UDP/IP/ETHERNET NETWORK AS AN INTEGRATION LAYER FOR DISTRIBUTED AVIONIC APPLICATION: A CASE STUDY

Summary. The paper discusses an application of standard UDP/ IP/Ethernet local area network as a communication layer for real-time distributed avionic application. The main objective of the paper is to propose and discuss hardware/software network configurations which improve the control device's data exchange even if the network must conduct another data intensive stream services.

Keywords: IEEE 802.3, LAN, Real-Time Systems, UDP/IP, Avionics, Unmanned Aerial Vehicles

SIEĆ KOMPUTEROWA KLASY UDP/IP/ETHERNET JAKO WARSTWA INTEGRACYJNA DLA ROZPROSZONEJ APLIKACJI AWIONICZNEJ

Streszczenie. W artykule rozważane jest zastosowanie standardowej lokalnej sieci komputerowej klasy UDP/IP/Ethernet jako platformy komunikacyjnej dla pokładowej rozproszonej aplikacji czasu rzeczywistego. Głównym przedmiotem analiz prowadzonych w pracy jest dobór konfiguracji sprzętowo-programowych dla sieci, w których należy zachować przepustowość dla danych procesowych systemu sterowania przy obecności innych znaczących transferów danych.

Słowa kluczowe: IEEE 802.3, lokalne sieci komputerowe, systemy czasu rzeczywistego, protokoły UDP/IP, awionika, bezpilotowe statki powietrzne

1. Introduction

From the computer engineering perspective, a modern aircraft is a federation of microprocessor systems cooperating with a pilot or remote operator. The basic autopilot
module digitally controls speed, course and height of a flying vehicle. Another digital modules can control trajectory of the aircraft during the flight, conduct an automatic take-off and landing as well as support vehicle's navigation on the airfield. The current aircraft's sensors and actuators, such as AHRS (Attitude and Heading Reference System), an engine speed detector, electrical or hydraulic motors can digitally communicate with microprocessor systems. Additionally, modern flying vehicles, especially UAVs (Unmanned Aerial Vehicles) apply digital video data streams as a support of the UAV's operator or a data source for a real-time terrain inspection.

A systematic grow of on-board digital devices entails a development of specialised digital networks for reliable and fast enough data exchange between the digital nodes of an avionic system. Currently, ARINC 429 [1] computer network is a predominant medium for data exchange in modern airliners. For smaller general aviation vehicles and UAVs CAN [2] supported by CANaerospace [3, 4] protocol is usually applied. Both above mentioned digital network standards offer reliable data exchange between standard control avionic instruments. Unfortunately, their bandwidth (100 kbit/s for ARINC 429 and up to 1 Mbit/s for CAN) becomes a serious barrier when the increasing number of nodes appears in the network or the nodes intensively produce the data.

To overcome the problem with the increasing data flow in the avionic systems the aviation authorities decided to adapt IEEE 802.3 (Ethernet) standard [5] to the digital avionic networks needs. There are two successful avionic industrial adaptation of IEEE 802.3 standard: ARINC specification 664 [6, 8] and Time-Triggered Ethernet [7]. The ARINC specification 664 network applies statically configured switches, where virtual links determine the data routes. The links have time slots (so called Bandwidth Allocation Gaps) within which data packages must be transferred. The format of data is strictly defined. The behaviour of the network is predictable within a set of virtual links and statically configured switches. Time-Triggered Ethernet uses a fault-tolerant clock synchronization mechanism (SAE AS6802). It synchronizes non-faulty networking components even in the present of faulty clocks. This assures Guarantee of Service for systems with high safety needs. Each message is forwarded down to the packet in a precise way. This offers a message passage control over the network traffic scheduled in time. Both ARINC specification 664 and Time-Triggered Ethernet solutions are currently gradually introduced in airliners [6, 9, 10]. These new solutions are expensive and it will take a significant time to introduce them into general aviation vehicles and UAVs.

The successful introduction of profiled IEEE 802.3 networks into airliners as well as the financial barrier that prevents from applying such solutions in general aviation vehicles and UAVs led to application of standard IEEE 802.3 devices in aviation industry. Standard Ethernet as an integration platform for the avionic devices brings the significant throughput
increase (comparing to ARINC 429 and CAN solutions). On the other hand, the network behaviour is definitely less predictable, especially when its overload occurs.

This paper reports an attempt to introduce IEEE 802.3 (Ethernet) network as a communication layer for inter-avionic device data exchange in an experimental UAV system. Ethernet network is applied for integration of a set of new on-boards components which potentially would produce intensive data streams.

2. Experimental System Overview

Figure 1 shows the main components of the experimental UAV system [11] where the additional local area network (LAN) will be applied. The flying platform is a modified “MP-02 Czajka” [12] ultra-light plane. It still can be operated by a qualified pilot, but simultaneously it can behave as an UAV. Its main modifications include the new experimental: Autopilot; AHRS; and electrically operated ailerons, flaps, elevator and rudder build into the plane structure. CAN network is used to integrate them. The modified plane can also communicate via radio-link with the mobile Ground Station where its operator is able to supervise the mission. Ground Station software makes it possible to plan and remotely over-see the flight. A mission operator can also “take over” the UAV and directly control the UAV's flight using virtual flight instruments installed on the ground. Additionally, the flight platform is able to send the video stream which can be used for an area inspection or as an operator's support. The currently developed UAV system's computer network structure is depicted in Fig. 2. A new LAN segment is being planned as the integration platform for the system elements which may produce intensive data streams, such as ATOL (Automatic TakeOff and Landing) and Auto Taxi modules. It also replaces the previous communication channel between the air plane's control system (see CAN subsystem) and Ground Station. Autopilot executes as a bridge between the LAN and currently on-board CAN network. The new ATOL module is able to conduct automatic take-off and landing of the UAV if it operates from a typical airfield. It uses video and other measurement systems to effectively execute its algorithms. The Auto Taxi module makes it possible to relocate the UAV on a standard commercial airfield. This subsystem should support the movement of the UAV on ground in its way to a runway as well as automatically lead the UAV after its landing to the safe service area.

The preliminary input data for the Auto Taxi subsystem would be visual signs painted on the airfield. This subsystem ought to interact with the air traffic controllers (using separate dedicated electronic channel) and simultaneously provide the collision avoidance with other vehicles in the area. A part of the network is a specialised radio channel which enables to
keep the Ethernet based communication on the range of operation of UAV (e.g. up to 80 km). The central on-board local area network module is a network device. Its set-up as well as transmission parameters have the predominant impact of the whole system performance.

Fig. 1. General overview of the Experimental UAV System
Rys. 1. Główne elementy eksperymentalnego systemu ze statkiem bezpilotowym

3. Main Development Issues

Figure 3 shows the new network data channels identified during the system development. The dotted lines denote possible video streams and intensive sensory data, whereas the continuous lines denote control data. The LAN must primarily provide the bidirectional control data channels between: Ground Station and Autopilot, ATOL and Autopilot, Auto Taxi unit and Autopilot, Ground Station and ATOL, and finally Ground Station and Auto Taxi unit. Auto Taxi unit and ATOL may produce additional video or data intensive sensory data which would be transferred to Ground Station for the on-line and off-line analysis. The overall system can work in several modes, where main input reference signals maybe produced by different system modules. Ground Station, Auto Taxi module, ATOL module or even Autopilot itself can produce the main input reference control signal depending on the current system mode.
The main control data produced by the Autopilot module (collected from local CAN network) include the state of the aircraft: its altitude, GPS position, speed, course, roll and pitch angles, fuel or battery level, and flight mission report. Depending on the mission mode Ground Station, Auto Taxi or ATOL analyses the Autopilot output data stream and produces the main input reference signals for the aircraft control system. All hardware modules connected to the LAN execute real-time control applications [13, 14]. The complete system constitutes a distributed real-time embedded system [15]. The crucial feature of a real-time system is to produce algorithmically correct data within assumed timing constraints. If the system is a distributed one, it is expected to exchange data in a timely manner either.

Fig. 3. Data channels
Rys. 3. Kanaly przesyłania danych

The “traditional” data buses applied in the avionic systems, such as CAN, ARINC 429 or profiled Ethernet networks give the ability to predict the transmission delays in a precisely defined local area network. However, this solutions were rejected in the experimental UAV system development process due to low bandwidth or high costs. One of the main issues analysed during the current system development is the way of applying “standard” network devices to turn the system into “near real-time”. The primarily concern in the network behaviour is the assurance of uncluttered control data transfer. Video and additional sensory data should be postponed if the control data is transmitted between the nodes of the system. This should be acquired by adequate network devices set-up.

It is also worth noticing that ATOL, Auto Taxi module, Autopilot and Ground Station devices can adjust their hardware and software to meet the improved control data exchange. Generally, they are able to cooperate with standard LAN devices. Their communication software is based on standard SOCKETS interface [16]. Thereafter, each data transmission is conducted in a separate IP/UDP channel. NATO STANAG 4586 (Edition 3) protocol [17] is implemented over the UDP data transfer layer to assure easier inter-module integration.
4. Network Configurations Study

The assurance of an uncluttered control data transfer at the expense of video and sensory streams in a LAN can be solved in a several ways. The following subsections discuss the possible network device's configurations cooperating with adequately modified network nodes which finally should led to solution of the formulated problem. Both managed and unmanaged network devices application is taken into consideration.

Fig. 4. Unmanaged switches application in solution of the problem
Rys. 4. Zastosowanie niekonfigurowalnych przełączników do rozwiązania problemu

### 4.1. Unmanaged Switch Application

Figure 4 shows the solution of the problem where unmanaged Ethernet switches are applied. The network traffic disjunction between control data and video streams is achieved by dividing the network into two separate physical sub-networks. This solution's advantage is that the network devices do not have to be configured. Simultaneously, network nodes have to be equipped with at least two physical Ethernet ports: one for the control data streams and the second for video and data intensive stream. The physical ports can acquire separate IP addresses and this way the data streams become easily divided. Additionally, the radio-link should also provide two independent communication channels. This solution is the simplest and the most safe with regard to network configuration. Similar approaches are still used in aviation industry [18]. However, it requires two separate switches, double physical ports for each network node, and double radio channel.
4.2. VLAN Concept Application

The reduction of network devices on-board can be achieved by basic managed switch offering the VLANs definition, as in Fig. 5. Two simple separate VLANs [19, 20] grouping only selected physical ports can replace two physical switches. The switch configuration includes only physical port junction into VLANs and as a consequence still double physical ports in the network nodes must be applied.

4.3. Layer 2 Quality of Service Mechanism Application

The solution of the problem which applies advanced switch management abilities is depicted in Fig. 6. The prioritisation and isolation of the different data streams in one LAN can be achieved by application of Quality of Service mechanisms [19, 20, 22] in switches as well as network nodes. Modern Ethernet network interfaces offer so called tagging mechanism. The Ethernet frames leaving the network node's interface are equipped with an additional identification number (tag) having the value between 0 and 4096. Consequently, it is possible to distinguish data streams produced by separate sockets using their (different) tag numbers. The tagged Ethernet frames can be easily sorted within the LAN and naturally attached to respective VLANs. As the Ethernet frames are distinguishable, several VLANs can share the same physical network ports. This eliminates the need of doubling physical ports on both switch device and network nodes (compare sections 4.1 and 4.2). Additionally, the subsequent VLANs can have a priority level attached. This in consequence gives the possibility to prioritize data stream belonging to one VLAN over the others. Typically, up to 8 priority levels can be attached to the VLANs.

The fusion of tagging, VLANs and priorities mechanisms enables to effectively manage the LAN traffic and fulfil the system restrictions defined in section 3. The control data streams can be prioritized over the video data intensive sensor ones. This in consequence improve predictability of the control data transfer.

4.4. Layer 3 Quality of Service Mechanism Application

The solution of the problem comparable to the one discussed in subsection 4.3 is shown in Fig. 7. In this case the central network device is a router (or advanced managed switch). Its routing table as well as IP protocol prioritizing features [21, 22] may be effectively applied for data streams management. To effectively conduct IP packet's management the network nodes should have two separate virtual network devices defined. Each of it ought to have a separate IP address attached. The distinguishable data streams should use separate IP interface. Consequently, the router should acquire two (or more if necessary) packet streams
coming from different IP addresses. The network node's IP interfaces can also be applied for the packet's priority definition as it is defined in IP protocol definition. The IP packets management is processed by means of the router's routing table and recognised packet's priorities.

5. Conclusions

The paper discusses the hardware/software configurations of LAN that should enlarge the predictability of an avionic distributed real-time control system. It is expected that control data streams passed over the network would have got priority over others, possible intensive
ones. The problem formulation comes from an experimental UAV system currently developed by authors of this publication. The introduction of new data intensive hardware modules in a system causes extension of the aircraft's internal LAN. A new Ethernet/IP/UDP network segment is being built into UAV system structure. Due to financial constraints and successes announced in a similar projects [18, 23] standard IEEE 802.3 switches and routers have been taken into consideration as central network device instead of IEEE 802.3 profiled solutions [6, 8, 7].

The attempts of solving the system extension problem let to four hardware/software network configurations that ought to satisfy the developed system constraints: the video and data intensive sensor streams should have minor influence on the data control streams coexisting in the same LAN segment.

Different types of network devices, such as unmanaged and managed switches as well as routers were considered in the system development. The unmanaged and basic managed switches are cheaper choice, but, to the author's knowledge, require multiple physical Ethernet port application on the network nodes. The application of both fully managed switches and routers gives the ability to effectively run LAN traffic. In this case network nodes can have single physical ports, however they should offer a bit more advanced internal networking software. At the current stage to authors development, the application of managed switches seem to be the most promising solution. These devices offer effective traffic management, probably the fastest switching mechanisms, and have reasonable price.

The paper discusses the 10/100/1000 Mbit industrial solutions currently available on network and avionic devices market. The authors are aware about incoming “10 Gbit Ethernet” devices [5] that may open an new chapter in avionic LANs. The next stage of
author’s work will be experimental assessment of discussed network configurations within developed UAV system.

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Omówienie

W artykule rozważono kilka przykładowych konfiguracji sprzętowo-programowych lokalnych sieci komputerowych, w których istotne znaczenie ma zachowanie transmisji strumieni danych czasu rzeczywistego zakłóconych danymi video. Strumienie danych czasu rzeczywistego przesyłają dane procesowe pewnego rozproszonego systemu sterowania – zapewniają między innymi stabilizację parametrów lotu statku powietrznego. Strumienie video wspomagają pracę operatora oraz wybranych podsystemów pokładowych (np. automatyczny start i lądowanie na typowym lotnisku lub autonomiczna nawigacja po płycie lotniska). Rozważania zostały zainspirowane problemem postawionym w czasie.
rozbudowy infrastruktury informatycznej pewnego systemu bezzaałogowego obiektu latającego.

Autorzy pracy są świadomi istnienia wprowadzanych obecnie w przemyśle lotniczym rozszerzeń sieci TCP/UDP/IP/Ethernet zapewniających zwiększoną przewidywalność terminowości przesyłania danych, takich jak ARINC 653 [6] czy Time Triggered Ethernet [7]. Zauważają jednak, że obok wspomnianych, kosztownych rozwiązań coraz częściej producenci statków powietrznych decydują się na wdrożenia „standardowych” urządzeń sieciowych i twórcze zastosowanie wbudowanych już rozszerzeń protokołów sieciowych do integracji pokładowych komponentów sprzętowych.

Opierając się na sformułowanych przesłankach, w kolejnych podrozdziałach artykułu rozważane są potencjalne rozwiązania programowo-sprzętowe, które można zastosować do integracji urządzeń pokładowych z zastosowaniem standardowych urządzeń sieciowych. Na rys. 4 pokazano sposób integracji urządzeń za pomocą fizycznie rozdzielonych podsieci. Podejście takie jest najprostsze, choć wymaga rozbudowanych fizycznych interfejsów sieciowych urządzeń pokładowych. W dalszej kolejności zauważono (por. rys. 5), że stosując tylko mechanizm wydzielania sieci wirtualnych w obrębie pojedynczego konfigurowalnego przełącznika, podobny rezultat można uzyskać z zastosowaniem pojedynczego urządzenia sieciowego. Analiza dostępnych na rynku zaawansowanych przełączników oraz programowych komponentów współczesnych systemów operacyjnych doprowadziła do zaproponowania konfiguracji sieci jak na rys. 6. Dzięki mechanizmom wspierającym standard IEEE 802.3q istnieje możliwość separacji strumieni danych oraz ich priorytetowania z zastosowaniem zredukowanej liczby interfejsów i urządzeń sieciowych. Okazuje się również, że współczesne przełączniki i routery wspierają także priorytetowanie strumieni z zastosowaniem pola usług zróżnicowanych protokołu IP. W prowadzonych rozważaniach zaproponowano zatem potencjalną konfigurację sieci na bazie przełącznika warstwy 3 routera (por. rys. 7).

Opracowane studium potencjalnych rozwiązań będzie stanowiło punkt wyjścia do wdrożenia struktury sieci komputerowej w eksperymentalnym systemie z bezpilotowym statkiem powietrznym.

Addresses

Sławomir SAMOLEJ: Rzeszow University of Technology, Department of Computer and Control Engineering, al. Powstańców Warszawy 12, 35-119 Rzeszów, Poland, ssamolej@prz.edu.pl

Tomasz ROGALSKI: Rzeszow University of Technology, Department of Avionics and Control Systems, al. Powstańców Warszawy 12, 35-119 Rzeszow, Poland, orakl@prz.edu.pl