot t} - e^{-\lambda_{\text{of}} \cdot t} \cdot e^{-(2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t}]$$
$$P_{\text{Tot(of,rrlr)}} = e^{-(\lambda_1 + \lambda_2 + 2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t} + e^{-(\lambda_1 + \lambda_2 + l_2 \cdot \lambda_4) \cdot t} - e^{-(\lambda_1 + \lambda_2 + l_2 \cdot \lambda_4 + 2 \cdot \lambda^*_{\text{rrl}} + N \cdot \lambda_{\text{rrlr}}) \cdot t} \quad (23)$$

The tenth case is the organization of backup of the base station and the base station controller network communication line via RRL and repeater RRL (Figure 2.j).

$$P_J = 1 - (1 - P_{\text{rrl}}) \cdot (1 - P_{\text{rrlr}}) = 1 - [1 - P_{\text{rrlr}} - P_{\text{rrl}} + P_{\text{rrl}} \cdot P_{\text{rrlr}}] = P_{\text{rrlr}} - P_{\text{rrl}} \cdot P_{\text{rrlr}} + P_{\text{rrl}} \quad (24)$$

Here, P_J- is the reliability indicator when the communication line is organized via RRL and repeater RRL. In this case, the reliability value when the base station and the base station controller network communication line is backed up via RRL and repeater RRL is calculated as follows:

$$P_{\text{Tot(rrl,rrlr)}} = P_1 \cdot P_2 \cdot P_J = P_1 \cdot P_2 \cdot (P_{\text{rrlr}} - P_{\text{rrl}} \cdot P_{\text{rrlr}} + P_{\text{rrl}}) =$$
$$= e^{-\lambda_1 \cdot t} \cdot e^{-\lambda_2 \cdot t} \cdot [e^{-(2\cdot\lambda^*_{\text{rrl}}+N\cdot\lambda_{\text{rrlr}})\cdot t} + e^{-2\cdot\lambda_{\text{rrl}}\cdot t} - e^{-2\cdot\lambda_{\text{rrl}}\cdot t} \cdot e^{-(2\cdot\lambda^*_{\text{rrl}}+N\cdot\lambda_{\text{rrlr}})\cdot t}]$$
$$P_{\text{Tot(rrl,rrlr)}} = e^{-(\lambda_1+\lambda_2+2\cdot\lambda^*_{\text{rrl}}+N\cdot\lambda_{\text{rrlr}})\cdot t} + e^{-(\lambda_1+\lambda_2+\lambda_{\text{rrl}})\cdot t} - e^{-(\lambda_1+\lambda_2+2\cdot\lambda_{\text{rrl}}+2\cdot\lambda^*_{\text{rrl}}+N\cdot\lambda_{\text{rrlr}})\cdot t} \quad (25)$$

The results of the calculations on the developed analytical expressions are shown in Table 2, comparing the reliability of the backup communication line over time in Figure 3. The results were based on the following values:

$l_1 = 1{,}1$ (км); $l_2 = 1{,}2$ (км); $\lambda_{\text{rrl}} = 20 \cdot 10^{-5} \left(\frac{1}{час}\right)$; N=4;

$\lambda^*_{\text{rrl}} = 22 \cdot 10^{-5} \left(\frac{1}{hours}\right)$; $\lambda_1 = 38 \cdot 10^{-6} \left(\frac{1}{hours}\right)$; $\lambda_2 = 17 \cdot 10^{-6} \left(\frac{1}{hours}\right)$;

$\lambda_3 = 30 \cdot 10^{-5} \left(\frac{1}{hours}\right)$; $\lambda_4 = 1{,}33 \cdot 10^{-10} \left(\frac{1}{hours}\right)$; $\lambda_{\text{rrlr}} = 18 \cdot 10^{-5} \left(\frac{1}{hours}\right)$.

In Figure 3, we can compare the reliability results when the base station and the base station controller system communication lines are backed up in different types.

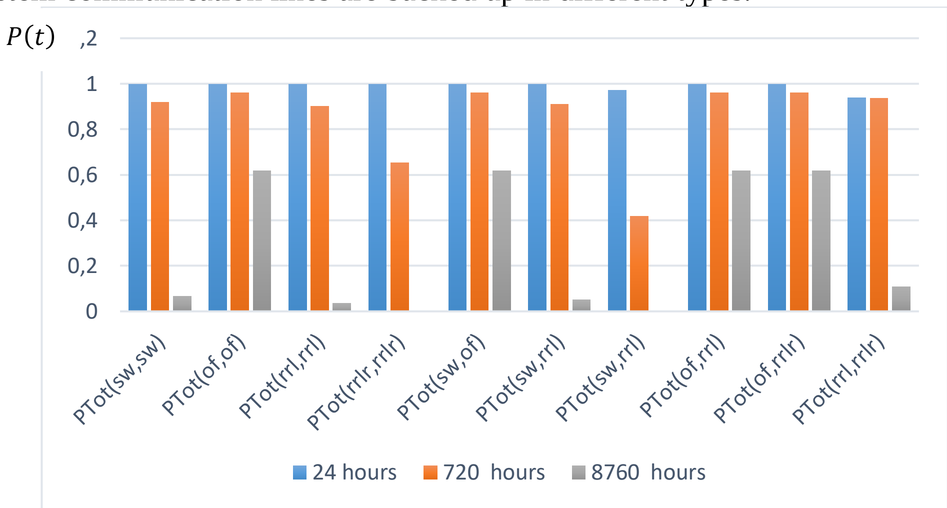

Figure 3. ***Comparison of reliability results when base station and the base station controller system backup communication lines of different types.***

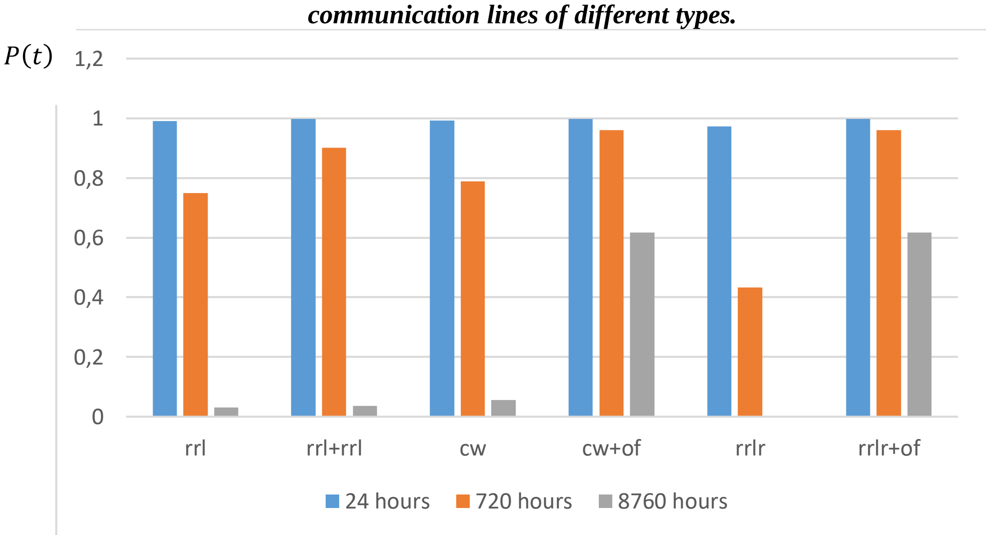

Figure 4. ***Dynamics of reliability change through base station and the base station controller system communication line backup.***

In Figure 4, we can see the dynamics of the reliability change by backing up the base station and the base station controller system communication line. In this case, it can be seen that the reliability values of the backup communication line have increased compared to the unreserved communication line.

Conclusion

The developed analytical expressions allow to calculate the reliability of the base station and the base station controller system for the following types of backup communication lines between base station and the base station controller: via copper wire cables, through optical fiber cables, through RRLs without tutors, through RRLs with tutors, through copper wire cable and fiber optic cable , communication lines formed by RRL without copper wire cable and tutors, RRL with copper wire cable and tutors, RRL without fiber optic cable and tutors, RRL with optical fiber cable and tutors, RRL without tutors and RRL with tutors.

The calculations obtained as a result of the developed analytical expressions show that the reliability results in different time intervals (24 hours, 720 hours, 8760 hours) in the base station and the base station controller system can be concluded as follows:

1. Reliability decreases with increasing number of elements in the organization of communication lines between base station and the base station controller.

2. The efficiency of using optical fiber cables is high when backing up communication lines in the base station and the base station controller range.

3. The developed analytical expressions can be used in the design of the base station and the base station controller system.

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