Method of optimization onboard communication network

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Abstract. In this article the optimization levels of onboard communication network (OCN) are proposed. We defined the basic parameters, which are necessary for the evaluation and comparison of modern OCN, we identified also a set of initial data for possible modeling of the OCN. We also proposed a mathematical technique for implementing the OCN optimization procedure. This technique is based on the principles and ideas of binary programming. It is shown that the binary programming technique allows to obtain an inherently optimal solution for the avionics tasks. An example of the proposed approach implementation to the problem of devices assignment in OCN is considered.

1. Introduction

At present days active research is being carried out in the field of improvement the design process of modern onboard networks built on the principle of distributed modular electronics (DME) [1]. Since architecture and avionics account 30% of the total cost of an aircraft the design of an optimal architecture is a key task [2]. Due to a non-optimal design of architecture of the aircraft's control system the optimal functioning of some processes may be reduced. In this way, in some critical cases such a non-optimal functioning of the control system may lead to the situation when some tasks significantly affecting the flight safety cannot be properly performed. The solution of such problems is an expensive task, so it makes the aircraft more expensive and less competitive.

The result of designing the architecture of the DME is the optimal (in the sense of some set of the target parameters) architecture of avionics systems for the aircraft. Modern avionics systems based on the DME architecture are characterized by the significant increase in functions as well as by the degree of system integration [3,4]. Also the developed avionics systems should be easier, safer and cheaper (from the service point of view) in comparison with the systems of previous generations. Ensure the implementation of these requirements can be done not only by developing the new hardware configuration devices of the system, but also by optimization of the avionics’ systems architecture. The objectives of designing of avionics systems architecture usually conflict with each other, e.g., the increase in reliability may lead to an increase in the weight of the aircraft. In order to take into account possible alternatives to implement the different options and create an existing avionics architecture in the design it is advisable to use an approach based on the mathematical modeling and modern computer technologies.

2. Levels of architecture’s optimization for OCN

After collecting the available data the architecture design process begins. The architecture design of the onboard information-processing network is carried out at three levels [5]. At the first level all the
available requirements for the architecture of the onboard computing network are taken into account. First level contains:

1) Assigning devices. Distributes devices among installation sites. The initial data is a set of device types and a set of installation locations.

2) Assigning tasks. Provides an unambiguous assignment of tasks to devices. Tasks can be assigned to the device if the device has sufficient resources of each required type, and if the corresponding type of device may accommodate this type of task.

3) Assignment of peripheral wires. It is a laying of peripheral wires from equipment that is not related to the DME system, to DME devices inside the structure of aircraft installations.

4) Assignment of communication lines. Provides a minimum weight of communication lines. In addition to the structure, the initial data is a set of devices and communication lines, as well as the topology of their connection.

5) Assignment of signals (virtual links) to communication lines. The initial data is a set of transmitted signals, the topology of devices and communication lines, as information on the distribution of tasks.

At the second level the optimization of the onboard computing network is carried out and the device types are optimized (in accordance with the necessary resources) taking into account the data of the first level. First level contains:

1) Optimizing device types. It carries out the coordination of tasks and devices. Based on a set of potential device types, it is determined how many devices of what type should be used in which locations. During this process tasks are assigned to specific devices.

2) Network optimization. The process of synchronous determination of network topology, cable routes and signal transmission paths. The initial data is a set of all signals and their resources, performance and security restrictions, on the one hand. On the other hand it is the properties of communication lines and switches, for example, the bandwidth and the number of ports.

At the third level the optimized DME architecture is created. Creates the architecture of the DME based on the requirements of the systems and the aircraft. The calculation is based on a model of systems which includes all tasks, signals, as well as their resources and security requirements. Based on this data, a set of devices, locations and a connection network are defined in parallel with the assignment of all tasks and signals.

3. Mathematical technique for optimization of OCN

Integer programming is chosen as the main mathematical technique for optimization in the avionics problems. Integer programming is a discrete analog of linear programming (LP). Most of the problems listed above can be formalized in the form of problems of such a type. The main purpose of the linear programming is to find the vector of \( n \) variables \( x^{LP} \), which minimizes the linear target function \( f \) [6]:

\[
f^T x^{LP}
\]

taking into account that

\[
Ax^{LP} \leq b \tag{2}
\]

\[
x^{LP} \in \mathbb{R}^n_+
\] \tag{3}

An integer program (IP) is obtained by limiting \( x^{LP} \) up to integer values.

In the particular case \( x^{IP} = x^{BP} \in \{0,1\}^n \) the problem of binary programming (BP) takes place. It is defined as minimization of

\[
f^T x^{BP}
\]

taking into account that
The BP problems have the same degree of algorithmic complexity and can be solved using the same methods as the IP tasks. The proposed approach is not unique, namely the numerous examples of the application of heuristic algorithms (various modifications of the genetic algorithm, the algorithm of the ant colony, etc.) are well known. However, these algorithms have significant drawbacks. The main drawback of heuristic algorithms is the lack of standard approaches. Each task requires a unique solver and the selection of such a solver can only be carried out by a highly qualified expert. Heuristic algorithms require the configuration of a large number of parameters and cannot use the information on the gradients, which reduces their capability to solve the classical optimization problems.

4. An example of the implementation of a mathematical apparatus

As an example let us consider the level of assignment of devices that are mentioned above [7]. In order to solve the problem of assigning the devices using the BP methods the device positioning scheme in the installation sites is represented as a binary vector

\[ x_i = \begin{cases} 1 & \text{if device is assigned to the installation site} \\ 0 & \text{if it is not assigned} \end{cases} \]

Each element of the vector \( x_i \) represents a possible arrangement of devices, namely a special installation site that has sufficient resources to accommodate one device of this type. The characters above \( x_i \) represent the combination of the device \( D_j \) and the installation location \( J_k \). The element of the vector \( x_i \) is equal to «1», if the device \( D_j \) is assigned to the installation site \( J_k \) and «0», if it is not assigned. The number of all possible distribution options for a single device \( |x^D| \) is determined by the length of the vector \( x \), which is the dimension of the search space. However, this includes the solutions that do not assign a device to any installation site or assign it to several locations at once. A single-valued assignment is achieved by means of an additional equality (where \( D(i) \) is a device inscribed over \( x_i \)):

\[ \sum_{i \in \{1, \ldots, |x^D| \}} x_i = 1 \]

for each device \( j \). For all devices this expression is represented as a constraint matrix in the form of equality:

\[ A_{\text{single}}^{eq} = \begin{pmatrix} \begin{array}{cccc} D_1 & \ldots & D_1 & \ldots & D_{|D|^2} \\ 1 & \ldots & 1 & 0 & \ldots & 0 \\ 0 & \ldots & 0 & 1 & \ldots & \vdots \\ \vdots & & \ddots & \ddots & \vdots \\ 0 & \ldots & \ldots & \ldots & 1 & \end{array} \end{pmatrix} \begin{pmatrix} D_1 \\ D_2 \\ \vdots \\ D_{|D|^2} \end{pmatrix} \]

The right-hand side of the constraints is:

\[ b_{\text{single}}^{eq} = \begin{pmatrix} 1 \\ \vdots \\ 1 \end{pmatrix} \begin{pmatrix} D_1 \\ \vdots \\ D_{|D|^2} \end{pmatrix} \]

In addition, assignments that exceed the resource limits for any installation location are unacceptable. This is expressed in the form of inequality:
\[
\sum_{i=1}^{k} \rho_{\Phi_j}(i) x_i \leq \rho_{\Phi_j}^k
\]  
(11)

for each type of resource \( \Phi_j \), which is available on site \( J_k \), where \( \rho_{\Phi_j}(i) \) is the amount of site resources that are involved in a corresponding destination \( i \), \( \rho_{\Phi_j}^k \) is a number of resources, \( \Phi_j \) is a type of resources, which installation site is \( J_k \).

Constraints on the installation site should be taken into account before the optimization process begins. Undesirable combinations of devices and combinations of installation locations are deleted from the solution vector, so the search space narrows.

5. Optimization parameters for OCN architecture

The final architecture must be guaranteed to meet all the necessary requirements.

The main parameters of optimization of architecture are [8-13]:

1) Delivery guarantees and messages delivery time. For each type of aircraft, there are message sets that are important to deliver as quickly as possible. The loss or delay of such messages can lead to disaster.
2) The number of resources. Increase in number of different types of devices, increases the development costs, the initial provision, the administrative costs as well as the maintenance costs.
3) The mass of devices in the architecture. This parameter has a great influence on the fuel consumption, and on the efficiency of the aircraft, consequently.
4) The cost of architecture. The aircraft manufacturer expends these funds on equipment for the creation of an aircraft.
5) Restriction on the energy consumption. The more energy is consumed by the avionics system, the less energy remains for other purposes, or more energy needs to be generated, which increases the fuel consumption.
6) The space required by the avionics system on the board. This space is occupied by devices and cables in the frame of DME system. The maximum amount is limited.
7) Reliability and redundancy [14].

6. Conclusion

The main difficulties encountered by the developer in the layout of the DME system are:

- Resource constraints.
- Restrictions by the safety.
- Bandwidth limitations.
- Limit by size, etc.

Also, during the optimization of the architecture the additional conflicting goals lead to additional complexity. A large number of functions and hardware components create a variety of possible architectures that are difficult to estimate manually. For example, for the distribution of 20 functions between the five devices, there are several million combinations. Real architectures have 1000 functions distributed among 40 devices. At first, all the evaluated architectures should be checked for compliance with restrictions that reach several thousand. In this way the subset of the permissible architectures should be placed inside the set of architectures with the inherently performed restrictions. And finally, a large number of goals from different areas (partially contradicting each other) makes it difficult to choose the final architecture. The approach discussed in this article is based on the BP model which helps to keep track of the targets at any change in the architecture. Advantages of the proposed approach are:
– obtaining the optimal solution;
– avoiding the probability of unpredictable behavior (by full search of options);
– a large number of ready-made standard software products for which it is necessary to change
  the posing of the problem;
– software versatility (the problem being solved is described separately from the solution
  algorithm).

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