DISTRIBUTION METHOD OF THE RADIOMONITORING MEANS OF SATELLITE COMMUNICATION SYSTEMS

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Abstract: The method of distribution the means of radiomonitoring for observation data channels of satellite communications systems had been performed for consideration. The method is formalized description of the distribution process using mathematical tools of fuzzy set theory, methods of dynamic and fuzzy mathematical programming. It is intended for use in uncertain conditions when there is no clear assessment of superiority of one channel over another. The degree of importance was considered to be an indicator of channel’s advantage. It presented as fuzzy sets.

Keywords: radiomonitoring, satellite communication, communication systems, data channels.

Introduction
Satellite Communications System (SCS) for radiomonitoring are among the main sources of radio emission (SRE) (Slobodyanuk et al. 2008, p.228).

Radiomonitoring of SCS is considering as an ongoing process that implements the search and observation satellite data channels. But it is impossible to put on observation the whole set of channels at the same time because of the limited number of means. Therefore, to overcome the mentioned contradiction, means distribution by the tasks, radiomonitoring objects (RMO) and SRE is performed (Shurenok et al. 2012).

Existing methods and techniques of distribution analysis (Bondarenko and Pisarchuk, 2007; Slobodyanuk et al. 2008; Shurenok et al. 2012) showed that they have a number of drawbacks. One of the main among them is the lack of a formalized methodology that enables the distribution under uncertain conditions.

Thus, the aim of the paper is the development of distribution method of the radiomonitoring means on observation for data channels of SCS under uncertain conditions.

Method
Let us assume that the area of SCS radiomonitoring post’s antenna systems contains \( M \) satellites with channels, identified for observation. Accordingly, the set of communications satellites (CS) is \( Sp = \{Sp_1, Sp_2, ..., Sp_m, ..., Sp_M\} \), \( m = 1, M \). At each \( m \)-th satellite \( K_m \) channels were found. Thus, the total number of channels that require observation is \( K \). SCS radiomonitoring post includes \( An \) antenna systems and \( N \) radiomonitoring means, while \( N \geq An \), \( An << M \) and \( N << K \) (Shurenok et al. 2012).

A well-known approach of solving the problem of radiomonitoring means distribution for observation is to choose the variants considering the SRE importance (Gudz et al. 2013; Bondarenko and Pisarchuk, 2007). Thus, each SCS data channel can be associated with the coefficient of its relative importance \( W_{k_{Sp}} \), \( \forall k = 1, K_m \), \( \forall m = 1, M \) (Gudz et al. 2013).

Thus, it is necessary to distribute \( N \) radiomonitoring means for observation of \( K \) SCS data channels in order to cover the maximum number of objects with the most important channels.

In case if the value of the relative importance coefficients of the channel \( W_{k_{Sp}} \) is known, the method of dynamic programming is used (Kalihman and Vo'tenko 1979). However, in the face of uncertain conditions and dynamic change of the situation clear values of the input parameters are not always available.

Let \( W = \{0, 1, ..., I\} \) be the set that characterizes the channel’s importance degree, where \( I \) is the meaning of the highest importance degree. Then each channel, specified for observation, is associated with a fuzzy set \( W_{Sp} \) in \( W \), which is a set of pairs \( W_{k_{Sp}} = \{w, \mu_{W_{k_{Sp}}}(w)\} \), \( w \in W \), \( \forall k = 1, K_m \), \( \forall m = 1, M \), where
\(\mu_{w_k*}(w)\) is a membership function of \(w\) to the \(W_k^Sp\). In this case the problem of distribution can be solved by using fuzzy mathematical programming (Orlovskii, 1981; Bellman and Zadeh 1970).

The required distribution is the formation of a plan \(D_{Ob}\), which describes the appointment of a specific radiomonitoring means for observation SCS channels (Bondarenko and Pisarchuk, 2007). Obviously, there are many possible variants of \(D_{Ob}\) (Shurenok et al. 2012). Among them it is necessary to choose the plan \(D_{Ob}^*\), which will ensure the monitoring of the most important channels and the most complete SRE coverage.

According to the Bellman-Zadeh approach (Bellman and Zadeh 1970), the problem of plan \(D_{Ob}^*\) choice can be described as a multistep control process for the radiomonitoring means distribution for satellite data channels observation. Let the iterative selecting procedure of a plan being presented as invariant deterministic system with a finite number of states \(M\) (by the number of satellites).

Let’s denote the step’s number as \(t = 1, 2, \ldots, M\); \(x_t\) – the state of the system on the \(t\)-th step of iterative distribution procedure, which characterizes the number of radiomonitoring means, which remained undistributed during previous steps.

According to the procedure of dynamic programming control variables \(u_t\) in each \(t\)-th step is the number of radiomonitoring means assigned to observe \(Sp_t\) satellite channels. Let \(U = \{0, 1, \ldots, N\}\) be the set of possible control variables \(u_t\). Then the equation of state can be written in the following form:

\[
x_t = x_{t-1} - u_t, \quad t = 1, 2, \ldots, M.
\]

(1)

The observation plan \(D_{Ob}^*\) has being formed considering fuzzy constraints \(C_t\). Fuzzy sets \(C_t\) in \(W\) with a membership function \(\mu_{C_t}(u_t)\) characterizes the importance of the \(t\)-th satellite, in case that for observation after it assigned \(u_t\) radiomonitoring means. For further calculations we assume if \(u_t = 0\), then \(\mu_{C_t}(u_t) = \{1\}\), \(\forall w \in W\). Considering the definitions, we get the following expression:

\[
\mu_{C_t}(u_t) = \begin{cases} 
\max_{j=1, u_t} \left[ \mu_{w^j*}(w) \right], & \forall u_t = \{1, \ldots, N\}; \\
\{1\}, & \forall w \in W, \text{ if } u_t = 0.
\end{cases}
\]

(2)

Let the fuzzy goal be given as a fuzzy subset \(G_M^*\) in \(W\), that is fuzzy restriction on the \(x_M\) state of the system on the last step \(M\). It is formulated as: “\(w\) should be approximately equal to \(I\)” which corresponds membership function (Bellman and Zadeh 1970, p.147)

\[
\mu_{G_M}(w) = \left(1 + (w-I)^4\right)^{-1}.
\]

(3)

So the state of the system \(x_M\) can be expressed as \(x_M(x_0, u_1, u_2, \ldots, u_M)\) through solving the equations of state (1) for \(t = 1, 2, \ldots, M\). Using the rule of the fuzzy decision for the membership functions (Bellman and Zadeh 1970, p.152), it is possible to write it in the following way:

\[
\mu_D(u_1, u_2, \ldots, u_M) = \min \left\{\mu_{C_1}(u_1), \mu_{C_2}(u_2), \ldots, \mu_{C_M}(u_M), \mu_{G_M}(x_M)\right\}.
\]

(4)

It is necessary to find a solution for the problem, which is to determine the sequence of control parameters \(u_1, u_2, \ldots, u_M\) which has a maximum degree of membership to fuzzy decision \(D\), that is

\[
\mu_D(u_1^*, u_2^*, \ldots, u_M^*) = \max_{u_1, \ldots, u_M} \min \left\{\mu_{C_1}(u_1), \mu_{C_2}(u_2), \ldots, \mu_{C_M}(u_M), \mu_{G_M}(x_M)\right\}.
\]

(5)

Using the equation of state (1) the expression (5) and known mathematical transformation according to the method of dynamic programming we obtain the system of recurrence relations (Orlovskii, 1981, p.78):

\[
\begin{cases} 
\mu_{G_{M-v}}(x_{M-v}) = \max_{u_{M-v+1}} \min \left\{\mu_{C_{M-v+1}}(u_{M-v+1}), \mu_{G_{M-v+1}}(x_{M-v+1})\right\}; \\
x_{M-v+1} = x_{M-v} - u_{M-v+1}, v = 1, M.
\end{cases}
\]

(6)

As for any RMO and SRE needed to decide "whether or not to watch" a distribution procedure performs in the following manner.
Conventional optimization is conducted on the first stage. It starts from the last step because of \( x_0 = N \). Passing successively all the steps up to the first as a result we obtain two sequences of appropriate membership functions (Kalihman and Voi'tenko 1979, p.16): conditionally optimal fuzzy goals \( \mu_{G_M}(x_M), \mu_{G_{M-1}}(x_{M-1}), \ldots, \mu_{G_2}(x_2), \mu_{G_1}(x_1) \) and conditionally optimal control parameters of fuzzy restrictions \( \mu_{C_M}[u_M^*(x_M-1)], \mu_{C_{M-1}}[u_{M-1}(x_{M-2})], \ldots, \mu_{C_2}[u_2^*(x_1)], \mu_{C_1}[u_1^*(x_0)] \).

Thus, the control parameter value on the \( M \) -th step can take a value of \( 0 \leq u_M \leq N \). Considering the condition \( \sum_{t=1}^{M} u_t \leq N \), let’s take \( u_M = x_{M-1} \).

According to equation (2) for all possible values of \( u_M^* \) we calculate membership functions of conditionally optimal fuzzy constraints \( \mu_{C_M}(u_M^*) \). Using the known value of fuzzy goal at the last step \( G_M \) (3) by the system of recurrent relations (6) we can define conditionally optimal fuzzy goals \( G_{M-1}^* \) for all possible values of \( u_M^* \).

Then, for the \( M-1 \)-th step, the control parameter can takes the values of \( 0 \leq u_{M-1} \leq x_{M-2} \). According to equation (2) for all possible values \( u_{M-1}^* \) we calculate the value of membership function of conditionally optimal fuzzy constraints \( \mu_{C_{M-1}}(u_{M-1}^*) \). Using the previously found value of fuzzy goal \( G_{M-1}^* \) by the system of recurrent relations (6) we can define conditionally optimal fuzzy goals \( G_{M-2}^* \) for all possible values \( u_{M-1}^* \).

Similarly, we obtain the values of conditionally optimal fuzzy goals \( G_i \) and control parameters \( u_i^* \) for the remaining \( M-2 \) steps.

Unconditional optimization is performed from the first step. We choose optimal control parameter \( u_1^* \) to maximize the membership function of the solution using known values of membership functions of fuzzy constraint \( \mu_{C_1}(u_1^*) \), fuzzy goal \( \mu_{G_1}(x_1) \) and equation (5):

\[
\mu_D(u_1^*, u_2^*, \ldots, u_M^*) = \max_{u_1} \left[ \mu_{C_1}(u_1^*), \mu_{G_1}(x_1) \right].
\] (7)

Then we calculate \( x_1^* = x_0 - u_1^* \) by the equation of state (1). Accordingly, control parameter on the second step can take value of \( 0 \leq u_2 \leq x_1^* \). We choose optimal parameter \( u_2^* \) to maximize the membership function of the solution using known values of membership functions of fuzzy constraints \( \mu_{C_1}(u_1^*), \mu_{C_2}(u_2^*) \), fuzzy goal \( \mu_{G_2}(x_2) \) and equation (5): \( \mu_D(u_1^*, u_2^*, \ldots, u_M^*) = \max_{u_1, u_2} \left[ \mu_{C_1}(u_1^*), \mu_{C_2}(u_2^*), \mu_{G_2}(x_2) \right] \).

Similarly, we choose the optimal control parameters for the remaining steps.

**Results**

Based on the previous material distribution method can be represented as follows.

1. Conditional optimization stage.
   1.1. Determine the set of conditionally optimal fuzzy goals \( \{G_{M-1}^y\} \) and control parameters \( \{u_M^y\} \) for all possible values of \( x_{M-1} \).
      1.1.1. Choosing possible values of \( x_{M-1} = y \) form the set of \( y = 0, N \).
      1.1.2. Determine the conditionally optimal control parameter \( u_M^y \) and fuzzy goal \( G_{M-1}^y \) for chosen value:
         a) Calculating the membership function of fuzzy restrictions \( \mu_{C_M}(u_M^y) \) using (2), where \( u_M^y = y \);
         b) Repeating paragraph a) for the remaining values \( u_M^y = 0, y - 1 \);
c) Choosing conditionally optimal fuzzy goal $G_{M-1}^y$ by the membership function maximum of $\mu_{G_{M-1}^y}(x_{M-1})$ (6) and conditionally optimal control parameter $u_{M-1}^x$, that maximizes its, for variant $x_{M-1} = y$.

1.1.3. Repeating paragraph 1.1.2. for the remaining possible values $x_{M-1}$.

1.2. Similarly, repeating the procedure 1.1. to obtain the set of conditionally optimal fuzzy goals $\{G_t^y\}$ and control parameters $\{u_{t+1}^x\}$ for all possible values $x_t$, $\forall t = 1, M - 1$.

2. Unconditional optimization stage.

2.1. On the first step choose the optimal control parameter $u_1^*$ from the set of $\{u_1^y\}$ which maximizes the membership function of the solution (7).

2.2. Choosing the optimal control $u_2^*$.

2.2.1. Determine the system state on the first step $x_1^*$ after appointment $u_1^*$ radiomonitoring means on observation of RMO $Sp_1$.

2.2.2. Choosing such an optimal control parameter $u_2^*$ from the set of $\{u_2^y\}$ that corresponds to the system state $x_1^*$: $u_2^* = \{u_2 | u_2 \in \{u_2^y\}, x_1 = x_1^*\}$.

2.3. Repeating paragraph 2.2. for the choice of remaining optimal control parameters $u_t^*$, $\forall t = 3, M$.

3. Appointing radiomonitoring means on observation of CS $\{Sp_m\}$ according to the set of optimal control parameters $\{u_m^*\}$, $m = 1, M$, to the $D_{Ob}^*$ plan.

Conclusions

The distribution method of the radiomonitoring means on observation for data channels of SCS is developed. The proposed approach provides finding the rational distribution plan for the SCS radiomonitoring means and differs from the known methods by the using of the fuzzy mathematical programming and fuzzy set theory. Future research can be dedicated to the development of information system to support decision-making for the distribution of radiomonitoring means on observation for satellite data channels.

References


