Optimization of data transmission system information parameters for complex technical system's state diagnosing

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Abstract

Complex technical systems are often operated in tense, abnormal conditions, with a large number of correlated parameters. Timely and high-quality diagnostics, including remote diagnostics, of complex technical systems components can increase their reliability. To successfully solve the problem of such systems trouble-free operation in abnormal operating modes, it is necessary to maximize the use of information technologies with software and hardware diagnostic modules. In order to make a reasonable choice of system's information parameters for diagnosing complex technical system's state it is necessary to solve the problems of multi-parameter, multi-criteria optimization data transmission systems. Such task aimed for increasing the speed, minimizing the error and risk of system's elements failure, and maximizing the transmitted information protection. The objective function of optimizing the information parameters of the data transmission systems for remote diagnostics is its multi-parameter optimization of the variables that affect the remote diagnostics of all system's efficiency. Solving the problem of optimizing the remote data transmission systems for remote diagnostics information parameters based on the developed model allows us to find several Pareto-optimal solutions for quality indicators, which are affecting the efficiency of the data transmission systems for remote diagnostics. Basic parameters and characteristics of the data transmission system are the optimal number of devices types for monitoring complex technical systems technological parameters, topology efficiency, throughput, speed, error of the data transmission system, the risk of component failures and the information protection effectiveness in the remote diagnostics system.

Keywords

Complex technical systems, diagnostics, information parameters, data transmission system, multi-parameter, multi-criteria optimization, Pareto-optimal solutions, throughput, error.

1. Introduction

Considering the problem of diagnosing complex technical systems (CTS), these are objects often with multimodality, uncertainty of behavior, a large number of correlated parameters, functioning in tense, abnormal modes [1–3]. The purpose of CTS state diagnosing is to improve reliability, prevent accidents that cause shutdown and damage to systems, in many cases accompanied by human casualties and damage to the environment [4-6].

2. Description of Problem

The analysis of technical solutions that improve the reliability of the CTS operation showed that timely and high-quality diagnostics, including remote diagnostics, of the CTS components can

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improve the reliability of systems and their operation efficiency [4,7]. To successfully solve problem of CTS accident-free operation in abnormal operating modes, it is necessary to maximize the use of information technology with software and hardware diagnostic modules [4,8].

These can be elements and devices in Distributed Industrial Control Systems (DICS) serving technological objects of "critical infrastructure" (energy, transport, mining and processing of minerals, communications, national security, life support systems, etc.).

The system allows combining into a single system the lower level of technological subsystems for collecting, storing, transmission and distributing information with the upper level of control, monitoring and diagnostics.

To effectively perform their functions to maintain the high quality of processes and the specified characteristics of channels and paths for transmitting technological and other information, the CTS state diagnostic system must provide [9]:

- large flows information processing generated by a significant number of controlled parameters;
- increasing the reliability and reducing the redundancy of information at its processing stages;
- the speed and functioning of the system in real time, namely, the processing of information arriving at its inputs (reception and transmission of data between system's functional elements, synchronization of the information further analysis process) at a rate not lower than the rate of events development in the CTS.

In order to make a reasonable choice of the data transmission system (DTS) topology for diagnosing, its high-quality operational parameters, it is necessary to solve the problems of multi-parameter, multi-criteria optimization of information parameters aimed at increasing the speed, minimizing errors and the risk system elements failures, and maximizing the transmitted information protection [10]. The use of well-known optimization methods for solving practical problems of multi-criteria, multi-parameter optimization [10 - 12] should take into account: large dimension of problems (tens and hundreds of variables and constraints); topological complexity of the optimized function; significant computational costs; the need to solve the problem in a multicriteria formulation, the use of unrelated models. Thus, ensuring the quality of the functioning of the diagnostic information system (including the remote one) with optimal parameters is an urgent scientific and technical problem. The aim of the work is to maximize CTS remote diagnostics system efficiency by optimizing its information parameters.

3. Data transmission system for complex technical system state remote diagnostics development

Operation of a single open platform for CTS remote diagnostics systems should be based on ISO standards in the field of "Condition monitoring and diagnostics of machines" [13]. The use of a standard base allows for the unification of approaches to obtaining information from primary measuring instruments and its transmission.

In Fig. 1 shows the block diagram of the DTS is shown for diagnosing the state of CTS in a distributed information management system.

Any ship's CTS can be selected as an object of remote diagnostics.

The remote diagnostic (RD) system consists of two subsystems, one of which is installed on the ship, the other in the cloud or the coastal dispatch center.

The main method for diagnosing the state of CTS is the collection, processing and analysis of measurement information.

In order to optimize the information parameters of the DTS system of CTS ship's state, data transmission system model shown in Fig. 2.

Information transmission is carried out based on the use of one of the standards for digital information transmission systems IEEE 802.15, WiMax, IEEE 802.22, UMTS, LTE.

The system parameters are selected in such a way as to ensure a certain level of information transmission quality.

The accumulated diagnostic data of the CTS condition is sent in the form of reports to the coastal diagnostic center.

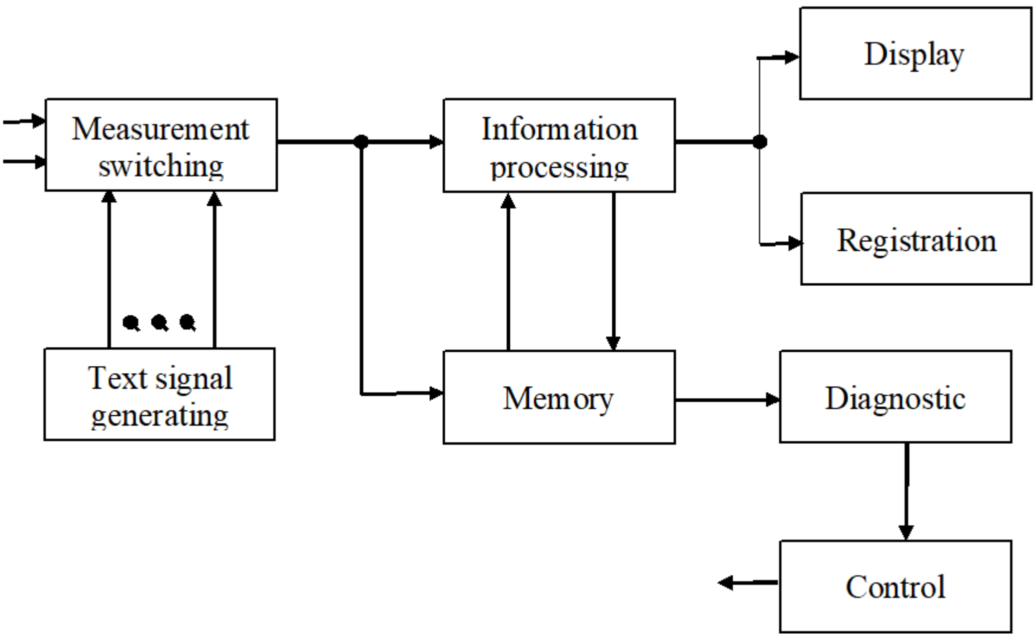

Figure 1: Block diagram DTS for diagnosing the state of CTS in a distributed information management system

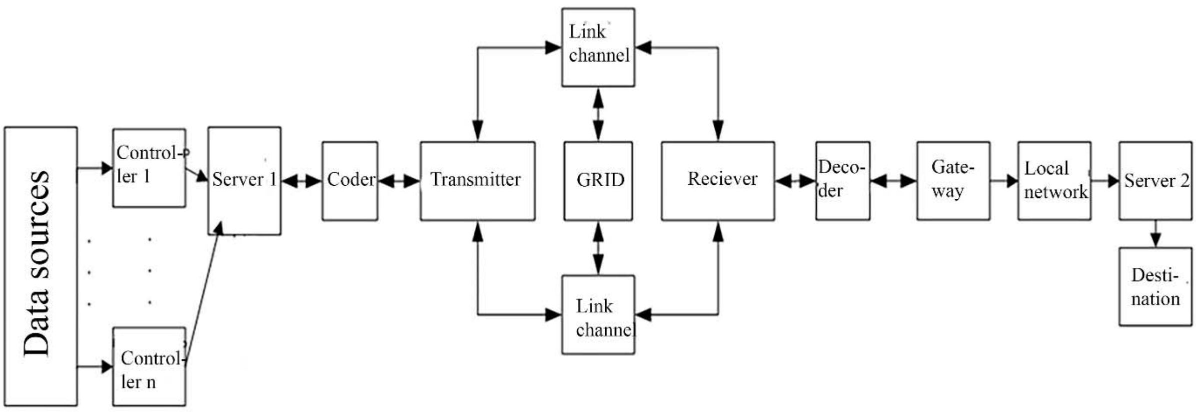

Figure 2: Block diagram of the DTS model for diagnosing the state of the ship's CTS

The quality of the DTS for RD system model is define by a set of characteristics that affect the efficiency of its operation: the topology (F_o); throughput (B); performance (T_Σ); permissible data transmission error (σ); efficiency of information protection in the system (Z_Σ), risk of DTS device failures in RD(R_Σ).

We assume that the model describing the RD system is linear, with both deterministic and stochastic lumped parameters.

The set of quality indicators of the model can be written in the vector form, the coordinates of which are particular indicators, and their specified values must be ensured (increased, improved to the desired level)

$$Q = \{\{F_0\}, \{T_\Sigma\}, \{B\}, \{\delta\}, \{R_\Sigma\}, \{Z_\Sigma\}\} \quad (1)$$

The generalized indicator of the quality of the functioning of the DTS in RD system is determined by the results of information parameters optimization, as well as its reliability characteristics. The objective function of optimizing the information parameters of the DTS in RD model of the CTS state is its variables multiparameter optimization that affect system's efficiency.

Data transmission system topology indicators optimization objective function can be presented is a such form

$$\varphi(F) = \max\ \varphi(F_o) = \max\ \varphi(\mathrm{D}, B, C)\,, \tag{2}$$
$$D = \{D_o \in D | D_{\min} \angle D \angle D_{\max}\},\ K = \{K_o \in K | K_{\min} \angle K \angle K_{\max}\},\quad C = \{C_o \in C | 0 \angle C \angle C_o\}$$

where D is length of data transmission paths;

K is compact structure of the system;

C is degree of system structure centralization;

D_0, K_0, C_0 are normalized partial criteria indicators of the system topology efficiency obtained by reducing the indicators D, B, C to dimensionless form.

Objective function of optimizing the response time of the data transmission system RD

$$\varphi(T) = \max\varphi(T_\Sigma) = \max\varphi(\sum_{l=1}^{p} T_{S_{no_i}}, T_{KO_l}, T_{C1}, T_K, T_{PD}, T_{KC}, T_{PK}, T_{DK}, T_S, T_{LC}, T_{C2})\,, \tag{3}$$
$$T = \{T_{S_{no_i}} \in T | T_{So_{\min}} \angle T_{So} \angle T_{So_{\max}}\},\ T = \{T_{KO} \in T | T_{KO_{\min}} \angle T_{KO} \angle T_{KO_{\max}}\}, T = \{T_{C1} \in T | T_{C1_{\min}} \angle T_{C1} \angle T_{C1_{\max}}\},$$
$$T = \{T_{PK} \in T | T_{PK_{\min}} \angle T_{PK} \angle T_{PK_{\max}}\},\ T = \{T_{DK} \in T | T_{DK_{\min}} \angle T_{DK} \angle T_{DK_{\max}}\},\ T = \{T_{C2} \in T | T_{C2_{\min}} \angle T_{C2} \angle T_{C2_{\max}}\},$$
$$T = \{T_K \in T | T_{K_{\min}} \angle T_K \angle T_{K_{\max}}\},\ T = \{T_{LC} \in T | T_{LC_{\min}} \angle T_{LC} \angle T_{LC_{\max}}\},\ T = \{T_S \in T | T_{S_{\min}} \angle T_S \angle T_{S_{\max}}\},$$
$$T = \{T_{KC} \in T | T_{KC_{\min}} \angle T_{KC} \angle T_{KC_{\max}}\}$$
$$\varphi(T) = \min\ \varphi(T_Z)\,,$$
$$T = \{T_Z \in T | T_{Z_{\min}} \angle T_Z \angle T_{Z_{\max}}\}$$
$$\varphi(T_K) = \max\ \varphi(n, T_L)\,,$$
$$T = \{T_L \in T | T_{L_{\min}} \angle T_L \angle T_{L_{\max}}\},$$
$$\varphi(T_{LC}) = \max\ \varphi(B_{LC}, f),\quad \varphi(T_S) = \max\ \varphi(BS, f),\ \ \varphi(T_{KC}) = \max\ \varphi(B_{KC}, f)\,,$$
$$\varphi(B) = \max\ \varphi(B_{LC}, B_S, B_{KC})\,,$$
$$B = \{B_{LC} \in B | B_{LC_{\min}} \angle B_{LC} \angle B_{LC_{\max}}\},\ B = \{B_S \in B | B_{S_{\min}} \angle B_S \angle B_{S_{\max}}\},\ B = \{B_{KC} \in B | B_{KC_{\min}} \angle B_{KC} \angle B_{KC_{\max}}\},$$

where $T_{S_{no_i}}$ is technological parameters control devices performance;

T_{KO} is controller performance;

T_{C_1}, T_{C_2} are server performance;

T_K, T_{DK} are encoder and decoder performance;

T_{PD} is transmitter performance;

T_{PK} is receiver performance;

T_{LC} is processing speed of network streams in the receiving local network;

T_S is processing speed of network packets in the receiving transit gateway;

T_Z is signal delay at redundant nodes;

f is network packet size;

B_{LC} is host local network bandwidth;

B_S is receiving transport gateway throughput;

B_{KC} is communication channel capacity;

n is code combination length;

T_L is time required to transmit the codeword.

Objective function of RD system data transmission error

$$\varphi(\delta) = \min \varphi(\delta_{S_{n0}}, \delta_{SPD}), \qquad (4)$$

$$\delta_{S_{n0}} = \frac{\delta}{X_{MV} \cdot 100}, \quad \delta_{SPD} = \frac{|\mathrm{y(t)} - \mathrm{y'(t)}|}{\mathrm{Y}}, \quad \delta = \lfloor \delta_{S_{no}} \in 0;1 \rfloor, \quad \delta = [\delta_{SPD} \in 0;1],$$

where δ is relative measurement error;

$\delta_{S_{n0}}$ are technological parameters control devices primary converters errors;

δ_{SPD} are errors arising from data loss of the data transmission system;

X_{MV} is measured value;

$y(t)$ is perfect signal;

$y'(t)$ is real signal;

Y is signal variation range;

t is signal observation time ($t_o \angle t \angle t_N$)

The task of optimizing information protection is to ensure the maximum level of security with a minimum risk from the likelihood of hacking - the data transmission system, i.e.

$$\varphi(Z_\Sigma) = \min \varphi(R_{HACK}, T_a), \quad \varphi(Z_\Sigma) = \max \varphi(N_f) \qquad (5)$$

at $N_f \geq N_{fo}$, $T_a \leq T_{ao}$, $R_{HACK} = p_{HACK} \cdot H$, $p_{HACK} = p_i \cdot p_a \cdot p_b \cdot p_c \cdot p_d$,

where R_{HACK} is multiplicative criterion of risk from the probability of hacking the data transmission system;

p_{HACK} is the probability of an information system being hacked, determined on the basis of expert data;

p_i is the probability that this information system falls into the list of possible targets and such on the information system;

p_a is the probability that the system will be selected from the list and attacked;

p_b is the probability that bordering technologies will be hacked;

p_c is he probability that attacks will intensify;

p_d is the probability that system will be harmed;

H – potential damage from information security breaches;

N_f is the number of functions that characterize the functionality of the data transmission system;

T_a is average time of access to data transmission system protection objects;

N_{f0} and T_{a0} are specified restrictions on the functionality and performance of the data transmission system.

The risk of RD structure failure is determined by the risk of CTS ($R_{S_{n0}}$) parameter control device failure, as well as the average risk of the data transmission system (R_{SPD}).

Objective function of the system RD devices failure risk

$$\varphi(R) = \min \varphi(R_\Sigma, R_{S_{n0}}, R_{SPD}, p_{S_{n0}}, H_{S_{no}}, R_i, P(S_i)) \quad (6)$$

CTS parameter monitors failure risk

$$R_{S_{n0}} = p_{S_{n0}} \cdot H_{S_{n0}}, \quad (7)$$

where $p_{S_{n0}}$ is the probability of CTS parameter control devices failure, determined on the basis of expert estimates;

$H_{S_{n0}}$ is damage from failure of CTS parameter control devices;

R_i is contingent transmission risk;

$P(S_i)$ is conditional transmission error probability.

Conditional risk in data transmission is determined by the sum of error probabilities

$$R_i = \sum_{i=1}^{m} l_{ij} \cdot p(S_j / S_i), \quad (8)$$

where S_j is erroneous signal;

S_i is original (correct signal);

l_{ij} are losses arising from an erroneous decision due to a system error;

$p(S_j / S_i)$ is error probability.

4. Experiments and results analysis

The solution to the optimization problem of the CTS state information parameters DTS in RD is based on the use of the developed optimization models. The goal is information DTS in RD effectiveness indication.

The model is designed to optimize the information parameters of the DTS in RD of CTS system in terms of the diagnostic system efficiency.

The method used, which makes it possible to study the developed model and optimize the information parameters of the DTS in state RD system, is based on the presence of many conflicting requirements for such system.

Optimal solutions to a multicriteria problem should be sought only among the elements of alternatives set. In this area, no criterion can be improved without deteriorating at least one of the others.

The complexity of solving multicriteria optimization problems is that the criteria compete with each other.

In most practical problems, the search for a more preferable solution according to one criterion leads to the fact that the solution becomes less preferable according to another criterion, i.e. solutions are incomparable.

The problem can be solved by applying the Pareto optimality principle [14,15]. The property of the optimal Pareto set is the ability to “reject” from the set of alternatives obviously unsuccessful ones that are inferior to others in all criteria.

As a result of solving the problem of optimizing information parameters, a set of alternative solutions is determined that correspond to the Pareto optimality principle and satisfy the set constraints.

The statement of the problem of multicriteria optimization includes three components, namely, the set of possible solutions, the vector criterion and the decision maker preference relation [10]. This strategy for solving optimization problems significantly differs from the known approaches of nonlinear programming, has a higher efficiency and provides significantly wider possibilities.

The sequence of the RD system information parameters optimization includes the following stages:

- determination of a set of independent parameters, as well as conditions that determine the permissible values of the variables;
- obtaining the objective function as a measure of the quality of the optimization object with the given variables;
- choice of method and solution of the optimization problem.

Thus, the formulation of the optimization problem for the information parameters of the RD system will make it possible to develop a model for multi-criteria, RD system multi-parameter optimization.

To study the model of multicriteria and multiparametric optimization of DTS in RD information parameters, one can use algorithms implemented in the free software IOSO 3.3 [16], based on the technology of constructing a response surface.

A distinctive feature of this technology is the high efficiency of finding the optimal solution in the study of the DTS in RD system, modeled at high levels of complexity and hierarchy, including the achievements of mathematical modeling (2- and 3-dimensional problems) and the ability to quickly integrate with such computational packages as ANSYS, NASTRAN, TaskFlow, Star - CD, FineDesign, etc.

The program implements an optimization algorithm that does not belong either to gradient methods of nonlinear programming, or to genetic ones.

Therefore, unlike genetic algorithms, it has a high convergence rate (the minimum required number of calls to the user model) and is characterized by the fact that:

- no starting points are needed to start work;
- the algorithm allows to successfully solve optimization problems in the presence of non-differentiability, noisiness, local non-computability of objective functions and limited parameters;
- it allows us to find several Pareto-optimal solutions within the framework of one task;
- has good ability to find the global extremum on multi-extreme problems.

The program is designed for the numerical solution of problems of multicriteria parametric optimization of complex functional dependencies in the presence of functional constraints and operates taking into account the objective functions (1) - (6). The ranges of the numerical values of the RD system quality indicators are given in Table 1.

Table 2

Ranges of numerical values of the DTS in RD system quality indicators

Level of quality	Limitations	
	Min	Max
Bandwidth (B)	10 MB/s	100 MB/s
Effectiveness of information protection (Z_{Σ})	0.95	1.0
Structure risks (R_{Σ})	0.2	0.37
Data transmission error tolerance (σ)	0.5 byte	1.0 byte

The solution to the optimization problem of information parameters DTS in RD is to find the maximum efficiency of the such system under certain states of its indicators.

In order to optimize the information parameters of the ship CTS RD system state the structure of the software for the functioning of the RD system has been developed (Fig. 3).

Data transmission system capacity is determined by the maximum bandwidth of the DTS in RD system, the receiving LAN, and the receiving DTS transport gateway.

The maximum throughput of a communication channel with additive noise is determined by Shannon

$$B = W \log_2 (1 + \frac{S}{W \cdot N}) \tag{9}$$

DTS bandwidth objective function

$$\varphi(B) = \max \varphi(W, S/N) \tag{10}$$

As an example, Fig. 4 shows the results when solving the DTS bandwidth optimization problem for W is channel bandwidth, S/N_0 is signal-to-noise ratio at the destination receiver.

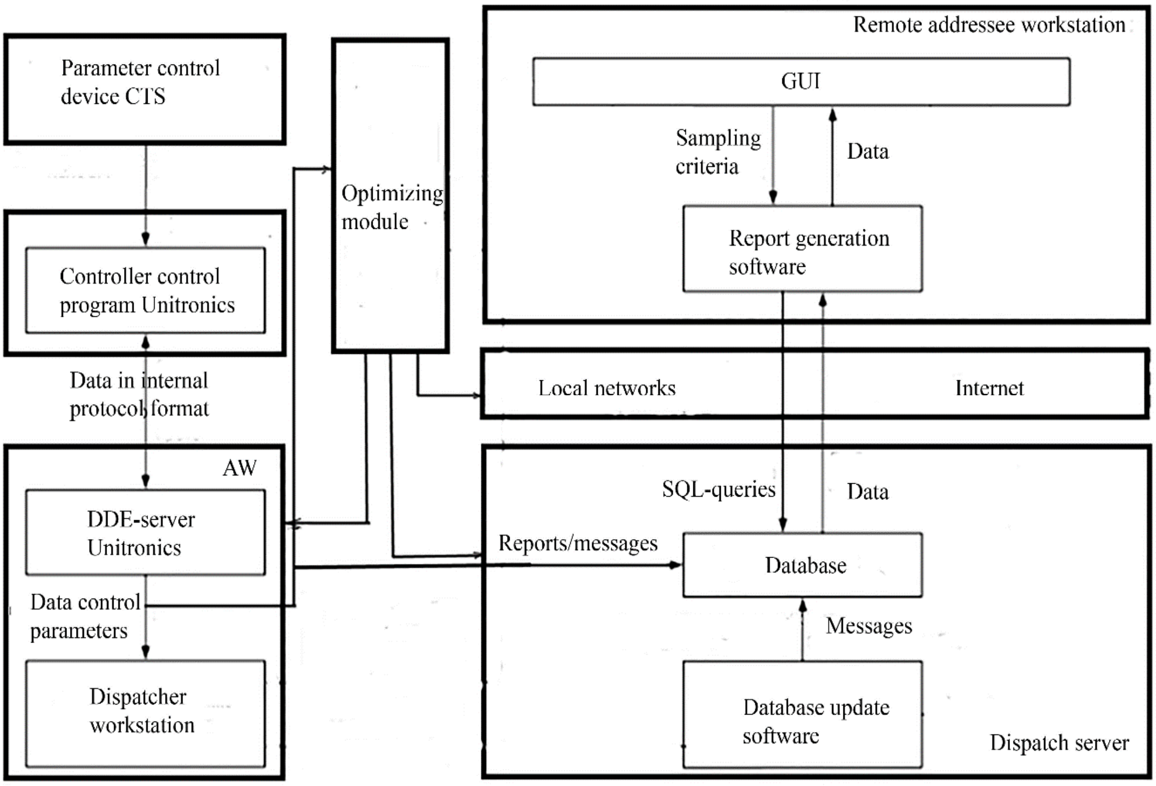

Figure 3: The structure of the DTS in RD software

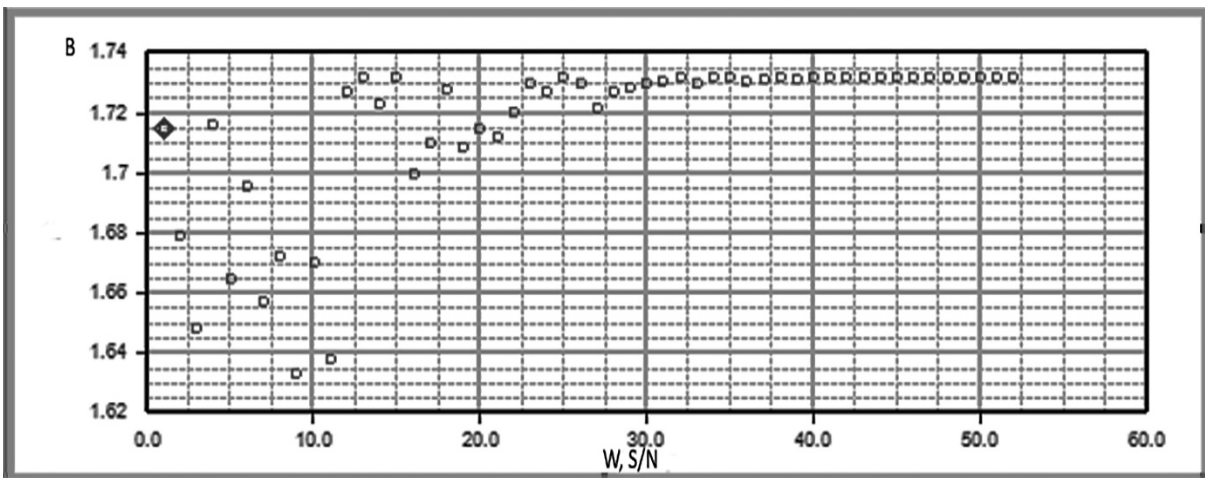

Figure 4: The set of Pareto-optimal solutions for the capacity B relative to the aggregate W and S/N

The solution to the optimization problem of the information parameters of the DTS in RD system based on the developed model allows us to find several Pareto-optimal solutions for the quality indicator (criterion) - the DTS throughput, which affects the efficiency of the RD system.

5. Conclusion

In the formulation and solution of the optimization problem for the information parameters DTS in RD of the CTS state, a set of independent parameters and conditions determining their admissible values were determined, objective functions were obtained, and a method for solving optimization problems was selected.

The developed model of optimization of information characteristics of the CTS state DTS in RD system allows:

- exclude the influence of the human factor when taking into account the CTS various technological parameters;
- generate reports on CTS states at any time for any reporting period for subsequent analysis;
- monitor the state of CTS in real time, which will avoid accidents during their operation;
- to reduce the risk of DTS in RD elements failures;
- improve the DTS efficiency.

The solution to the optimization problem of information parameters DTS in RD on the basis of the developed model makes it possible to find several Pareto-optimal solutions for indicators (criteria) of quality that affect the DTS in RD system efficiency, the main of which are: the optimal number of types of devices for controlling CTS technological parameters; topology efficiency; bandwidth; speed; system error; the risk of component failures; efficiency of information protection.

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