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Freshness analysis of functional sequences in launchers [*]

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Abstract: Nowadays, many embedded systems use specific data buses to guarantee the exchange of data. The next generation of space applications is moving to components off-the-shelf (COTS) technology as switched Ethernet network in order to reduce the financial cost, being attentive to the mass. However, performance should be gained without sacrificing the reliability and the properties that enabled a tele-monitoring. This paper focuses on how to obtain a single traffic capture file that will be sent over ground-board communications and how to test later the freshness requirement satisfaction. A freshness formalization is proposed as well as a freshness verification algorithm based on the analysis of single trace captured using multicast communications. An experimental evaluation has been leaded in nominal and link failure cases.

Keywords: Observability; freshness; switched network; tele-monitoring; space vehicles.

1. INTRODUCTION

In space applications (aircrafts, satellites, launchers), conventional communication technologies are evolving from specific buses and federative control strategies to switched topologies that will support modular and distributed architecture Monchaux et al. (2012). Component off-the-shelf (COTS) technology is aimed at replacing the current MIL-STD-1553B (Department of Defense (1978)) for control traffic and (TDMA based) Pulse-Coded Modulation buses for telemetry traffic, buses embedded in the european (unmanned) launchers. Switched Ethernet network are hence expected to be embedded into the next-generation of the space launchers (Robert et al. (2013)). Candidates protocols may be AFDX (ARINC 664 P7 (2003)) or TTEthernet (SAE AS 6802 (2011)).

Traffic monitoring can be the cornerstone for understanding such communication networks. The monitoring activity aims at collecting from the various network devices a set of relevant data. This enables to characterize the network state and therefore to identify unusual network behavior. According to the application domain, the purposes of the monitoring can also be different like network management, network security, network performance analysis, etc. The monitoring mechanisms depend directly on the intended application and also on the nature of the observed system.

In launchers, the on-board controller manages the control state by sending specific data from/to the sensors/actuators. It corresponds to traffic command (noted TC) for mission control, on-board operations scheduling and automated procedures. Additionally, the network supports telemetry traffic (noted TM) for low rate mission control and housekeeping data Notebaert (2014). By analyzing the content of the packets, it should be possible to retrieve the values measured by the sensors and those sent by the controller to the actuators. Hence, the network acts as an observer of the control state. This is the applicable approach for launchers. Indeed, the whole traffic is monitored on-board and both TC and TM exchanges are sent over a ground-board link. It enables tele-diagnosis of launchers by post-analysis studies and replaying a network in order to improve the performances of a given architecture. The Ethernet protocols used in launcher applications may be different from those used for industrial factory automation, but the demands on end-to-end delays and other real-time requirements remain in the same order of magnitude. The main difference comes from the fact that the diagnosis of the devices and applications states relies here on the packet captured on the network. There is no additional supervision traffic, such performance metrics like freshness have to be recovered from the traces sent by air-ground data link.

The objective of this paper is to propose a method to validate end-to-end freshness inside a network as part of an observability analysis. The main novelty consists in achieving such validation for launchers just based on a single frame capture file that will be monitored through a ground-board communication. Section 2 summarizes the related work concerning network monitoring. Section 3 details the challenges and restrictions of such method

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in which the network state is observed from a specific machine. It shows ambiguous situations to be taken into account for both freshness and ordering properties with regards to a sequence of frames. Section 4 explains how the method might be implemented while section 5 illustrates it on an experimental platform. It should be helpful for engineers to discuss about the performance of the avionics during a past launch and provide capacity to detect, isolate and report faults.

The processing time of each task will not be taken into account in this study. It is not assumed for the traffic to be periodic and it should be robust to dynamic change of the topology (for instance a booster separation) or a different mission of the flight.

2. RELATED WORK AND BACKGROUND

This paper aims at providing a framework to analyse the traffic capture. It will be helpful for trade-off of quality-of-service and to detect, isolate and report faults. For such critical real-time constrained application, numerous works have already focused on the performance evaluation of the network end-to-end delays (network calculus, trajectory approach, real-time calculus). However, avionics requires to verify different properties that encompass not a single, but a sequence of frames mapping a functional command. An important property is to test if the end-to-end freshness is satisfied as defined in Lauer et al. (2011). Consider the periodic chain $T_1 \xrightarrow{d_1} \dots T_n \xrightarrow{d_n} T_{n+1}$ (task T_i regularly produces data d_i for T_{i+1}; each task is computed on a given device). A δ-freshness requirement may be defined such that a data d_n is "globally" produced from data d_i themselves produced not earlier than δ time units before. From a traffic capture point of view, a functional sequence would be observed according to the frames $F_1 \dots F_n$ (that respectively corresponds to the transportation of data $d_1 \dots d_n$). The verification of the freshness requires then to evaluate the difference between the timestamp of the frame related to the event at the end of a functional sequence and the timestamp of the frame that corresponds to the earliest dependent event at the beginning of the sequence. The paper will show the challenges to retrieve such analysis: how to obtain a single traffic capture file that will be sent over ground-board communications and how to test later the freshness requirement satisfaction.

The first issue deals with the acquisition of a unique traffic capture file. There exist several different techniques to capture network traffic. A point-to-point link can be split with a special device, named network Test Access Point (TAP) which enables to connect a monitor on this particular link in a passive way. A second method, called port mirroring, consists of using a special switches function (available on the most of commercial switches), which enables to copy all traffic coming from all or part of ports to a dedicated port.

Contrary to conventional topologies based on a bus, many monitors have to be implemented to obtain a real picture of the communications in switched networks whatever is the solution retained for traffic monitoring Robert et al. (2015). It means that all local capture files should be sent to a common device that will merge the files in order to generate a new file that will represent the load all along the network (file that has to be transmitted to the ground via the telemetry channel). To merge all the local traces, it needs a global reference time with synchronisation offsets have to be as small as possible since the clocks in each monitor are initially running asynchronously and may produce significant offsets. The underlying question is therefore the time synchronization method that may be addressed by using a synchronisation protocol as Network Time Protocol (NTP) or IEEE1588 - Precision Time Protocol (PTP). Some work (mainly, in an operating system tracing) suggest to rely on offline synchronisation by using a post-processing algorithm. These algorithms are mainly based on regression analysis (linear, least-squares, convex hull, etc.) or linear programming. Robert et al. (2015) discuss the challenges and the limits of those methods.

The verification of properties has been already studied. QoS performance of switched Ethernet networks, and in particular, end-to-end delays have been estimated by determinist methods as noticed by Bauer et al. (2010): network calculus, real-time calculus, trajectory approach. End-to-end properties have been also estimated, especially for Integrated Modular Avionics (IMA). Lauer et al. (2011) propose hence computation of upper-bounds of end-to-end properties computed as optimal solutions of Integer Linear Programming. Results integrate here the computation time required by each function. Badache et al. (2014) propose then criteria enabling to quantify hence the quality of valid temporal allocations. These works are strongly linked to the notion of virtual links valid for AFDX networks. Furthermore, these estimations consider the knowledge of the traffic.

3. OBSERVABILITY

Assume that each message is sent over the network in multicast. The destination address corresponds to a group that gathers the original destination and the address of a PC that will be called the observer o. This station has then the availability to capture each frame that will be sent over the network.

A functional sequence is defined as a set of frames $F_1 \dots F_n$ sent by m devices ($m \leq n$). In launchers, three kind of devices can be distinguished: the sensors, the actuators and the controller. It leads that avionics requirements are usually linked to a set of exchanges between those three kind of devices. To simplify, the functional sequence $s \xrightarrow{X} c \xrightarrow{Y} a$ is now considered. It corresponds to the periodic transportation of a measure X produced by a sensor s and of an action Y computed by the (on-board) controller c for an actuator a. Fig. 1 details the exchanges, with the copy to the observer o.

We note $x(k)$ the date at which the sensor is sending the k-value of the measure and $y(l)$ the date at which the controller is sending the l-value of the command. An end-to-end freshness requirement means here that the value X, that has served to compute the value Y sent at $y(l)$, has to be received before but not δ time units before ($x(k) \geq y(l) - \delta$). Assume now that the delay of the frame sent at $x(k)$ is noted $\Delta(x(k))$. End-to-end freshness for a command $Y(l)$ will be satisfied if it can be found a measure $X(k)$ such that: