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A new method for reliability allocation of avionics connected via an airborne network

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ABSTRACT

Avionics are connected via an airborne network, and the realization of their functions depends on successful data transmission through the network. Once the system reliability goal has been defined, reliability allocation must be performed to the subsystems and components. However, the widely used reliability allocation methods are not capable of dealing with complex connections between avionic subsystems. In this paper, an improved Advisory Group on the Reliability of Electronic Equipment (AGREE) allocation method is proposed for multi-mission networked avionics. In the proposed procedure, both the complexity and the importance of components are explicitly considered. Analytic algorithms and Monte Carlo simulation are applied to calculate the reliability of such a complex network structure. To determine the reliability allocation values, a heuristic algorithm is proposed, and an allocation adjustment procedure is provided to avoid inconsistent allocations caused by the same category of components involved in multiple missions of avionics. Our numerical study on A380 avionics, whose data are transmitted through Avionics Full Duplex Switched Ethernet (AFDX), shows that the proposed method is practical and quite efficient in handling such complex reliability allocation problems.

1. Introduction

Avionics are critical aircraft systems, whose failures are among the top five reasons that caused Aircraft on Ground (AOG) as Seidenman and Spanovich (2011) stated. Air Wisconsin and Jet Age Airline claimed that nearly 50% and 30% of AOG incidents were related to avionics (particularly to interconnected equipments), respectively. The avionics reliability design becomes a hot research topic.

To clearly describe the avionics reliability allocation problem, we first define our system hierarchy. Three system levels, system, subsystem and component, are involved in our paper. The three system levels can be defined as follows: (1) a system is a combination of subsystems that complete a task together, (2) a subsystem consists of components, which can perform a specific function of the system, and (3) a component is an operating part of the subsystem. Taken the A380 Avionics as an example (see Fig. 1), the whole avionics is a system which is made up of subsystems including flight control subsystem, engine control subsystem, cockpit control-display subsystem, energy control subsystem, fuel and LG (landing gear) control subsystem, cabin control subsystem and airborne network subsystem. These subsystems can be further broken down to components. For example, the flight control subsystem contains three FCGC (flight control and guidance computer) and three FCSC (flight control secondary computer), and the airborne network subsystem involves ES (end system) and switches. Due to the complexity, the avionics contractor usually subcontracts the avionic subsystems and even components to several subcontractors for further design and manufacturing. To guarantee the reliability of the whole avionic system, the reliability assurance of avionic subsystems/components becomes an issue. As a result, scientifically allocating the system reliability goal to subsystems/components is a major job during the concept design phase of avionics, as it provides both a meaningful reliability design goal and a significant reliability demonstration criterion.

Nowadays, avionic subsystems and components are interconnected through an airborne network, via which both the information and the function integrations are realized (Penna, 2011). For example, the engine data captured by the engine control subsystem must be transmitted to the cockpit control display subsystem, and then the pilot can receive the engine information for further decision making. The data transmission plays a key role in the avionic system, and one or more data transmission used

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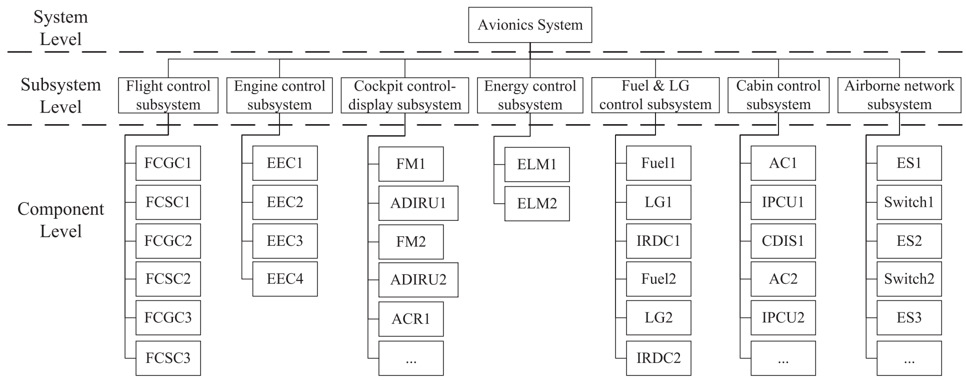

Fig. 1. The hierarchy of an A380 Avionics system. Note: AC – Air Conditioning ; ACR – Avionics Communication Router; ADIRU – Air Data Inertial Reference Unit; CDIS – Cabin Data Intercommunication System; EEC – Engine Electronic Control; ELM – Electrical Load Management; FM – Flight Management; IPCU – Ice Protection Control Unit; IRDC – Intelligent Remote Data Concentrator.

to complete a specified function (e.g. reception of the engine data, display the atmospheric pressure) is defined as a mission. It is obvious that the avionics is a multi-mission system.

For this multi-mission networked avionic system, as the multi-path redundant transmission is an intrinsic characteristic of the airborne network, the reliability block diagrams cannot be directly applied to avionic mission reliability modeling. In addition, the widely used reliability allocation methods (e.g. the Advisory Group on the Reliability of Electronic Equipment (AGREE) method, the Lagrange multiplier method, the dynamic programming method, the Aeronautical Radio Incorporated (ARINC) method and the expert rating method, see Zeng, 1995 and Ebeling, 2009 for details) work well with series and parallel systems, but cannot be directly used for avionic mission reliability allocation due to its networked structure. To solve this problem, Wang (2005) applied an analytic hierarchy process (AHP) to allocate the basic reliability for avionics, and the mission reliability goals are estimated based on the basic reliability allocation results to verify whether or not these goals are satisfied. However, the mission reliability model they used did not consider the airborne network interactions, so errors could not be avoided in verifying mission reliability.

Nowadays, with the rapid development of network technologies, studies on network reliability also have attracted more attention. For example, Guo and Li (2007) and Rostami et al. (2012) proposed network protocols considering network reliability. In the literature, new allocation methods for network reliability have also been reported. Mettas (2000) used a reliability model to describe the relationship between the network reliability and the component reliability, $R_S = f(R_1, R_2, \ldots, R_n)$, and applied the Birnbaum importance $I_i = \partial R_S / \partial R_i$ to quantify the reliability importance of component i. The reliability goal was allocated to find the optimum component reliability that minimizes the system cost. Ramirez-Marquez and Rocco (2008) presented an algorithm based on a probabilistic solution discovery approach and Monte Carlo simulation to solve the optimal allocation problem. The goal was to minimize the network design cost under a known constraint on the all-terminal reliability. Watcharasitthiwat and Wardkein (2009) used an improved ant colony optimization method to allocate the network mission reliability, and the minimum cost was obtained under the constraints of both two-terminal reliability and all-terminal reliability goals. These methods deal with optimal reliability allocation problems, where the system cost, weight, etc. are known and used as either the constraints or the objective. However, they are not applicable if the information about the system cost, weight, etc. are unavailable. To solve this problem, Li and Ren (2012) proposed a network reliability allocation method based on a heuristic algorithm, while it can only be applied for simple structured networks due to the analytical algorithm it used is NP-complete (Ball, 1986). Moreover, it could not be applied for avionics, because most data exchange components of avionics used in multiple missions are the same (e.g., the switch and the end system (ES)), and the relevant constraints were not included in this algorithm.

In this paper, we propose a new mission reliability allocation method for multi-mission networked avionics. The remainder of the paper is organized as follows. Section 2 describes the mission reliability allocation requirements for avionics. The improved AGREE algorithm is provided in Section 3. A case study of the A380 avionics is presented in Section 4 to validate our new method. Finally, concluding remarks are provided in Section 5.

2. Mission reliability allocation requirements for avionics

Mission reliability goals for avionics, assigned by allocating the reliability of the entire aircraft, are usually specified as Mean Time between Critical Failures (MTBCF) or the mission reliability (see Li, 1999; Wang et al., 2010). In this paper, we study the mission reliability allocation problem based on the following assumptions:

(1) Each of subsystems/components in avionics only has two states, normal and fault.
(2) There are no common-cause failures, i.e., the failures are independent.
(3) All failures follow exponential distributions.

Among these assumptions, the first two are frequently used in reliability allocation problems, e.g., Coit and Smith (1996), Kuo and Zuo (2002), Kroese et al. (2007) and Khalili-Damghani et al. (2013). However, multi-state systems and common-cause failures may exist in regular engineering systems, which have been further studied by Tian et al. (2008) and Daoud and Mahmoud (2008), respectively, but not for networked systems. In this paper, we only focus on two-state systems with independent failures. Assumption 3 is specified for the AGREE allocation method (see in Ebeling, 2009), which makes the problem easier to solve. The exponentially distributed failure assumption is widely applied in practice, such as Wang et al. (2001), Kuo and Zuo (2002) and Ardakan and Hamadani (2014). Moreover, it is suitable for electronics, particularly for aircraft electronics as Murphy et al. (2002) stated. Other failure time distributions will be studied in our future work.

3. Reliability allocation for multi-mission networked avionics

The AGREE allocation method (Ebeling, 2009) is the foundation of our improved mission reliability allocation algorithm for avionics, which is reviewed in Section 3.1. Section 3.2 proposes an improved AGREE method to solve the problem caused by the networked