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A Systematic Approach for Evaluating Satellite Communications Systems

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Abstract

The aerospace environment imposes straight operative conditions so every electronic system usually needs to be validated for these. The same way, communication systems need to be evaluated before their introduction in aerospace applications. In the paper we present a new methodology for the evaluation of communication systems in space applications. The methodology aims, by abstraction, at identifying all the critical aspects for the evaluation and at defining a standard and reusable framework in order to be applicable to any Communication Systems. The methodology has been applied for the evaluation of three Data Bus for satellite communications: 1553, 1-Wire and Profibus DP RS 485 based systems have been analyzed and evaluated[1].

1. Introduction

The high level of criticality and completeness demanded by industry in the aerospace field requires the identification of an evaluation methodology able to validate aerospace-designed systems with high accuracy, and to analyze those scenarios that may potentially impact their correct behavior. It is a matter of fact that the larger part of industry costs are represented by development expenses in validation and testing [1].

Satellites make large use of electronic devices with strong requirements in terms of physical space constrains, and tolerance to radiations, vibrations, faults, and shock. In order to efficiently analyze potential sources of hazard in this type of systems, it is mandatory to identify all the electrical and environmental conditions that may influence their behavior.

While the influence of these environmental factors is not always deducible a-priori using a theoretical approach, it may be possible to provide proper tools allowing to better understand the impact of a set of factors over the system, or a sub-part of it.

Several studies propose different solutions for validating communication systems in satellites and avionics, developing methods for the verification at different abstraction levels: from the electrical and physical level to the protocol level, [1] [2]. The main drawback of these solutions is that they are mainly application dependent (e.g., terrestrial, avionics, space, etc.). Thus, the definition of an application independent methodology allowing the evaluation of a communication system at all abstraction levels, including the system level, is still a challenging problem.

In this paper we propose a new methodology for the analysis and validation of communication systems. It is based on the abstract definition of critical aspects of the system and the identification of the potential impact factors on them. The framework is studied to have modularity properties that are very useful whereas the evaluation will need different approaches. Moreover, the abstract approach allows the methodology to be scenario independent.

This paper is organized as follows: Section 2 overviews the proposed methodology and a complete description of its abstraction level is provided. In Section 3 the methodology is described, step by step, to show the entire workflow. Section 4 shows the experimental results when the methodology was applied for the validation of three commercially available communication channels, namely 1553 Data Bus, 1-Wire and Profibus Decentralized Periphery (DP) RS485, [3] [4] [5]. Section 5 concludes the paper giving some future perspective of the methodology.

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[1] This work has been made in collaboration with Thales Alenia Space for the validation of communication channels to be used in a satellite. The target systems are described above in the paper.

2. Methodology Work Flow

For validation purpose, a generic *Communication System* can be modeled as a grey box containing a set of *Inputs* and a set of *Outputs* (the *System Grey-Box Structure* in Figure 1). The *Inputs* represent the set of controlling factors, internal or external at the system that may in turn influence the system behavior, e.g. environmental temperature, power supply voltage, etc., whereas *Outputs* represent the set of characteristics that are controlled or influenced someway by the inputs (all or a subset of). The way in which they are controlled or influenced can be available or derived by different.

Hereinafter, we will refer to inputs as *Impacting Factors (IPs)* and to outputs as *Features* (*Fs*), (Figure 1).

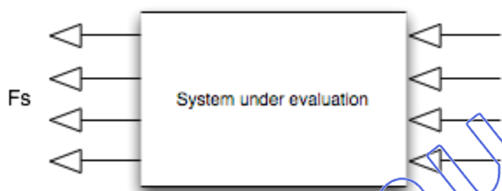

Figure 1. System Grey-Box Structure

The goal of the proposed validation methodology is to provide users a medium to understand how different Impacting Factor may influence the System under evaluations in terms of influence of the considered features. The proposed methodology is composed of several sequential steps, as follows:

1. *Selecting the target Communication System*. The communication system has to be properly defined in terms of standard, used devices, etc.,
2. *Gathering all the Features*. Features are extracted by analyzing the system and by carefully defining the aspects of the system that need to be validated. They can be clustered in classes that do not depend on a particular communication channel;
3. *Identifying all the Impacting Factors*. Using system designers experience and the system documentation (like the communication channel standard, the target application, etc.) the Impacting Factors are identified;
4. *Defining how each Feature may be influenced by IPs*. Each feature F is investigated to define how it is influenced by a subset of IPs;
5. *Defining how Impacting Factors and Features shall be evaluated*. Practical considerations on how the measurement campaigns have to be performed are made in order to obtain a scientific and structured way of work;
6. *Performing the Measurement Campaigns*. Once the campaigns are defined, they are made and all data is collected for the further evaluations.

3. Methodology Description

In this section we exploit the methodology, step by step, in order to show how it was design for. We focus on terminology definitions and abstraction strategies.

3.1 Features and Impacting Factors identification

The identification of Features and Impacting Factors, as described above, requires a deep analysis of the target system and scenario. Resorting to the system gray-box structure, the analysis has to be performed by gathering all the possible characterizations and constrains from channel specifications, designer guidelines and data sheets. The IPs are mainly derived from considerations strictly connected with the operative conditions. Furthermore, system's designers experience is very useful to achieve a correct IPs definition.
Features are chosen only if they can be monitored: when a Feature is found, the range of values it can assume has to be provided. Maximum, average and minimum nominal values shall be gathered, along with the absolute maximum and minimum values that are the critical operational values of the system.
Impacting Factors are selected typically by experienced analysis of the system and scenario. Every aspect that may modify the system behavior and its responses may be an input of the system. In this context, IPs are suitable for the definition of a *typical or maybe unexpected (but estimated) factors that can occur during the operations of the system in a given scenario*.
Theoretically, a feature doesn't influence other parameters of the system. If it would be found that a feature has impact on other features, this will mean that it is an impacting factor. This aspect shows the flexibility of the methodology.

3.2 The influence functions definition

Once Features and Impacting Factors are gathered, it is still missed any kind of information about their relationships. We can make hypothesis about the influence that every IP has on each F that may derive from the designer experience and from other considerations. We resort to a simple mathematical representation of the relationship between the F and the IPs by meaning of an *influence function*, as follow:

$$F_i = F_i(IP_1, IP_2, \ldots, IP_n)$$

Each feature F_i is expressed as a function of a subset of potential IPs. Each subset may be strictly connected with the scenario in which the system shall operate (environmental conditions, electrical factors, communication issues etc...). These conditions may be heterogenic so it is important to verify the feasibility of the validation under that particular condition. If that measurement is not feasible (for example because it is not possible to simulate the external orbital conditions of a system in a satellite) the IP shall be eliminated.
It can be easily noticed that the influence function is a n-dimensional function in its input space so it looks preferable identifying proper sub-spaces, or *target projections* of interest. In other words, a *target projection* is an influence function in which a subset of IPs is taken as fixed value and only few remaining IPs are free. Thus, each projection will require a target measurement campaign, aimed at providing the required set of data.
The identification of the target projections is made specifying the values the other IPs must assume. Target projections must definitely concern, among the others, Features and Impacting Factors that impacted on the selection of the current Communication Channel as a potential candidate for space applications.

3.3 Measurement Campaigns

Target projections identified in previous, have to be planned for measurement campaigns by definition of *Test Plans*, in order to gather experimental data. A *Test Plan* is created specifying the range of values for each IP to be considered, the measure granularity and how to perform the measures. It has to be expressed in terms of:

- tools to be used;
- methodology to grab measures;
- number of time the measure has to be repeated.

Finally, the Test Plan requires also the Wall time and Manpower estimation.
Now, for each target projection additional information is provided, since the test plan developed for the target projection contains all the details to perform the measurement campaign. Moreover, each target projection offers a view on a restricted portion of all possible aspects of the relationship between IPs and Fs. Hence, resorting to projections and their test plan, the evaluation process is someway clustered.
After the measurement campaigns are done a result analysis can be performed then a proper evaluation function may be defined. At this step, a key point is the definition of the strategy to properly collect the experimental data. The better the data is collected and organized the better it can be analyzed and used.
What is expected from the evaluation process is to derive a proper set of design requirements as a set of mandatory constrains to be followed when using the selected communication system in the field of interest and in the environments considered with respect to the IPs involved in each scenario. Furthermore, the evaluation gives the important advantage of easily derive a set of design guidelines, suggestions or recommendations aiming at improving some feature of the selected Communication System.

4. Experimental Results

The presented methodology has been applied to three communication channels: MIL-STD 1553, 1-Wire and Profibus DP RS485 Data Buses. They need to be investigated to use in space and avionics applications.
MIL-STD-1553 describes a 1 Mb serial network [3]. It includes the definition of a physical layer and a message level protocol. Since its development in the 1970s, it is mainly used in legacy avionics, power, sensor and control systems [6]. There are two variants of 1553, the A version and the B version. The differences between the variants are minor but actually all systems should be using 1553B.
Profibus DP is the most popular type of fieldbus with more than 14 million nodes (2006) in use worldwide [7]. In Europe it dominates with more than 60 % of the factory automation market. Profibus is designed for high-speed data exchange and only the Physical Layer and Data Link Layer are specified [4].
The 1-Wire technology uses a single wire (ground referenced) to accomplish both communication and power transmission. Its peculiarities define the 1-Wire bus as a low cost communication channel, mainly used for sensors networks [5].
Following the first steps of the methodology, it was possible to build a complete list of functionalities of the data buses and to describe them in terms of features and impacting factors.
We were able to detect different classes of features after a deep analysis of the specifications, by applying a the system grey-box structure at the data bus opera-

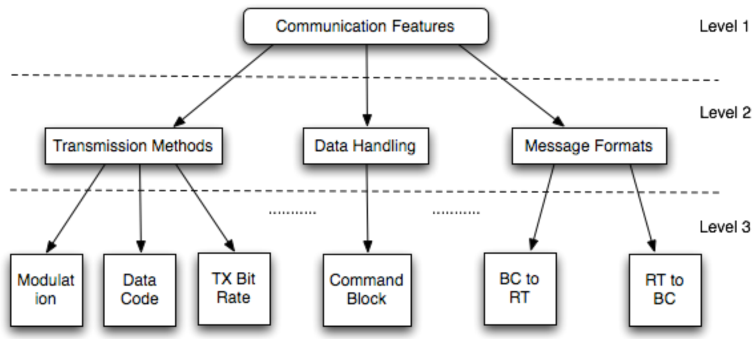

Figure 2. MIL-STD 1553 Features

tions. Features were hierarchically classified, for convenience, starting from a common, easy to understand, top-level domain (electrical features, communication features, dependability features and so on). For each class of features we identified the subsets of low-level features, as we were able to find them on the documentation. Obviously, we found that the more the data bus is used commercially, the more the description in terms of features is well done.

The impacting factors were identified during brainstorming sessions by considering all the possible variables that may impact on the system. So, the satellite system designers can have a key role in defining IPs and collecting their significant values. The same way of features, it was possible to identify hierarchical classes of IPs that may impact on the functionalities and features of the data bus. In order to provide some example, these IPs include subsystem frequency, physical layout of the bus, network typologies, environmental conditions, fault tolerances and so on. For each class of IPs we identified the more specific factors derived from the constrains imposed by the satellite application. For example, the satellite environmental conditions can impact on the data bus in a satellite and they were identified in: operating temperature variations, radiations, EMC, vibrations, humidity and so on.

Figure 2 provides an example of the structure for the 1553 Data Bus features. It exploits some of the Features in the Communication class (first level of the diagram). To simplify we have shown only a subset of the features gathered.

The hierarchical organization of features and impacting factors was used to interconnect the two structures as explained in Section 3.2. Resorting to influence functions (that we omit here for simplification) we connect the impacting factors to the feature they are suppose to influence to. Thus hierarchy simplifies the link information because the connection results to be hierarchical too: if a feature at level *n* is connected to a set of IPs, all the children features inherit the connections to that set.

5. Conclusion and future work

In this paper we have presented a methodology for the evaluation of communication systems. The methodology provides a complete framework for the evaluation at all the abstraction levels. The modular structure of the methodology gives us the interesting chance to evaluate the system by measuring each class of feature separately and to experiment how the system reacts to the action of different IPs by keeping the IPs constant and only one variable.

Future work aims to apply complete measurement campaigns and to extend the methodology with a innovative results analysis strategy, in order to complete the evaluation process.

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