AN AIRBORNE DATA BUS NETWORK SYSTEM OF INTERFACE ADAPTIVE AND FLEXIBLE CONTROL

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Abstract

For the problems of unbalanced utilization between avionics application requirements and network resources, compact-coupling interface between application and network, centralized network management, etc. Considering to characteristics of the next generation full function domain integrated modular avionics, an airborne data bus network of interface adaptive and flexible control (IAFC) is proposed, which provides multidimensional network profiles, separates control, task, management and maintenance traffic load, reduces the protocol-coupling orienting to mixed-critical traffic, avoids the propagation of faults in shared airborne network, that make the avionics system on configuration-free dynamic join and routing, and meet the real-time, reliable, and orderly communication requirements of the cross-domain and mixed-critical traffic flow. To meet the requirements of future airborne integration of avionics, electromechanical management, and flight control systems.

1 Introduction

Airborne network systems are the key to aircraft "safety flight and enabling tasks", which support interconnection and interoperability among airborne system such as electro-mechanical system, flight control system and avionics system, and support mixed-critical traffic flow transmission.[1][2]. A380, B787 and A400M aircrafts use AFDX network [3] as avionics and electro-mechanical backbone network, use 422, 429 [4] as the main bus for flight control system. F-35 uses fiber channel (FC) [5] network as the avionics backbone network, uses 1394B [6] as the main bus for flight control system.

Those integrated modular avionics system [7][8] generally have the following problems. The system requirements and network resources are not balanced. The coupling between the airborne subsystems is strong, lets it's easy to cause the spread of faults and large-scale outbreaks, which makes it is difficult to troubleshoot and maintain upgrades. The network planning is rigid and static, the network service management is excessively centralized, and the system scalability is poor, which cannot meet the increasing deployment of multi-mode services.

In this paper, to meet the requirements of future integration of avionics, electromechanical management, and flight control systems, an airborne data bus network of interface adaptive and flexible control (the IAFC network) is proposed, which consists of the backbone network, branch network and terminal network. Then in the following, the key properties of the IAFC network and the technologies to enable these properties are discussed.

2 Airborne networks

2.1 Integrated Modular Avionics

Under the current Integrated Modular Avionics (IMA) Architecture, in order to ensure the real-time, reliable, and orderly communication of mixed-critical traffic flow, network protocols are been enhanced. Based on Ethernet, the AFDX network adopt redundancy, virtual link, bandwidth allocation gap, rate constrain, static route...etc. to ensure the certainty transmission of traffic flow, which can support the integration of avionics and electro-mechanical management. At the same time, EDE protocol is adopt based on AFDX, which improve the real-time and orderly communications of mixed-critical traffic flow, to support the integration of flight control. Fiber channel (FC) adopts credit, redundancy and priority mechanism to support the integration of avionics. And the Time Triggered Ethernet (TTE) [9] [10] extends high precision distributed time synchronization based on AFDX, to support the integration of avionics, electro-mechanical management and flight control. Generally, the IMA architecture has the following drawbacks:

- Airborne network has been common medium to the propagation of functional faults. The network provides public and open channel to all function subsystems, all safety level data, and all missions' priority traffic load. Traffic flows have to compete for arbitration rights to output-scheduled port and channel throughout uniform and shared network. Also, system's potential and visible faults can spread among different function systems easily.
- Self-recovery ability [11] to system's faults is absent. The avionics application is tightly coupled with the interface of the network, and system control is highly complex, once a node function fails, the network needs to be reconfigured to support the dynamic migration of the task, to support system work reliably. The network configuration-tables context switch would occupy lots of run-time cost of avionics systems.
- Network ability to support plug and play is very limited. If new nodes need to join the network system and interconnect with other nodes, system integrators have to modify and reload network configuration-table to match new topology and logical interaction.
- Network expansibility is inflexible. High-reliability network protocol is difficult to design and mixed-critical traffic is complex to plan. A huge of associated messages needs to pre-arrange, system architecture is insecure to increasing of node and traffic load, and inherited design is insufficient.

2.2 Requirements of future airborne network

The main problem of traditional airborne network design is try to build a uniform and absolute network protocol profile to pack all mixed-critical traffic requirements such as control, task, audio and video stream, and sensor signals, etc. Hence, the more complex and tightly coupled protocol sets would be constructed. However, the specified network protocol service superset compressed with all subsystem requirements in unique and static dimensional profile is much beyond actually real network protocol requirements from independent subsystem.

The integration of next-generation airborne systems brings forward a direct demand to network that nodes should have a capability to active join and adaptive control based on transformable topology, and to support dynamic mesh interconnection [12]. The airborne system needs to satisfy with the dimensional requirements from airborne system task, control, management, maintenance, and precise synchronization, and to support mixed type of messages such as bursting, stochastic, periodical and huge-stream to transmission in determinism and reliability, with simple, efficient, transport, and flexible features, and ultimately achieve the aim to mesh-adaptive dynamic joint, system intelligent management, and fault self-recovery.

Among them, the avionics domain demands that the mission terminals and the radio terminals should have the capability to dynamic adaptive join, plug and play, multi-center self-organization, real-time and reliable communication, and flexibly intelligent control. The electromechanical management domain needs that the monitor terminal should layout near to the source of signal, dynamic adaptive join, and the control-related terminals have the ability to transmit in determinism and reliability. The flight control domain requires that control-related terminals transmit without mission and achieve highly integrity communication [13].

3 The IAFC Architecture

To build a novel airborne network architecture characterized as transformable topology, with heterogeneous protocols across all domains, uniform visualized application network interfaces support dynamic adaptive mesh-join, flexible deployment, mixed multi-dimensional &multi-pattern, and mixed-critical traffic flow. Which oriented to mixed-critical system and QoS level, provides multi-dimensional network profiles that separates control, mission, management and maintenance traffic load, reduces the protocol-coupling orienting to mixed-critical types of service, and avoids the propagation of faults in shared airborne network, that make the avionics system on configuration-free dynamic join and routing, and meet the cross-domain, mixed-critical service, real-time, reliable, and orderly communication requirements of airborne system.

This paper proposes an IAFC architecture, consists of the backbone network, the branch network and the terminal network, as shown in Fig 1, has the following features.

- According to the needs of each network domain of the airborne system, a variety of physical links that meet multiple network protocols are been construct, to achieve whole connection of the airborne network.
- Provides low latency, high-determined, high -precision time synchronization, and dynamic maintenance for integrated systems with high levels of security.

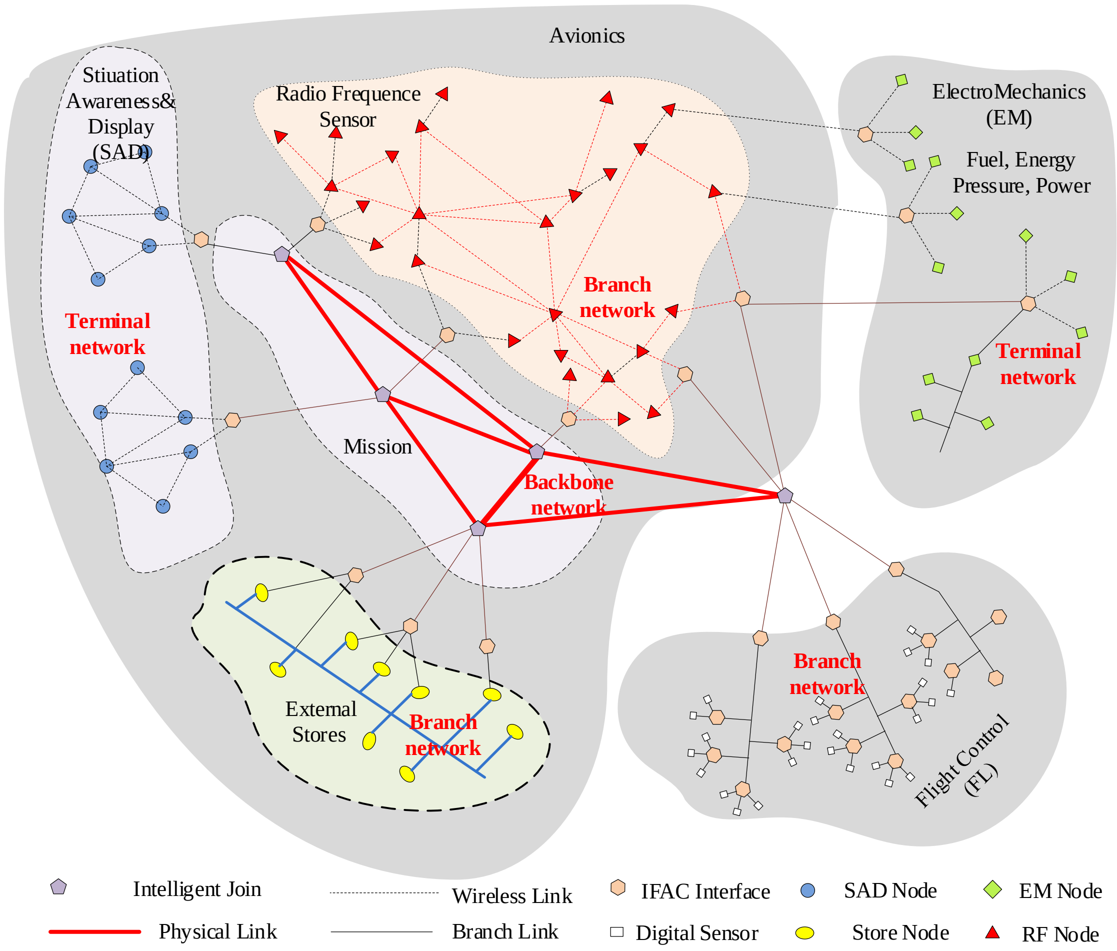

Fig 1 System architecture based on IAFC

- Adopts a hierarchical network architecture consists of the backbone network, the branch network and the terminal network. The backbone network adopts ultrahigh speed and capacity switch network, provides high speed, reliable and security transform service. The branch network adopts bus network of different mission level, security level and task type, to provide access to functional terminals. The terminal network uses wireless access to provide local data acquisition and information transmission, to meet the plug-and-play and interconnection requirements of the front-end micro distributed components.

- Provides standard control interface to the system, supports quick join of application equipment.
- Adopts hierarchical network interactive nodes with intelligent routing control, which can realize the optimization of routing path, and allocate optimal channel dynamically.

3.1 Backbone network

Backbone network is the core network, is the information bridge connecting RF sensor domain, electromechanical domain, external stores domain, flight control domain and cockpit mission domain, etc. which provides ultrahigh speed (40G~100G), high reliable transmission service. The backbone network generally uses fiber channel (FC) switching technology, with high real-time characteristics, can support parallel and non-interfering transmission of different service types, security levels and mission-critical data. In Fig. 1, the backbone network shows as red bold lines.

3.2 Branch network

Branch network is the main access network, is the path connection between airborne functional domains and the backbone network. To improve reliability, physically one functional domain can contain one or more access branch. The branch network provides high speed (1Mbps~1Gbps), and high reliable service, such as 1394B and MIL-STD-1553B [14] data bus. By providing different access control services, support isolation for control, tasks, management, and maintenance of traffic data. The branch network provides adaptive universal network interfaces for terminal devices that use functional buses and networks, to meet the fast access requirements of devices. In Fig. 1, the branch network is shown in the form of "lightning" or partially red dotted lines

3.3 Terminal network

Terminal network faces a large number of avionics and electromechanical terminals. It is used to connect a group of networks within the functional domain that have similar functions, spatial deployment, and strong logical relationships, and is oriented to sensors, processors, actuators, and terminals. For example, a set of sensors in the engine system, such as temperature, pressure, speed, etc., can form a terminal net. The form of the terminal network is relatively flexible, wireless, switched or bus networks can be used as required. Information can be exchanged between devices in the same terminal network, and the information of each device in the terminal network can be accessed in the branch network and the backbone network, to carry out long-distance transmission or aggregation. Terminal information exchanges in different functional domains need to be forwarded through the access branch network and backbone network. In Fig 1, Terminal network is represented by the black dashed line. The following gives several application solutions for airborne networks:

- Radio frequency (RF), photoelectricity, and cockpit terminal systems use wireless grid network, to support the dynamic interconnection, plug-and-play and no logical center of airborne systems. The medium and high-speed data (100Mbps~ 1Gbps) are aggregated through the branch network and backbone network.
- Electromechanical sensor terminals use the RS422 bus and the Wireless Sensor Network (AWSN), to aggregate low-speed data (1 Kbps~250 Kbps) to the remote interface unit (RDIU), and then enter the branch network convergence processing.
- Terminal systems such as atmosphere, navigation, RF, etc. use strong real-time and high-security wired networks, and converge low-speed data through the access branch network and backbone network.

4 IAFC key properties

The implementation of an IAFC network should require following key properties.

Traffic management: to support across domain dynamic interconnection among the avionics, electromechanical, and flight control, and carry the dynamic management of mixed traffic such as critical, crucial, urgent, general, and best effort.

Transformable topology: heterogeneous protocols across all domains, dynamic adaptive mesh-join, flexible deployment, mixed multi-dimensional &multi-pattern, and mixed-critical traffic flow equipment interconnection, to meet flexible interconnection of mixed network profiles packed heterogeneous protocols across all domains, and ensure control, mission, management, maintenance traffic separation. The network architecture consists of the core backbone network, the bypass branch network and the terminal network. The backbone network uses super-high-speed, super-huge-mass switching network, providing high-bandwidth, high reliability, huge-mass transmission services. The branch network support mixed safety-critical and mixed mission-crucial traffic, as specified bus network to meet the terminal end system access to different domains. The terminal network adopts the plug-and-play, dynamic interconnection, multi-center self-organizing wireless mesh, wireless sensor network and high reliable wired network to support cluster interconnection affront-end distributed intelligent micro-terminals.

Resource allocation: provide dynamically adaptive access and resource allocation based on semantic rules of network requirements. Through the semantic description of the use of the network, including bandwidth, application pattern, safety level, traffic type, transmission reliability and determinism requirements, it can dynamically join the network, share network resources.

Transmission optimization: Based on unique, uniform, universal and standard transparent transmission control mechanism, IAFC provides a unified, universal and standard virtual interface to the access system. The system supports transparent access to the virtualized network resources. At the same time, it can realize the allocation, scheduling, recycling and other management of logical and physical resources, real-time dynamic load balance of terminal communications resources, and the establishment of the optimized communication channel.

Channel adaptation: provide flexible smart matching of heterogeneous network protocols. Adopt distributed sensing and processing method, IAFC transmission services segment support metadata across-plane logic link intelligent real-time dynamic analysis conversion, and IAFC distributed virtual network management segment support cross-planar real-time network address translation adaptation, the establishment of dynamic transmission channels, and efficient and reliable self-guide data load transmission in different bus transmission channel.

Data monitoring: based on mechanism of data source control, self-management, active monitoring, to achieve accurate network-monitoring and data-acquired of huge-traffic based on concurrently network.

5 IAFC enabling technologies

The previous paper proposes that the IAFC architecture is made up by the connection of the backbone network, branch network, and terminal network through intelligent interfaces, which solves the problem of physical interconnection between the onboard devices. The following further discusses how to use the network in a network containing different physical forms, to implement on-time, on-demand, and real-time transmission.

The traditional airborne network design is based on the pre-analysis of network service types and transmission capabilities. It plans and configures system resources (such as physical links, message IDs, source ports, and destination ports), users need to provide detailed information to adapt system resources based on the established network architecture. This design must develop different interface control files for different application networks (such as 1553B, FC, 1394B, INFINIBAND, WDM, etc.), specify each information length, cycle, real-time and other restrictions. When new equipment is added, all transmission tables of related networks need to be re-planned, makes the dynamic expansion capability is weak.

To overcome this weakness, this paper considers the airborne global network as a whole, and defines a dynamically access and resource allocation method based on semantic demands, which including the physical network layer, virtual interface layer, semantic description layer and access demand layer (or application layer), as shown in Fig 2.

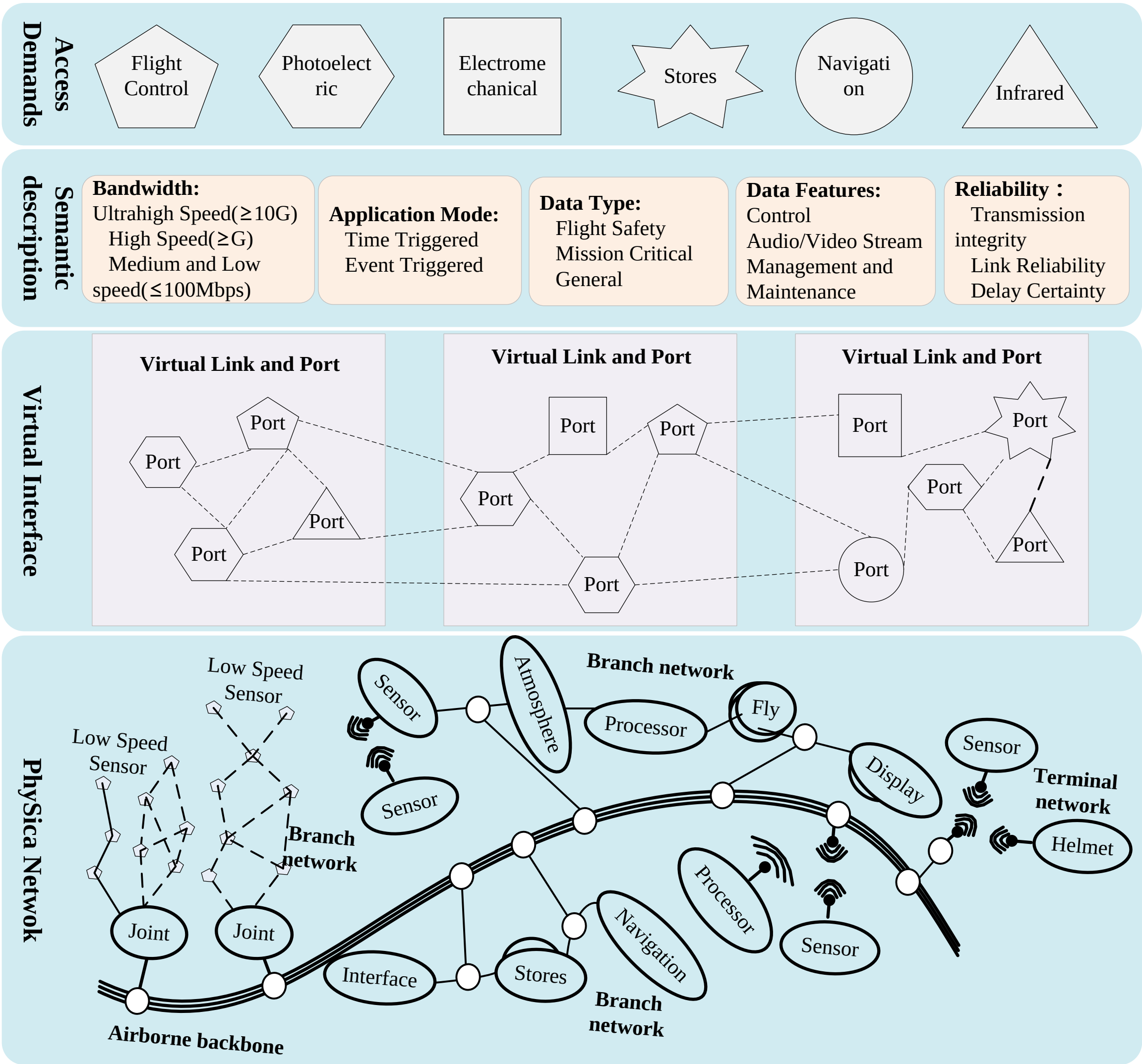

Fig 2 dynamically access and resource allocation based on demands

5.1 Physical network layer

The lowest physical network layer refers to the physical forms, parameters, and the address and transmission protocols of the core backbone network, the access branch network, and the terminal network.

5.2 Virtual interface layer

As the key to implementing an adaptive bus network, the virtual interface layer is built on top of all physical networks. It can use universal and standard specifications to unify the airborne global heterogeneous network into a single plane, provide a network address covering all networks, support transparent access to the virtualized network resources, and implement the management of the allocation, scheduling, and recovery of logical and physical resources of the onboard system. It uses intelligent analysis and management of existing communication data to establish an optimal channel in real time. From the communication view used by the users, the virtual interface includes a unified airborne address, virtual channel, and logical port. The virtual interface layer needs to dynamically allocate available logical channels and ports for the adaptivelyconnected on-board system, and is responsible for mapping logical resources to specific network physical resources.

Table 1 gives an example of the definition of the unified address of the airborne network system. It can be seen that the virtual interface layer uniformly addresses the physical devices in different network domains, and implements the mapping from logical address to specific devices and messages to physical links. The airborne network system will be abstracted as a connected graph on the virtual interface plane. The airborne equipment will be abstracted as the points in the graph. The physical link will be abstracted as the edge connecting the points. The end-to-end transmissions in the network will convert into the path planning problem of a pair of nodes in the graph [15] [16].

Table 1 Airborne equipment address define

Equipment Address (A.B.C.D.E.F.G.H)	Data Width (64bits)	Ranges
Mission domain(A)	8	1~2F
Task domain(B)	8	0~1F
Function domain(C)	8	1~FF
Equipment type(D)	8	0~1F
Equipment module(E)	8	0~FF
Backbone Network Access point (F)	8	1~FF
Branch Network Access point (G)	8	1~2F
Terminal Network Access point (H)	8	1~1F

In this way, all onboard devices are unified into one address space without having to pay attention to which network they specifically in. In addition to address mapping, the virtual interface layer needs to provide logical link to physical link conversions for upper-layer applications. Since there is no predefined information transmission path, the virtual interface layer must estimate and store the transmission parameters on the physical link, to satisfy the new application data's transmission.

5.3 Semantic description layer

The virtual interface layer solves the problem of address identification when interacting between applications. What needs to be solved below is how to select the proper transmission path (routing) under the demand constraints. The airborne global heterogeneous flexible interconnection network defines the user's needs of the network (including bandwidth, application mode, security level, service type, transmission reliability, certainty, etc.) by semantics. Based on the network physical structure and protocol, it provides abstract semantic description of network service capabilities. Through the analysis of network usage requirements, the user's needs are split into independent configuration items, and they are classified and scientifically expressed mathematically according to the characteristics, then they are defined as measurable parameters. The user's requirements are mapped to the constraints of these parameters, and then the mathematical modeling is taken based on network needs, to properly design the network transmission routing and configuration of network resources. These parameters are proposed by the access demands layer.

5.4 Access demands layer

The access demands layer is the layer where the application is located, where communication middleware such as DDS (Subscription Publishing Mechanism) may also be added to further isolate the application and communication. When the application sends information, it only needs to specify the requirement semantics of the current information and the unified destination address, the transmission of the information can be completed. The access demands layer abstracts the traffic’s transmission requirements into the transmission model, and the virtual interface layer determines the final physical transmission path through the airborne network graph by the parameters of each network, and the resource usage conditions, then the transmission of the information is completed.

6 Data transmission example

Figure 3 shows a schematic connection graph of an onboard IAFC network. The backbone network uses a high-speed FC bus, the branch network uses 1394B (flight control), 1553B (stores), the terminal network uses 422 (electromechanical), wireless network (infrared front end), and the airborne full-area network is formed through the interconnection of IAFC interfaces. Then a comprehensive system of avionics, flight control, and electromechanical domains is achieved.

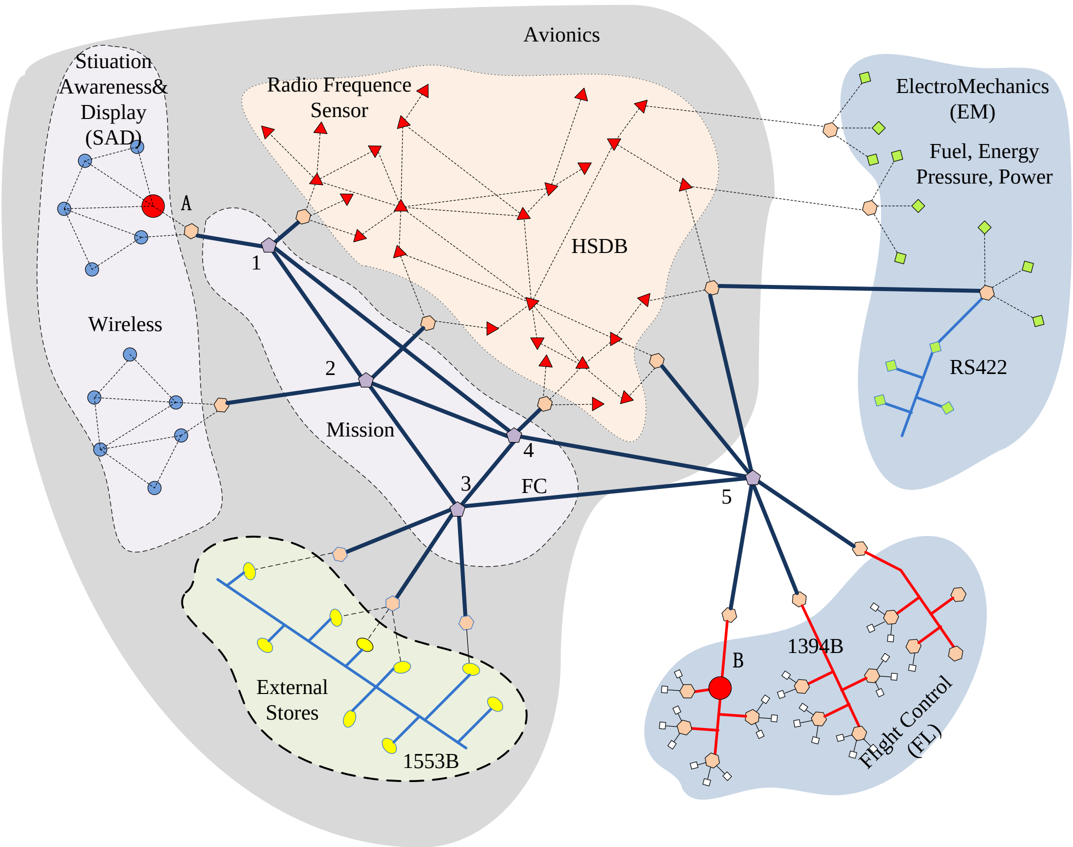

Fig 3 Transmission example of IAFC network

As shown in Fig. 3, the data of the infrared photoelectric front end needs to send to the flight control system, that is sent from A to B in the graph. The airborne backbone network can be abstracted as a graph G = (V, E), where V represents the set of routing nodes in the airborne network, i.e. $V = \{v_1, v_2, \ldots, v_n\}$. E represents the set of edges between nodes in the network, and each link between nodes $e(i, j) \in E$. At this point, the data transmission is translated into finding the best path (P (A, B)) from A to B in the graph G = (V, E).

Define the capabilities and current operating status of link $e(i, j)$ between node i and j as:

$$e(i, j)=\{b_{ij}, p_{ij}, s_{ij}, \alpha_{ij}(t), m_{ij}, \ldots\} \quad (1)$$

b_{ij}: transmission bandwidth between node i and j.
s_{ij}: security level between node i and j.
p_{ij}: max bit error rate of link transmission between node i and j.
$\alpha_{ij}(t)$: flow cumulative function of link $e(i,j)$.
m_{ij}: network protocol between node i and j, 0 indicates support time triggered, and 1 indicates support event triggered.

Then we can define.

$$P(\text{A}, \text{B})=\sum_{i,j \in V} e(i, j) \quad (2)$$

In fig 4, assure that link e(1, 4) has a low level of link security, and link e(2, 4) has a high level of link security. Besides of link security, other properties are the same. Then we have:

- Focus on end-to-end transmission delay, the shortest path P(A, B)=A-1-4-5-B should be chose.
- Focus on transmission security, then high security path P(A, B)=A-1-2-4-5-B should be chose.

Conclusion

This paper analyzes the current status of the airborne network and the direction of development, proposes an IAFC network architecture, and describes the composition of its backbone network, branch network, and terminal network. The IAFC network realizes the interconnection of different networks on a unified virtual interface plane, and converts the end-to-end transmission into a dynamic path-planning problem under multiple constraints. Users do not need to care about specific network protocols, interfaces, routes and configurations, they care about their own access requirements in terms of bandwidth, application mode, security level, service type, transmission reliability, and certainty. When the user proposes different application requirements, the virtual interface layer can construct the network topology according to different constraints, and then calculate the integrated weights of the network transmission model to select the optimal transmission path, thereby simplifying the process of system development, and achieve the end-to-end transparent transmission of the avionics terminals, which can meet the needs to future integration of avionics, electromechanical management, and flight control systems.

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