Comparative analysis of reliability prediction models for a distributed radio direction finding telecommunication system*

Dmitry Aminev[1], Alexander Zhurkov[2], Sergey Polesskiy[2], Vladimir Kulygin[2], Dmitry Kozyrev[1,3]

[1]V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, Moscow, Russia
[2] National Research University Higher School of Economics, Moscow, Russia
[3] RUDN University, Moscow, Russia
aminev.d.a@ya.ru,petrovyc@gmail.com,spolessky@hse.ru,vkulygin@hse.ru, kozyrevdv@gmail.com

Abstract. We consider the problem of reliability assurance of a local ground-based distributed radio direction finding system (RDFS), which consists of a local dispatching center (LDC) and unattended radio terminals (URT), which are up to several hundred kilometers apart from the LDC and are connected to the LDC via communication channels. The performance criteria of the RDFS are defined according to its topology and structure. Requirements on the mean time between failures (MTBF) and the availability factor are imposed. A methodic has been developed for determining the reliability parameters both in approximate analytical form and in the form of a formalized simulation model that takes into account different hierarchy levels of the system from the topology of the network and communication channels to the printed board assemblies and individual types of electronic components. Simulation and calculation of reliability measures was performed using an automated system for reliability calculation of electronic modules and reconfigurable manufacturing calculation (ASONIKA). The weak spots (least reliable elements) of the RDFS have been revealed and recommendations were given to ensure the reliability of individual elements and the RDFS as a whole. The composition of spare parts for LDC, URT equipment and communication channels is proposed.

Keywords: reliability model, diagnostics, radio technical system, communications network, system topology, communication channel, radio direction finding, radar, methodic, link.

1 Introduction

Despite the rapid development of global navigation satellite positioning systems, video surveillance and machine vision, radar and radio direction finding is still

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widely used at present, for the reason that in remote and underdeveloped areas radars and does not undetectable automatic direction finders (ADF) are among the main flight facilities [1].

The radio direction finding system (RDFS) is distributed over large area (fig. 1), has a multi-level star topology and consists of equipment of the local dispatching center (LDC), communication channels and unattended radio terminals (URT), which, depending on the allocation conditions can be far from the LDC up to several hundred kilometers [2, 3]. Therefore, the vital task is to provide reliable functioning of the RDFS [4] and work out recommendations on reservation of its elements.

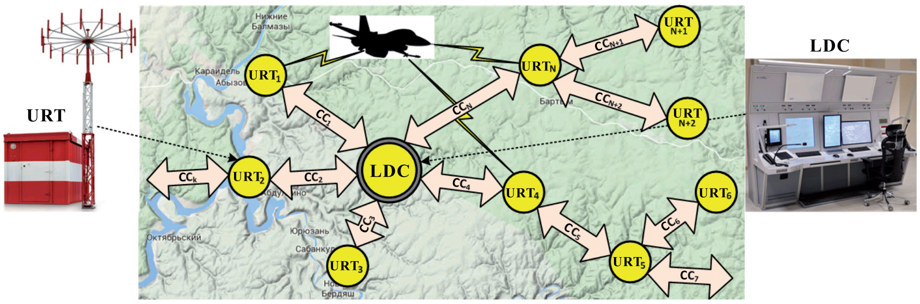


Fig. 1. Ground-based distributed radio direction finding system

As a part of solution of this problem, it is necessary to create a reliability model, for which at the initial stage it is necessary to analyze the structure and components of the RDFS, to formalize the statement of the reliability enhancement problem, to develop a method for reliability evaluation. Then it is necessary to develop a reliability block diagram, and, on the basis of an expert estimation of operational failure rates of components, to perform both analytical and numerical modeling and compare the obtained results. Based on the modeling results recommendations are to be given on the reservation of components and the composition of spare parts.

2 Structure of the distributed RDFS

Structural diagram of URT and LDC interaction is shown in Fig. 2. Automatic Direction Finder (ADF) receives signals from the quasi-doppler (QD) antenna and generates a corresponding corner bearing quadrature voltage, from which analogue phase converter (APC) forms a bearing value as a phase shift. Phase code converter (PCC) generates a bearing angle code out of the phase shift. Remote signaling (RS) device is a receiver, which indicates breakdowns (hardware temperature, fire, smoke) to the URT and performs the following functions: receives and stores in its buffer the status signals form ADF and URT hardware, generates information existence signals and transmits the RS digital code and control signals. Remote control (RC) device performs remote on/off switching of the ADF, reception and processing of ADF information in APC and PCC modules. Matching device (MD) collects code messages from the PCC, RS, RC and peripheral control unit (PCU) into a single data packet, which is transmitted to the links through the interface unit with the channel (IUC) and secondary sealing equipment (SSE). PCU monitors the performance of URT components while in operation and while performing repair or maintenance works. Secondary power system (SPS) provides power to the other elements of the scheme. Non-end URTs are equipped with a retransmitter (RT), which provides data exchange between end URTs and the LDC via CCs.

LDC hardware is designed to: collect bearing information from URT via communication channels (CC); with the help of bearing values determine the location of an object at the moment of radio contact of its on-board transmitter; provide control over URT via the CC; perform bearings membership test; display and record the air situation; perform the automated control of the technical state of URT and LDC hardware.

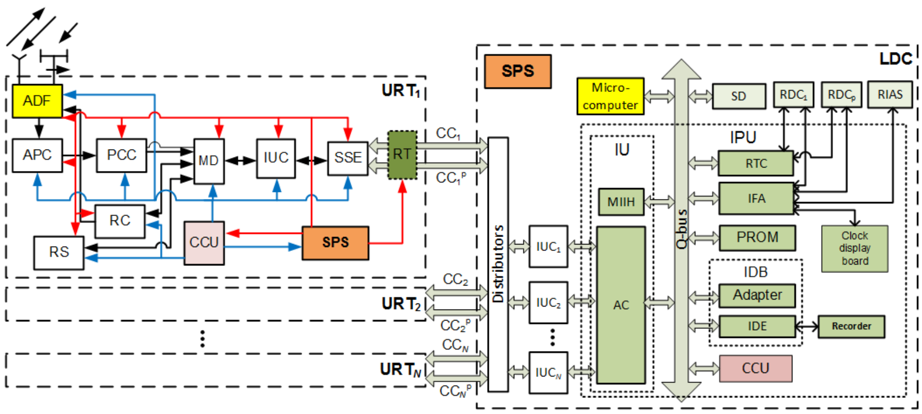


Fig. 2. Structural scheme of interaction between NSD and the TIR

LDC hardware consists of a micro-computer with management firmware, service data storage device (SD), information processing unit (IPU), the reference indicator of air situation (RIAS), remote dispatching controller (RDC), interface unit with a channel (IUC) to interact with an available communication system through distributors.

IPU is designed to: collect information on bearing and signals coming from the IUC and input it to the microcomputer; prepare the information on air situation to display it on RIAS; perform URT remote control and reception of signals; record and store the dynamic information displayed on RIAS; store service data in accordance with which the input information is conversed; perform oversight.

IPU includes an interface unit (IU), a remote technical controller (RTC), an image forming apparatus (IFA), an information documenting block (IDB), a configurable PROM and a central control unit (CCU). IU provides interface between a CC and a microcomputer, and control over the map data recording in PROM. IU consists of interfaces hardware (IH) and the map information input hardware (MIIH). IH allows to receive/transmit code messages between the microcomputer and the IUC. IDB provides (i) connection between a recording and storing device and a microcomputer; (ii) conversion of "Common Bus" interface to the "Q-Bus" interface. IDB consists of the information documenting equipment (IDE) and adapter boards. IDE operates in two modes recording and displaying. IFA is a part of the display equipment and provides: (i) interface between RIAS and a microcomputer, (ii) RIAS backup, (iii) generation of the current time code. PROM is designed for storing programs and constants, according to which the input information is transformed. Output of programs and constants is performed upon request from the microcomputer. CCU refers to the control and diagnostic equipment and is designed to provide timely information on the technical condition of LDC. The objects of control are CCU, RTC, PROM, IDB, IU. The rest of the LDC is controlled by the microcomputer's CPU. To manage the CPU control and to ensure the monitoring and diagnostic coordination between channeling equipment and communication channels, CCU has a "semi-active" access to the "Q-bus" that allows to automatically transfer data from CCU into the microcomputer for displaying it RIAS and form the microcomputer to the CCU for displaying it on its front panel.

3 Problem statement

The initial data for reliability assessment of a distributed RDFS is: its topology, LDC and URT structure, type of CC, information about operational failure rate of all printed board assemblies and communication channels, clear criteria of the system efficiency, working time schedule and operating conditions. Performance criteria of the distributed RDFS at the top level of its hierarchy are defined by the requirements for the coverage area, that is, the territory where the RDFS can determine the coordinates of an emitting object using radio direction-finders with covering radius R_{ADF} (fig. 3).

RDFS coverage area is divided nominally into 4 quadrants with respect to the cardinal directions in relation to LDC. In general case each quadrant contains URT (denoted by U on the diagram, and U* stands for intermediate URT equipped with a repeater). At that the number of URTs for each quadrant may be different — m_1, m_2, m_3, m_4.

Since the RDFS is spatially distributed, it is reasonable to consider 2 operation states working state and state of failure. While in the working state, all the RDFS units operate adequately without faults. The condition for the failure state is disability of all the URTs in at least one quadrant. Mathematically, these criteria can be expressed as follows:

$$Q_0 = \overline{\{U^1_{1\ldots m1} \& U^2_{1\ldots m2} \& U^3_{1\ldots m3} \& U^4_{1\ldots m4}\}} \times \Delta t_i, \quad (1)$$

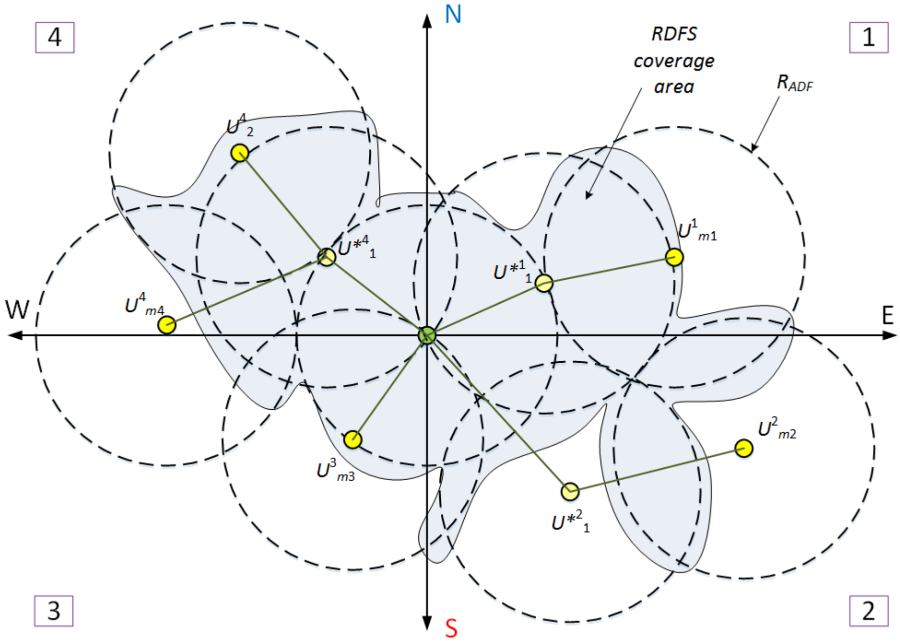


Fig. 3. Distributed RDFS coverage area

where Q_0 is a failure function, Δt_i is a time period during which the failure occurs.

Mean time before failures (MTBF) shall be at least 500 hours under day-and-night service. There can be used telegraph, telephone, radio relay, tropospheric, fiber optic and cellular communications links as communication channels. Printed board assemblies of all the system components are 170 × 200 mm in size and have an average degree of integration (20–30 elements with 2–3 microchips each). Restoration of the RDFS should be ensured through a cold redundancy (replacement of components with ones from the set of spare parts), and the restoration time τ_B should not exceed 30 minutes.

4 Reliability assessment method

We propose a reliability prediction method for the RDFS, which consists of six consolidated procedures. This method allows to carry out a comprehensive assessment of reliability measures together with analysis of the obtained results, search for the most critical nodes and release of recommendations. This reliability assessment method is represented in the form of integrated definition language (IDEF0) diagram in figure 4.

Consider the sequence of actions performed by a researcher in accordance with the described method. It includes performing the following activities:

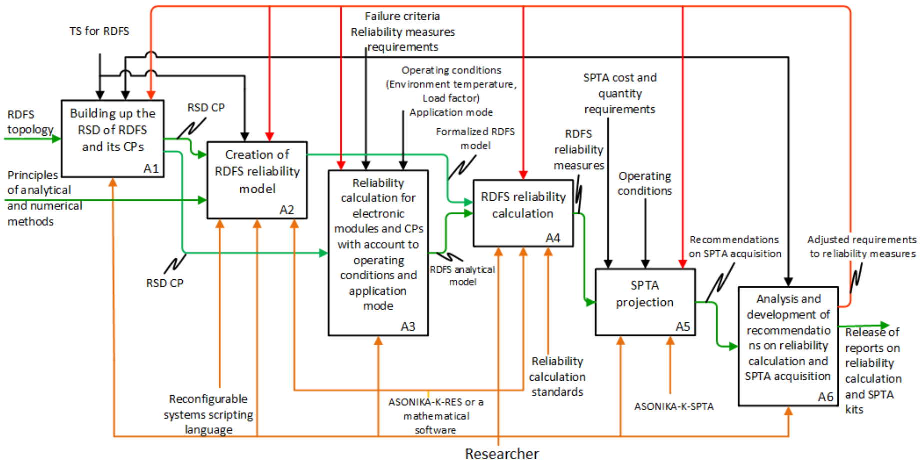


Fig. 4. IDF0 diagram of reliability assessment method

- Activity A1. Construction of a reliability structure diagram (RSD) of RDFS and its components. RSD is based on the analysis of requirements of technical specifications for the RDFS, the failure criterion, and the reliability measures requirements. The necessary data for building up the RSD are: RDFS topology, a list of system elements (specification).

- Activities A2. Building of a formalized reliability model is performed: an analytical model, formed on the basis of logical-probabilistic method; a simulation model, formed on the basis of the numerical Monte-Carlo method using a complex systems description language. The formalized model is built on the basis of RSD and the reliability measures data listed in the technical statement (TS). Rules for building the simulation model are given in [5] and for the analytical one – in [6, 8]. To avoid inaccuracies, it is recommended to build the simulation model directly in the automated system for reliability calculation for functionally complex systems - ASONIKA-K-RES.

- Activities A3. Top-down and bottom-up calculation of reliability characteristics is performed first for electronic components, then for electronic modules and components of RDFS, with account of temperature conditions, load factors and other parameters that may affect reliability characteristics, as well as with account of the average daily cycles of application modes of RDFS elements.

- Activities A4. Complex RDFS reliability calculation is performed based on the formalized reliability model, which describes the behavior of the RDFS in different states and the reliability characteristics of individual components calculated while performing functions A2 and A3, respectively, including the use of MathCad and ASONIKA-K-RES computing software.

- Activities A5. Calculation and optimization of individual, group, or multi-level [7, 9] sets of spare parts, tools and accessories (SPTA) is performed, relevant to the current configuration and operation model of the RDFS with account of the chosen replenishment strategy. The main objective of the SPTA projection is to ensure the maintainability factors which are defined for these types of RDFS. It is recommended to use the ASONIKA-K-SPTA system for the calculation and optimization of SPTA sets.

- Activities A6. A comprehensive analysis of the obtained results of the RDFS calculation is performed, including reliability assessment of the system and its elements on different hierarchy levels. Also search for critical nodes is carried out by the means of identifying ones that contribute most to the decrease in the entire system reliability as well as by comparison of the obtained data with the specified one by the TS. Besides the acquisition analysis of SPTA is done. According to the results the report documentation is released, which contains information on the on RDFS reliability and recommendations for SPTA acquisition.

5 Reliability model

Using logical connections of the operating RDFS components needed for successful system functioning (see. Section 2 and 3), the topology and structure of hardware components, as well as the basics of logical-probabilistic method, the RDFS reliability model can be represented in the form of reliability structure diagram (RSD) shown in Fig. 5

Also Fig. 5 depicts RSD of RDFS hardware components and a state diagram of the system birth-death process.

From Fig. 5 (b) we conclude that failure of any of the URT components leads to failure of the whole URT except for a failure of one of the CCs or RDC. Communication channels are cold standby connected. At that all the URT modules are in hot standby with a critical failure condition failure of $N-1$ URT modules.

Analysis of RDFS RSD (see. Fig. 5 (a)) shows that LDC failure leads to the failure of the whole complex, and failure of end and non-end URTs in each quadrant leads to the system failure only in case of failure of n out of m URTs.

It is assumed in the analytical model for reliability measures assessment that operating time and recovery time of RDFS RSD elements are exponentially distributed, and failures and repairs of RDFS elements are statistically independent events. [12]

First we consider an arbitrary separate group of redundant elements shown in Figure 5 (assume that LDC is excluded from consideration, and thus the subject of study are four areas of the reliability structure diagram). Birth and death scheme can be represented as a simple state diagram (see Figure 5 (d)), where state S0 corresponds to the absence of failures in the group, state S_1 — the presence of a failure in the group, S_i — the presence of i failures in the group, S_n — failure of the entire group (when all the elements of the group fail — both the main and the redundant ones).

Consider a sequence of four sections, each containing two groups with redundancy. Denote: λ — URT failure rate, λ^* - URT* failure rate, μ and μ^*

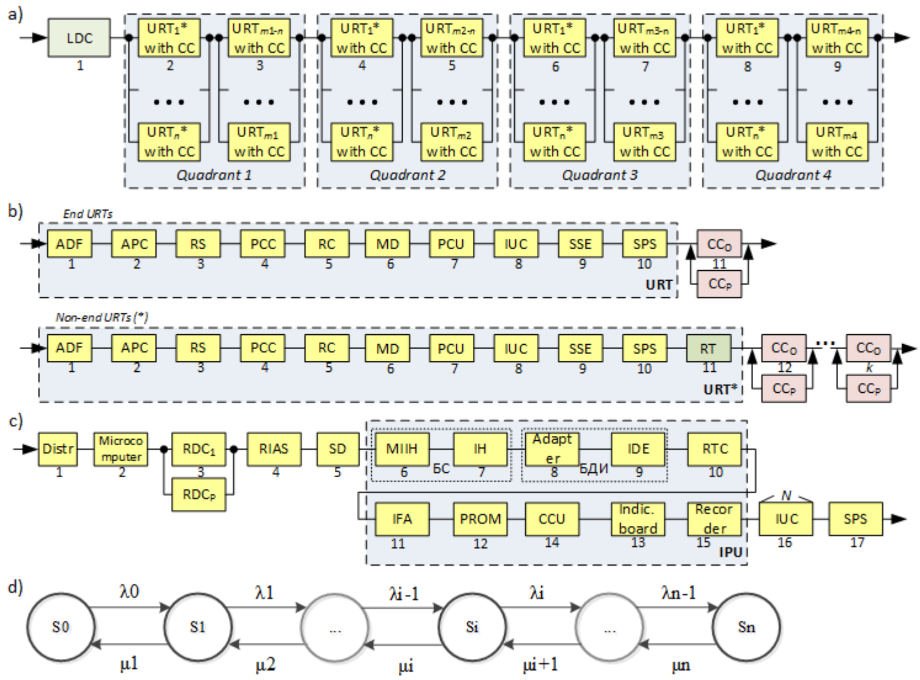


Fig. 5. RSD for topology of (a) RDFS, (b) URT complex, and (c) LDC and a state diagram of the birth-death process (d)

— corresponding recovery rates. Failure flows of redundant groups of URT and URT* are simple Poisson flows so we can use the principle of superposition. Indeed, now each state of the birth-death process in Fig. 5(d) (except for the first and last states) implies a failure either of an URT, or an URT* or a restoration of an URT or an URT*, or no changes. It is noteworthy that the situation, is taken into account when the system is in the i-th state and we consider the possible events that can happen in a short time Δt. We write an event S_i as follows:

$$S_i = A_i^{\text{URT}} \cup A_i^{\text{URT*}} \cup B_i^{\text{URT}} \cup B_i^{\text{URT*}} \cup D_i^{\text{URT}} \cup D_i^{\text{URT*}} \quad (2)$$

Failures of URT or URT* correspond to outcomes A, restorations of URT and URT* correspond to outputs B, and zero changes correspond to outputs D. According to the extended axiom of addition, we obtain:

$$P(S_i) = P(A_i^{\text{URT}}) + P(A_i^{\text{URT*}}) + P(B_i^{\text{URT}}) + P(B_i^{\text{URT*}}) + P(D_i^{\text{URT}}) + P(D_i^{\text{URT*}}) \quad (3)$$

Thus, the expression above remains valid, but now every event A, B and D should be presented as the union of the corresponding events in each section of the reliability structure diagram:

$$
\begin{aligned}
A_i^{\mathrm{URT}} &= A_{i,1}^{\mathrm{URT}} \cup A_{i,2}^{\mathrm{URT}} \cup A_{i,3}^{\mathrm{URT}} \cup A_{i,4}^{\mathrm{URT}} \\
A_i^{\mathrm{URT}*} &= A_{i,1}^{\mathrm{URT}*} \cup A_{i,2}^{\mathrm{URT}*} \cup A_{i,3}^{\mathrm{URT}*} \cup A_{i,4}^{\mathrm{URT}*} \\
B_i^{\mathrm{URT}} &= B_{i,1}^{\mathrm{URT}} \cup B_{i,2}^{\mathrm{URT}} \cup B_{i,3}^{\mathrm{URT}} \cup B_{i,4}^{\mathrm{URT}} \\
B_i^{\mathrm{URT}*} &= B_{i,1}^{\mathrm{URT}*} \cup B_{i,2}^{\mathrm{URT}*} \cup B_{i,3}^{\mathrm{URT}*} \cup B_{i,4}^{\mathrm{URT}*} \\
D_i^{\mathrm{URT}} &= D_{i,1}^{\mathrm{URT}} \cup D_{i,2}^{\mathrm{URT}} \cup D_{i,3}^{\mathrm{URT}} \cup D_{i,4}^{\mathrm{URT}} \\
D_i^{\mathrm{URT}*} &= D_{i,1}^{\mathrm{URT}*} \cup D_{i,2}^{\mathrm{URT}*} \cup D_{i,3}^{\mathrm{URT}*} \cup D_{i,4}^{\mathrm{URT}*}
\end{aligned}
\tag{4}
$$

Naturally, the question arises as to how to define the failure criterion for the whole RDFS. Consider the circuit starting from the events S_0. The system has no failures and the only possible transition can be made to the event S_1, which may represent the denial of URT or URT* on any section of reliability structure diagram. Occurrence of failure (recovery) of URT in any section of the circuit has equal probability because of the identity of elements (the same is true in respect of URT*), thus, we cannot say exactly in which section URT or URT* will fail. Further failures and recoveries will not only be interleaved with of URT or URT*, but also with sections of reliability structure diagram. Eventually, this leads us to the last condition of Sn, which is the occurrence of failure in any of the eight reserve containing groups. The logical assumption would be that the failure occurred in the group with the lowest redundancy rate, as the probability of failure of this group is higher than that of other groups.

Based on the detailed analysis of the scheme of birth and death of the complex (see. Fig. 5d) and using the spatial state method and the method of structure diagrams, we construct the analytical models for calculating the probability of no-failure operation ($R_{\mathrm{RDFS}}(t)$), availability factor (A_{RDFS}) and MTBF ($T_{0\,\mathrm{RDFS}}$).

The model is as follows:

$$
\begin{aligned}
R_{\mathrm{RDFS}}(t) &= \left[e^{-\lambda_{\mathrm{LDC}}\cdot t}\right] \times \\
&\times \left[\exp\left\{-\frac{\lambda_{\mathrm{URT}n1*}\cdot t}{\sum_{s=0}^{n}\sum_{i=0}^{s}\frac{1}{(i+1)!C_{n-s+i+1}^{i+1}\gamma^i}}\right\}\exp\left\{-\frac{\lambda_{\mathrm{URT}m1}\cdot t}{\sum_{s=0}^{n}\sum_{i=0}^{s}\frac{1}{(i+1)!C_{m-s+i+1}^{i+1}\gamma^i}}\right\}\right]_1 \times \\
&\times \left[\exp\left\{-\frac{\lambda_{\mathrm{URT}n2*}\cdot t}{\sum_{s=0}^{n}\sum_{i=0}^{s}\frac{1}{(i+1)!C_{n-s+i+1}^{i+1}\gamma^i}}\right\}\exp\left\{-\frac{\lambda_{\mathrm{URT}m2}\cdot t}{\sum_{s=0}^{n}\sum_{i=0}^{s}\frac{1}{(i+1)!C_{m-s+i+1}^{i+1}\gamma^i}}\right\}\right]_2 \times \\
&\times \left[\exp\left\{-\frac{\lambda_{\mathrm{URT}n3*}\cdot t}{\sum_{s=0}^{n}\sum_{i=0}^{s}\frac{1}{(i+1)!C_{n-s+i+1}^{i+1}\gamma^i}}\right\}\exp\left\{-\frac{\lambda_{\mathrm{URT}m3}\cdot t}{\sum_{s=0}^{n}\sum_{i=0}^{s}\frac{1}{(i+1)!C_{m-s+i+1}^{i+1}\gamma^i}}\right\}\right]_3 \times
\end{aligned}
\tag{5}
$$

$$\times\left[\exp\left\{-\frac{\lambda_{\mathrm{URT}n4*}\cdot t}{\sum\limits_{s=0}^{n}\sum\limits_{i=0}^{s}\frac{1}{(i+1)!C_{n-s+i+1}^{i+1}\gamma^{i}}}\right\}\exp\left\{-\frac{\lambda_{\mathrm{URT}m4}\cdot t}{\sum\limits_{s=0}^{n}\sum\limits_{i=0}^{s}\frac{1}{(i+1)!C_{m-s+i+1}^{i+1}\gamma^{i}}}\right\}\right]_{4}$$

where: λ_{LDC} – LDC failure rate, 1/h; t – operating time; $\lambda_{\mathrm{URT}nX*}$ – failure rate of a n-th non-end URT of quadrants 1,2, 3 and 4, 1/h; $\lambda_{\mathrm{URT}mX*}$ – failure rate of an n-th end URT of quadrants 1,2, 3 and 4, 1/h; $\gamma=\frac{\lambda}{\mu}$ – duty ratio; $\mu=\frac{1}{\tau_B}$ – recovery rate , 1/h; C_{N-s+i}^{i+1} — number of combinations; $N=n+1$ – total number of elements; n (or m) – number of redundant elements.

The model of A_{RDFS} is as follows:

$$A_{\mathrm{RDFS}}=\left[\frac{T_{0\,\mathrm{LDC}}}{T_{0\,\mathrm{LDC}}+\tau_{B\,\mathrm{LDC}}}\right]\cdot\left[\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\right]_{1}\times$$
$$\times\left[\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\cdot\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\right]_{2}\times$$
$$\times\left[\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\cdot\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\right]_{3}\times \tag{6}$$
$$\times\left[\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\cdot\left(1-\prod_{j=1}^{N}\frac{\tau_{B\,j}/T_{0\,j}}{1+\tau_{B\,j}/T_{0\,j}}\right)\right]_{4}$$

where: $T_{0\,\mathrm{LDC}}$ – LDC mean time to failure, h.; $\tau_{B\,\mathrm{LDC}}$ – LDC mean time to recovery, h.; $T_{0\,j}$ – MTBF of a j-th element, h.; $\tau_{B\,j}$ – mean time to recovery of a j-th element, h.; m – number of redundant elements; N – total number of elements.

The model of $T_{0\,\mathrm{RDFS}}$ is as follows:

$$\frac{1}{T_{0\,\mathrm{RDFS}}}=\frac{1}{\left[\frac{1}{\lambda_{\mathrm{LDC}}}\right]}+\left[\frac{1}{T_{0\,\mathrm{GR\,URT}_{n*}}}+\frac{1}{T_{0\,\mathrm{GR\,URT}_{m1}}}\right]_{1}+$$
$$+\left[\frac{1}{T_{0\,\mathrm{GR\,URT}_{n*}}}+\frac{1}{T_{0\,\mathrm{GR\,URT}_{m1}}}\right]_{2}+\left[\frac{1}{T_{0\,\mathrm{GR\,URT}_{n*}}}+\frac{1}{T_{0\,\mathrm{GR\,URT}_{m1}}}\right]_{3}+$$
$$+\left[\frac{1}{T_{0\,\mathrm{GR\,URT}_{n*}}}+\frac{1}{T_{0\,\mathrm{GR\,URT}_{m1}}}\right]_{4} \tag{7}$$

where: λ_{LDC} – LDC failure rate, 1/h; $T_{0\,\mathrm{GR\,URT}_{n*}}$ – MTBF of a group of non-end URTs, h.; $T_{0\,\mathrm{GR\,URT}_{m1}}$ – MTBF of a group of end URTs, h.

Calculation of $T_{0\,\mathrm{GR\,URT}_{n*}}$ or $T_{0\,\mathrm{GR\,URT}_{m1}}$ is performed according to the following mathematical model:

$$T_{0\,\mathrm{GR\,URT}_{n*}}\,(T_{0\,\mathrm{GR\,URT}_{m1}})=\frac{1}{\left(\prod\limits_{j=1}^{N}(1+\lambda_j\tau_{B\,j})-\prod\limits_{j=1}^{N}(\lambda_j\tau_{B\,j})\Big/\sum\limits_{j=1}^{N}\frac{1}{\tau_{B\,j}}\prod\limits_{j=1}^{N}(\lambda_j\tau_{B\,j})\right)} \tag{8}$$

where: λ_j – failure rate of a j-th element, 1/h; $\tau_{B\,j}$ – mean time to recovery of a j-th element, h.; m – number of redundant elements; N – total number of elements.

Though it is possible to build a general formalized simulation model for RDFS RSD (see. Fig. 5a) but it will be cumbersome. For that matter we give an example of a model that precisely corresponds to the topology of Figure 2 with the number of URTs in quadrants $m_1 = 1$, $m_2 = 2$, $m_3 = 3$, m_4. RSD for such RDFS is shown in Fig. 6.

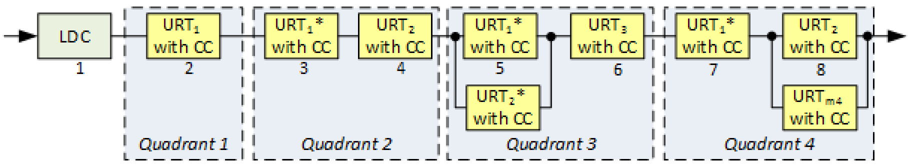


Fig. 6. RSD of RDFS with the number of URT equal to $m_1 = 1$, $m_2 = 2$, $m_3 = 3$, $m_4 = 2$

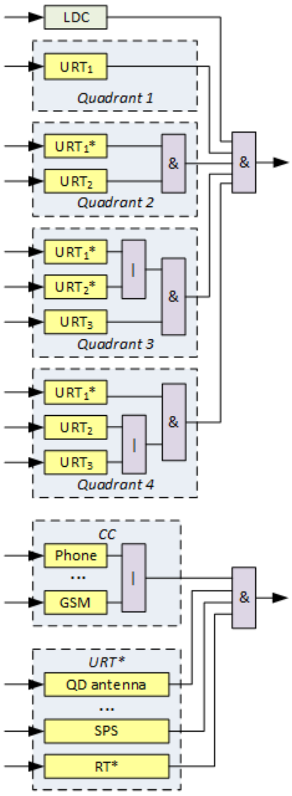
Using the description language for reconfigurable systems simulation models [5, 10], we construct a formal model of the RDFS. Its simplified form can be represented as follows:

$$F(x) = \{\text{LDC} \,\&\, n * (\text{non-end URT}) \,\&\, m * (\text{end URT}) \,\&\, \text{CC}\} \tag{9}$$

where: LDC = {Distributors & IUC & IH & ... & RIAS}; URT = {QD antenna & ADF & ... & SPS & RT (for non-end)}; CC = {Telephone | Telegraph | Radio Relay | Fiber optic | Mobile}.

Fig. 7a shows a simulation model of the upper-level of RDFS in the form of a block diagram describing the RDFS functioning in accordance with the RSD shown in Fig. 6. Based on the efficiency criteria, LDC and all four sets of URTs (for the four quadrants, respectively), are connected via a logical “AND”, which means that RDFS fail in case of failure of any of these elements.

URT* simulation model in Fig. 7a describes the URT* functioning in accordance with RSD shown in Fig. 5b. According to the URT* failure criteria, five types of communication channels connected via logical “OR” means the implementation of the reliability criterion of at least one communication channel; the output of the logical “OR” is connected with the rest of URT* via a logical “AND”, which means that the failure occurs when any of the elements or all of the communication channels fail. The initial data for the numerical model are the failure rate and the mean time to recovery, besides there are behavior patterns of components in case of failure. A fragment of a simulation model in the form of a pseudo code describing the operation of a RDFS communication channel is shown in Fig. 7b.



a)

```
distribution Dis_work_Telephone (30e-6);
distribution Dis_recovery_Telephone (const 1);
...

knot Telephone
{
state: Fail, Recovery, Work;
mode: Normal;
startState: Work;
startMode: Normal;

cntrlMode: unDistribution;

tableDistribution:
            | Normal |
 Recovery   | Dis_work_Telephone |
 Work       | Dis_recovery_Telephone;

tableStateChange:
            | Normal    |
 Work       | Recovery |
 Recovery | Work;
};
...

function FunctLines
{
 return (Telephone | Telegraph | Rad | Optic | Mobile);
};
```

b)

Fig. 7. Representation of RDFS simulation model in the form of a block diagram (a) and a fragment of pseudocode for a communication channel simulation (b)

6 Example of reliability calculation for RDFS topology

As an example of reliability calculation we carry out a comparative analysis of reliability measures of a restorable geographically distributed system using RDFS RSD topology shown in Fig. 6, using analytical models describing the reliability structure diagram in Section 5 - models (1) - (4), respectively, and the numerical simulation model (see fig. 5.) [5, 6].

All the input data for the reliability calculation of RDFS part (see. Fig. 5 b,c), namely the failure rate and mean time to repair are given in Table 1 [11]. Assume the operating time equal to 24 hours, since such systems run continuously and on a round-the-clock basis.

In numerical calculation example, the values of operational failure rate and mean time to repair for each element of the RDFS RSD were assigned with the help of analogies methods and expert evaluation.

Table 1. Operational failure rate λ and the mean time to repair τ_B of components of the distributed RDFS

No.	Group	Module	λ, 1/h	τ_B, h.	No.	Group	Module	λ, 1/h	τ_B, h.
1	URT	QD antenna	$25 \cdot 10^{-6}$	2,0	18	LDC	Distributors	$15 \cdot 10^{-6}$	0,5
2		ADF	$30 \cdot 10^{-6}$	0,5	19		IUC	$10 \cdot 10^{-6}$	1,0
3		APC	$15 \cdot 10^{-6}$	1,0	20		IH	$20 \cdot 10^{-6}$	1,0
4		PCC	$10 \cdot 10^{-6}$	1,0	21		MIIH	$40 \cdot 10^{-6}$	1,0
5		MD	$20 \cdot 10^{-6}$	0,5	22		RTC	$10 \cdot 10^{-6}$	0,5
6		IUC	$10 \cdot 10^{-6}$	1,0	23		IFA	$50 \cdot 10^{-6}$	1,0
7		SSE	$15 \cdot 10^{-6}$	0,5	24		PROM	$20 \cdot 10^{-6}$	1,0
8		CCU	$10 \cdot 10^{-6}$	1,0	25		Adapter	$5 \cdot 10^{-6}$	0,5
9		RS	$5 \cdot 10^{-6}$	0,5	26		IDE	$40 \cdot 10^{-6}$	1,0
10		RC	$20 \cdot 10^{-6}$	1,0	27		Controller	$5 \cdot 10^{-6}$	1,0
11		SPS	$15 \cdot 10^{-6}$	1,0	28		CCU	$10 \cdot 10^{-6}$	1,0
12		RT*	$15 \cdot 10^{-6}$	1,0	29		Recorder	$15 \cdot 10^{-6}$	0,5
13	Link	Telephone	$30 \cdot 10^{-6}$	1,0	30		Indication board	$10 \cdot 10^{-6}$	1,0
14		Telegraph	$25 \cdot 10^{-6}$	1,0	31		RDC1	$20 \cdot 10^{-6}$	0,5
15		Radio relay	$10 \cdot 10^{-6}$	1,0	32		RDCr	$20 \cdot 10^{-6}$	0,5
16		Fiber optic	$20 \cdot 10^{-6}$	1,0	33		RIAS	$30 \cdot 10^{-6}$	1,0
17		Mobile	$10 \cdot 10^{-6}$	0,5	34		Microcomputer	$20 \cdot 10^{-6}$	0,5

The results of calculation of $R_{\mathrm{RDFS}}(t)$, A_{RDFS} and $T_{0\,\mathrm{RDFS}}$ through analytical and numerical methods are summarized in Table 2. Also results of mutual error calculation are presented.

Verification of developed models (see. Section 5) was carried out in two stages. At the first stage modeling of standard (typical) redundant structures was carried out, for which analytical formulas are known without assumptions. According to the simulation results the measure values have been obtained with an error less than 0.5-1% relative to the analytical models, which is due to an error of a finite number of experiments. At the second stage, the calculation of reliability measures for RDFS RSD topology shown in Fig. 6 was performed. The calculation results are shown in Table 2.

To build an accurate analytical model of RDFS reliability assessment (see. Fig. 6) it is necessary to analyze 2^{18} possible states of the system, taking into account the sequence of failures, therefore we obtained only a lower-bound estimate of $R_{\mathrm{RDFS}}(t)$. The developed models allow to fully describe the algorithms and fault criteria of RDFS. To verify the models experts from RDFS developing enterprises were involved, which gave the expert confirmation of model adequacy.

There were obtained expected results for three reliability measures that can be considered closer to the truth, compared with analytical models, where admittedly the assumptions where made leading to undercount in one case and

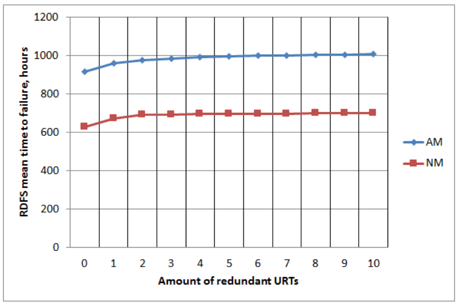
Table 2. Comparison of reliability measures of a distributed RDFS

Calculation method	Reliability measures			Mutual calculation error, %		
	$R_{\text{RDFS}}(t)$	A_{RDFS}	$T_{0,\text{RDFS}}$	$\Delta(R_{\text{RDFS}}(t))$	$\Delta(A_{\text{RDFS}})$	$\Delta(T_{0,\text{RDFS}})$
Analytical method (structure graph method)	0,9740966	0,9991321	915	2,509337	0,0232334	31,2568
Numerical method (method of Monte Carlo simulation)	0,99854	0,9989	629			

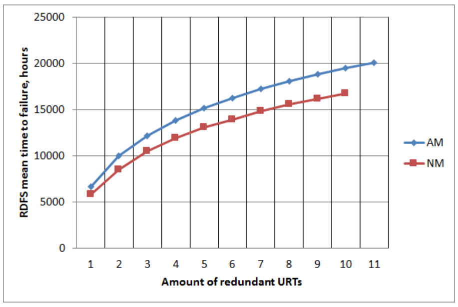
overstating in other case. For RDFS in estimation of $R_{\text{RDFS}}(t)$ the 2.5% difference was obtained, while the error for $T_{0\,\text{RDFS}}$ is 31% which is a substantial difference.

While checking the stability and correctness of analytical and numerical models is supported by figures (see. Fig. 8 a,b).

As can be seen from Fig. 8a the increase in the number of end URTs over 4 stops to give a substantial contribution to $T_{0\,\text{RDFS}}$, but the increase in the number of redundant end URTs in quadrant 2 of RDFS leads to a substantial increase of T_0 — almost 3 times.



a)



b)

Fig. 8. Plot of mean time between failures of the RDFS (a) and its second quadrant (b) against the number of redundant end URTs in quadrant 2

As for the analysis of quantitative values of parameters of reliability of RDFS, it shows the need to improve indicators of recovery through creation of an effective system of repair, namely making up a set of components by own sets of SPTA. As it can be seen from the experience of designing similar systems, the best option is a two-tier system of SPTA, while single set of SPTA is provided for URT and URT*, SPTA group kit is located near LDC. The main parameters that influence the composition of SPTA are the replenishment strategy (for similar systems the most economically efficient strategy is a continuous strategy of replenishment) and the failure rate, obtained in our case through the results of expert estimation. On the basis of this the following components will preliminary become parts of SPTA - 2 , 5, 10, 13, 14, 16, 20, 21, 23, 24, 26, 31-34 (see. table 1).

7 Conclusion

Performance criteria for a distributed radio direction finding telecommunication system (RDFS) were defined according to its topology and structure. There was developed a unified IDEF0-diagram of RDFS reliability assessment method. Comparative analysis of analytical and numerical models for RDFS reliability prediction was carried out.

A methodic has been developed for determining the reliability parameters both in approximate analytical form and in the form of a formalized simulation model that takes into account different hierarchy levels of the system from the topology of the network and communication channels to the printed board assemblies and individual types of electronic components. The analysis of both models showed that the difference in mean time to failure of the whole RDFS is significant and is not less than 31%. It is primarily due to strong assumption in analytical calculations for redundant groups with restoration contrary to a more precise description of the algorithm of system functioning and failures in the framework of numerical model. A formalized model was built for its implementation in the automated system for reliability simulation of functionally complex systems (ASONIKA-K-RES).

An optimally matched set of spare parts, tools and attachments is able to provide a high value of the system availability factor.

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