Optimal configuration algorithm of a satellite transponder

M S Sukhodoev[1], I I Savenko[1], Y A Martynov[1], N I Savina[2] and V V Asmolovskiy[1]
[1] Tomsk Polytechnic University, 30, Lenina ave., Tomsk, 634050, Russia
[2] Tomsk State University, 36, Lenina ave., Tomsk, 634050, Russia

E-mail: smike@tpu.ru

Abstract. This paper describes the algorithm of determining the optimal transponder configuration of the communication satellite while in service. This method uses a mathematical model of the payload scheme based on the finite-state machine. The repeater scheme is shown as a weighted oriented graph that is represented as plexus in the program view. This paper considers an algorithm example for application with a typical transparent repeater scheme. In addition, the complexity of the current algorithm has been calculated. The main peculiarity of this algorithm is that it takes into account the functionality and state of devices, reserved equipment and input-output ports ranged in accordance with their priority. All described limitations allow a significant decrease in possible payload commutation variants and enable a satellite operator to make reconfiguration solutions operatively.

1. Introduction

The complexity and functionality of the modern satellite payload are constantly increasing. It allows increasing the payload throughput and using satellite positions effectively on the geostationary orbit. Thus, astronautics has an increasing problem concerning the scheme size of the onboard communication equipment (OCE). It is possible to specify the following factors that lead to payload structure complication:

- the number of OCE transponders;
- functional backup;
- the use of scheme with multiple frequency transformations;
- the provision of a straight and reverse communication link.

Modern satellite payload may include up to 100 transponders and each transponder can include up to 20 devices (along with switches). Therefore, payload communication matrix can increase significantly forcing the payload scheme increase up to a huge size. Hence, the manual satellite payload reconfiguration becomes a difficult task for the operator. The current paper suggests determining the algorithm of OCE optimal configuration [5]. The authors offer to consider OCE as an oriented weighted graph. Also this paper describes a mathematical model based on automata theory that allows defining criteria that should be considered during determination of the transponder optimal configuration.

2. Related work

Scientists [2] define 3 tasks arising when determining the optimal satellite payload configuration:

- Initial satellite payload configuration. This task occurs at the repeater designing stage and consists in defining of initial positions of switches for the optimal initial satellite payload configuration before satellite starts.
- Maintenance configuration. This task requires minimization of the number of switches as well as the number of their revolutions.
- Maintenance configuration with active transponders. This task arises in case of active equipment failure. When solving this task it is necessary to decrease inactive time of active channels and minimize the number of rotating switches.

The authors suggest mathematical models for each of the tasks described above. Also the paper consists of the descriptions of successful algorithms, developed by the authors. Their models allow finding all possible OCE configurations, which are not always necessary for the operator.

In article [1] other scientists suggest using the breadth-first search recurrent algorithm to search all possible ways of channels commutation. The conducted experiments showed the effective results of a small commutation network (seven switches and ten amplifiers) but it is expected that the algorithm will be limited due to a significant time increase for data processing on huge commutation network.

We should note that it is of great importance for the operator to find a single optimal solution for a specific OCE configuration state instead of all possible configurations.

3. The use of automata theory for creating a repeater mathematical model

The application of automata theory allows considering OCE as a mathematical system with input and output channels. This mathematical system can be only in one finite condition and at one discrete instant in time that allows describing the ways of its state transitions. In automata theory the notion of an abstract automaton (AA) is described by a six-component set:

$$A = (\mathrm{S}, \mathrm{X}, \mathrm{Y}, \delta, \lambda, \mathrm{s}_1),$$

where

$S = \{s_1, \ldots, s_z, \ldots, s_Z\}$ – set of states, or AA alphabet;

$X = \{x_1, \ldots, x_z, \ldots, x_Z\}$ – set of input signals, or input AA alphabet;

$Y = \{y_1, \ldots, y_z, \ldots, y_Z\}$ – set of output signals, or output AA alphabet;

δ – transition function of AA, which brings a state–input signal pair (s_k, x_f) into accord with AA state, (s_i), that is, $s_i = \delta(s_k, \mathrm{x}_f), s_i \in S$.

λ –transition function of AA, which brings a state-input signal pair (s_k, x_f) into accord with AA state (y_i), that is, $y_i = \lambda(s_k, \mathrm{x}_f), y_i \in Y$.

s_1 – initial state of a finite automaton.

The abstract automaton can be represented graphically as a “black box” that converts input signals to output ones [2].

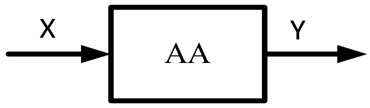

Figure 1. Graphic representation of an abstract automaton

3.1. OCE as a finite Moore machine

In OCE there are two main processes:

- transformation of the input frequency into the output one (receiving device);
- signal power amplification.

IOP Conf. Series: Materials Science and Engineering **124** (2016) 012098 doi:10.1088/1757-899X/124/1/012098

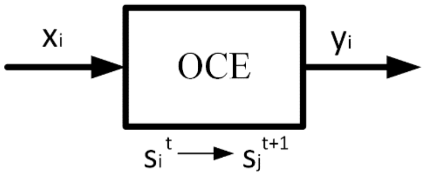

Figure 2. Graphic representation of OCE as a finite automaton

A Mealy automaton has been chosen for description of the mathematical model of the repeater as the repeater state depends on input signal sets. Switches positions and active devices states define OCE state at any moment of time.

$P=\{p_1,\ldots,\mathrm{p}_z,\ldots,\mathrm{p}_Z\}$ – finite set of switches positions;

$D=\{d_1,\ldots,d_z,\ldots,d_Z\}$ – finite set of device states (on/off);

$T=\{t_1,\ldots,t_z,\ldots,t_Z\}$ – finite set of transponders, which are determined by OCE configuration, switches positions and devices states $t_i=\{P^t,D^t\}$, where P^t – positions of switches belonging to OCE, $P^t\subseteq P$. D^t – states of devices belonging to OCE, $D^t\subseteq D$.

$$S_i=\{t_1,\ldots,\mathrm{t}_Z\}$$

Therefore, it may be concluded that the main task of transition function δ is a transponder commutation by calculating the required position of switches– P and devices states – D relatively current initial state – s_k and input frequency – x_f. Automata theory implies that only one symbol from the input set can be fed to the device input at a time. Thus, the main purpose of the transition function is to find the optimal commutation of one transponder. The optimal transponder commutation is a minimal number of switches in the transponder, that is, the power of set P^t tends to minimum

$$|P^t|\to\min$$

where P^t – the number of transponder switches.

The quantity of possible OCE states is finite and differs due to the number of switches of different types, which can take several positions depending on the type and possible states of devices. It is defined as follows:

$$n=\prod_{i=1}^{m}\prod_{j=1}^{n}s\left(p_j^i\right)$$

where m – transponders number, n – transponder devices number, p_j^i - transponder switches, s – function determining the total quantity of states of the switch according to its type.

The states transient time is defined by the turn-on time of one transponder, which is dtermined by the characteristics of the devices contained in the transponder.

Input and output sets are the sets of input and output signal frequencies defined by the repeater configuration. The output frequency, which is defined by the frequency transform function, will correspond to input frequency. This function depends on OCE configuration/state s_i. The formula considering a multiple frequency transformation is as follows:

$$x_i-\sum_{k=0}^{d}f\left(p_k,\mathrm{t}_i\right)+\sum_{m=0}^{u}f\left(p_m,\mathrm{t}_i\right)=y_i,$$

where d – the number of reducing converters belonging to the transponder, u - the number of increasing converters belonging to the transponder, p_d – frequency decreasing converter $p_d\in P^t$, p_u – frequency increasing converter – $p_u\in P^t$, f – function of calculating the converter frequency.

IOP Conf. Series: Materials Science and Engineering **124** (2016) 012098 doi:10.1088/1757-899X/124/1/012098

Modelling task is solved using an OCE design framework [2]. This mathematic model (1) allows the framework to realize the required functions, namely: calculations of the output frequency of the transponder, specifying the criteria of selection of the repeater optimal configuration, which are considered by the shortest-path algorithm described below [7].

4. Description of the shortest-path algorithm

There are many algorithms used for finding as short path as it is possible, such as the algorithms of Dijkstra, Floyd–Warshall, A*, Ant colony [4]. The most suitable algorithm is Dijkstra's algorithm.

The algorithm proposed in this paper is a particular case of the repeater reconfiguration task. The essence of this algorithm is finding the optimal configuration of a transponder taking into account the following limitations:

- use of a minimal number of transponder devices;
- working capacity and the state of onboard equipment (on, off or malfunction);
- back-up equipment
- compliance of input ports with output ports ranged according to their priority.

A program description of the repeater schema is represented as a graph and is stored in the multilinked list. It is connected with the representation of graph nodes by the full-fledged software models of the devices with their preset behaviour and properties. It allows defining the device status, its type or the switch position. The list is formed during the algorithm initialization and has algorithm complexity $O(\mathrm{n}^2)$. This list stores the object pointers, as well as the pointers to input and output devices with different degrees of connectivity. These structures are called plexuses.

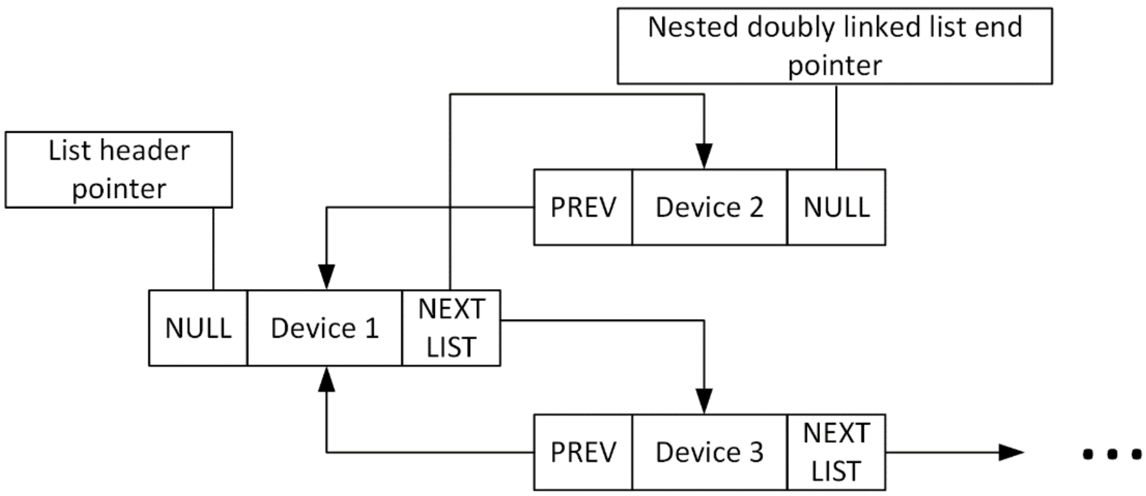

Figure 3. Graph description using plexus

This proposed algorithm uses a priority matrix to optimize the search of the transponder optimal configuration. This matrix consists of input and output ports sorted by priority.

Let us consider a repeater active scheme with an active transponder and malfunction devices (Figure 4). This scheme consists of a receiving device, filters, power amplifiers, an output multiplexer and switches allowing the repeater reconfiguration. The active transponder is marked up by a bold line, the reserved devices - by hatching, and out of service devices are marked up by double hatching.

IOP Conf. Series: Materials Science and Engineering **124** (2016) 012098 doi:10.1088/1757-899X/124/1/012098

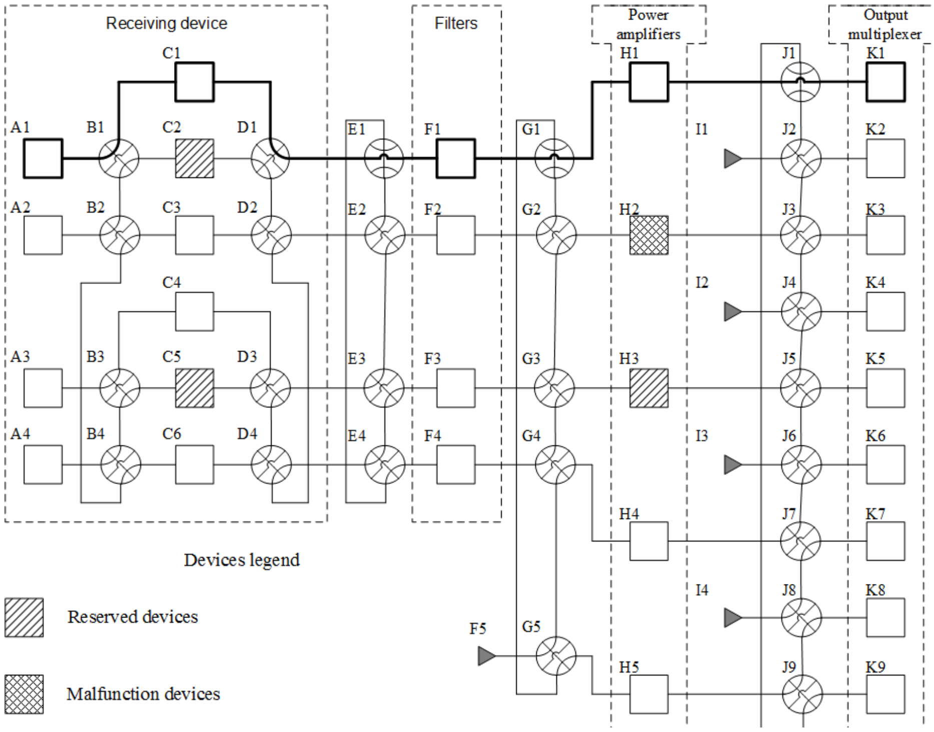

Figure 4. Example of an active scheme of the repeater

The current repeater configuration should be taken into consideration when the repeater scheme transforms into to a weighted directed graph. For this purpose it is necessary to follow the rules given below:

- all devices are marked as graph nodes;
- all possible device links are presented as arcs that connect corresponding graph nodes. At that one considers the directions, at which the signal passes in the transponder;
- the weights (lengths) of the arcs that are included into the reserved devices are set to be equal to a maximal number of switches in one matrix of switches. The rest weights are set to be equal to 1. This weight distribution provides the use of the reserved devices only in case when all possible variants of pass through the basic devices are impossible;
- the links of malfunction devices are not represented in the graph (for example, C_5 and H_2 devices in Figure 5);
- the switches, through which active transponders pass, are represented as two nodes in the graph. Their arcs are connected using the current OCE scheme configuration and state (for example, B1 switch is represented as B1.1 and B1.2 nodes connected respectively).

The weighted oriented graph corresponding to the example of the active scheme of the repeater is represented in Figure 5.

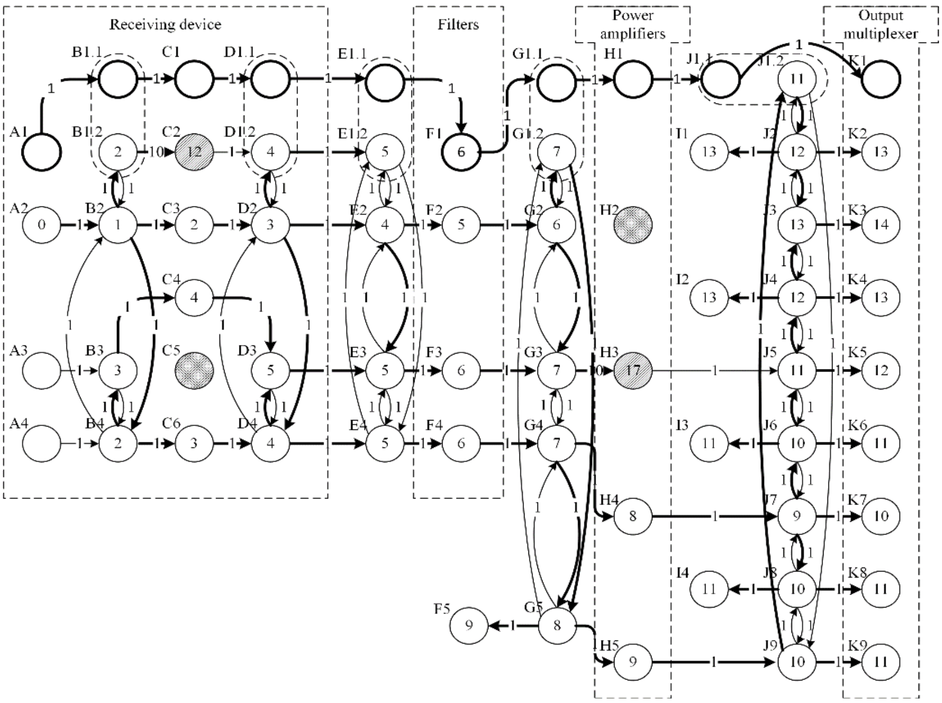

Figure 5. Weighted oriented graph corresponding to the current repeater scheme

Further, it is necessary to identify the shortest route from one node that represents an input port to all possible graph nodes. To solve this task Dijkstra's algorithm is proposed. This algorithm allows finding the shortest routes from one node to all possible graph nodes in the weighted oriented graph for arcs with positive value weight.

Thus, we can identify all possible repeater configurations for the chosen input port. Figure 5 shows the example of this solution for A2 input node. The value of the shortest route to each node is marked up in the center of each node and is graphically represented using bold graph arcs.

Further, the operator is offered to choose one of the possible transponder configurations according to the matrix of the priority output ports. This considers the current repeater configuration and devices states. In case output port K3 has a higher priority for input port A2 the possible shortest routes for the specified transponder are the following:

A2 - B2 - B4 - C6 - D4 - E4 - F4 - G4 - G5 - H5 - J9 - J1 - J2 - J3 - K3
A2 - B2 - C3 - B2 - D4 - E4 - F4 - G4 - G5 - H5 - J9 - J1 - J2 - J3 - K3
A2 - B2 - C3 - D2 - E2 - F2 - G2 - G1.2 - G5 - H5 - J9 - J1 - J2 - J3 - K3
A2 - B2 - B4 - C6 - D4 - E4 - F4 - G4 - H4 - J7 - J6 - J5 - J4 - J3 - K3
A2 - B2 - C3 - B2 - D4 - E4 - F4 - G4 - H4 - J7 - J6 - J5 - J4 - J3 - K3

Thus, the proposed algorithm complexity will be equal to $O(\mathrm{n}^2)$ at worst, and at best it will be $\Omega(n)$. It has been experimentally proven that finding the shortest route for OCE, containing about 300 devices and about 200 switches on PC with Intel Core i3 processor, is less than 1 second. This allows the operator to make prompt decisions about OCE reconfigurations or to execute it in an automatic mode.

References

[1] Gulgonul S E, Koklukaya, Erturk I and Tesneli A Y 2012 *Proceedings of the First IEEE Aerospace and Electronic Systems Society (AESS) European Conference on Satellite Telecommunications* 6400090

[2] Stathakis A, Danoy G, Bouvry P, Talbi E and Morelli G 2015 *Engineering Optimization* ***47(12)*** *1709-1734*

IOP Conf. Series: Materials Science and Engineering **124** (2016) 012098 doi:10.1088/1757-899X/124/1/012098

[3] Savenko I I, Sukhodoev M S, Tsapko S G and Simonov P K 2015 *International Siberian Conference on Control and Communications, SIBCON 2015* 7147228

[4] Savenko I I, Sukhodoyev M S, Kosmynina N A, Ryzhkov D N and Tsapko S G 2014 *Components of Scientific and Technological Progress* **19(1)** 31-33

[5] Martynova Y A, Martynov Y A, Mustafina D B and Asmolovskiy V V 2014 *Proceedings of 2014 International Conference on Mechanical Engineering, Automation and Control Systems, MEACS 2014* 6986883

[6] Teresa M Braun 2012 *John Wiley & Sons, New York, A.B.D.*

[7] Ozhiganov A A 2013 *Tutorial*