INVESTIGATE THE EVOLUTION OF ARINC PROTOCOLS AND THEIR EFFECTS ON MAINTENANCE

Executive summary

Aircraft Data Networks experienced rapid development with the evolution of Avionics where navigation communication equipment needed to be connected to a dedicated wiring. As technology advanced, even the most essential tasks such as steering and wire-fly became a challenge and needed interconnection. Inter-system communication and signalling are crucial subjects since the inception of electronic devices and their use in aircraft. Previously common sensory feedback along with engines and radar needed to be interconnected with cockpit controls for system communication. Detailed analysis of ARINC protocols such as A429, A629 and A664 has been conducted in this research. This chapter also uses in-depth analysis of quantitative data which were used to justify the reason behind this research. Evolution of major ARINC protocols has been thoroughly discussed and the impact it had on avionics maintenance industry have been critically evaluated. Furthermore, the five chapters of this research would provide a vivid picture of the entire research followed by recommendations which states the use of µAFDX as the next generation technology in avionics industry.

ACKNOWLEDGEMENT

Conducting this research has been one of the most enriching experiences of my life. The contribution of this research to enhance my knowledge base and analytical skill has been paramount. It gave me the opportunity to face challenges in the process and overcome them. This would not have been possible without the valuable guidance of my professors, peers and all the people who have contributed to this enriching experience. I would like to take this opportunity to thank my supervisor ----------------------- for the constant guidance and support provided to me during the process of this research. It would not be justified if I did not thank my academic guides for their important and valuable assistance and encouragement throughout the research process. I would also like to thank my friends who had provided me with help and encouragement for collecting primary data and valuable resources. Finally, I would like to thank the professionals from the retail industry who have participated in the research survey and provided with valuable inputs into the subject. The support of all these people has been inspiring and enlightening throughout the process of research in the subject.

Heartfelt thanks and warmest wishes,

Yours Sincerely,

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Chapter 1: Introduction

1.1 Introduction

Inter-system communication and signalling are crucial subjects since the inception of electronic devices and their use in aircraft. Previously common sensory feedback along with engines and radar needed to be interconnected with cockpit controls for system communication. Aircraft Data Networks experienced rapid development with the evolution of Avionics where navigation communication equipment needed to be connected to a dedicated wiring. As technology advanced, even the most essential tasks such as steering and wire-fly became a challenge and needed interconnection. As a result, ARINC 429, 629, 664 (AFDX) were invented and are almost used by entire aircraft engineering industry.

In this research, major ARINC protocols would be critically analysed which would help to achieve the objective of this research. ARINC 429 is found in most of the civil aircrafts whereas ARINC 629 enhanced autonomous terminal access communication. AFDX or ARINC 664 is said to achieve the highest standard of avionics network protocol along with latest electronic equipment use and aircraft wiring. The following chapters would further evaluate these three protocols along with data analysis which would help to investigate evolution of ARINC protocols and its impact on aircraft maintenance.

1.2 Aim of the research

The aim of this research is to investigate the evolution of ARINC protocols and their impact on aircraft maintenance engineering industry.

1.3 Research objectives

- To analyse different ARINC aircraft protocols in aircraft industry
- To evaluate the evolution of ARINC protocols
- To compare benefits and drawbacks of different ARINC protocols
- To understand the impact of various ARINC protocols on aircraft maintenance

1.4 Research questions

- What are the different ARINC protocols that are used in aircraft industry?
- How has the evolution of ARINC protocols occurred since inception of aircraft industry?
- What are the benefits and drawbacks of ARINC 429, 629 and 664 protocols?
- What is the impact of various ARINC protocols on aircraft maintenance?

1.5 Research topic background

Evolution of aircraft data networks is the main theme of this dissertation which has an adverse effect on aircraft maintenance engineering industry. Various avionics data network protocols which are based on avionics system architecture are useful for inter-system communication in aircraft coordination. Evolution of ADN that ranges from ARINC 429 to ARINC 629 to ARINC 664 also known as AFDX would be critically analysed in this research. Furthermore, it has also been observed that use of complex use of electronic equipment and wiring in aircraft have changed the way of aircraft maintenance.

According to the opinion stated by Nachlas (2017), introduction of data bus protocol in ADN helped to reduce aircraft weight and simplified its maintenance and design. Three types of avionics systems architecture are commonly used in aircraft known as independent avionics, federated system and integrated architecture. Based on this architecture the following research would evaluate each ARINC protocol and evaluate their feasibility. Hence, this study would enable the researcher to analyse each protocol and their impact on aircraft maintenance.

1.6 Rationale of research study

The main reason for selecting this research is because evolution of aircraft protocols has an impact on aircraft maintenance but lacks significant number of research. Not many researchers have spoken about this impact on aircraft maintenance which is why this research would help to establish a relation between ARINC protocols and aircraft maintenance. Aeronautical radio Incorporated or ARINC provides system engineering solutions and transport communications not only to aviation or aircrafts but also to government and defence units (Kazi, 2013). However, this research would focus on ARINC protocols on aircraft industry and would also evaluate the improvement of aircraft maintenance through ARINC protocol development.

1.7 Research study purpose

The selection of this would focus on evolution of ARINC aircraft protocols and its positive or negative effects on maintenance. Most of the aircrafts use ARINC communication system that includes both primitive and latest ARINC protocols. However, this study would focus and compare various ARINC protocols namely ARINC 429, 629 and 664 to provide a comparative analysis of them. Furthermore, the evolution of ARINC protocols would also help to assess its impact on aircraft communication maintenance and aircraft maintenance as a whole.

1.8 Research structure

The researcher has focused on making short chapter-wise divisions of research topics so that each perspective can be understood in a detailed manner. The entire research consists of five chapters which are summarised as following:

Chapter 1: Introduction

Basic details that are needed to be understood for the chosen topic are included in this chapter. As the name suggests, this chapter would give a brief introduction about ARINC protocols and its impact on aircraft maintenance. Research objectives and aims are the key areas of this chapter that justifies the purpose of this research.

Chapter 2: Literature Review

Wildemuth (2016) stated that concepts and theories assist a researcher to evaluate a particular area of study. Chapter 2 would take help from certain literary sources to understand the concept of different ARINC protocols in a detailed and standardised format. Furthermore, this chapter would include a critical perspective of the study that would analyse pros and cons of other relevant topics.

Chapter 3: Research Methodology

This chapter includes research process which helps in better data collection related to the research topic. Neuman (2013) stated that research methodology assists in guiding the researcher to gather useful data that would support the basis of a research. It would also include research philosophy, design and approach that would help in better analysis of this study.

Chapter 4: Data findings and analysis

This chapter would focus on collection of information and interpret them which would help in achieving the objective of this research. Various techniques involved in data analysis would help to justify the research based on responses from participants.

Chapter 5: Conclusion and recommendations

The final chapter of this research would include an overall view of the study and the outcome of the research. Based on research objectives, the researcher would link the objective to the research to determine the success level of this research.

1.9 Summary

ARINC protocols are important to maintain and coordinate communication system in aircrafts and this research would relate the effects of ARINC protocols to aircraft maintenance. Evolution of protocols would be mentioned in literature review followed by research methodology and data analysis that would compare different ARINC protocols and their usage. Hence, it would help the researcher to investigate evolution of ARINC protocols and their effects on aircraft maintenance as a whole.

Chapter 2: Literature Review

2.1 Introduction

Every aircraft operations require a high standard of inter-system communication which helps in simplifying complex tasks in the air. This is the reason for modification of integrated modular avionics which are based on avionic computing standards. As stated by Newman and Greeley (2017), evolution of ARINC protocols helped to correlate security, technology and cost-efficiency in modern day aircraft.

This chapter would focus on the evolution of ARINC protocol since its inception from 1930. All concepts and theories would be related to ARINC protocols such as ARINC 429, 629 and 664. Comparison among each ARINC protocols would be conducted which would help to evaluate the benefits and drawbacks of one over the other. Working structure, topology and protocol are some of the components of ARINC protocols that would also be discussed in this chapter. This foundation would enhance the research topic in a detailed manner allowing application of protocols for better analysis in rest of the research work.

2.2 Conceptual framework

Bilimoria *et al.* (2014) stated that conceptual framework in a research helps in categorising key theories for enhanced evaluation of a particular research topic. ARINC protocols and their evolution followed by its effect on aircraft maintenance are the key concepts that are highlighted in conceptual framework.

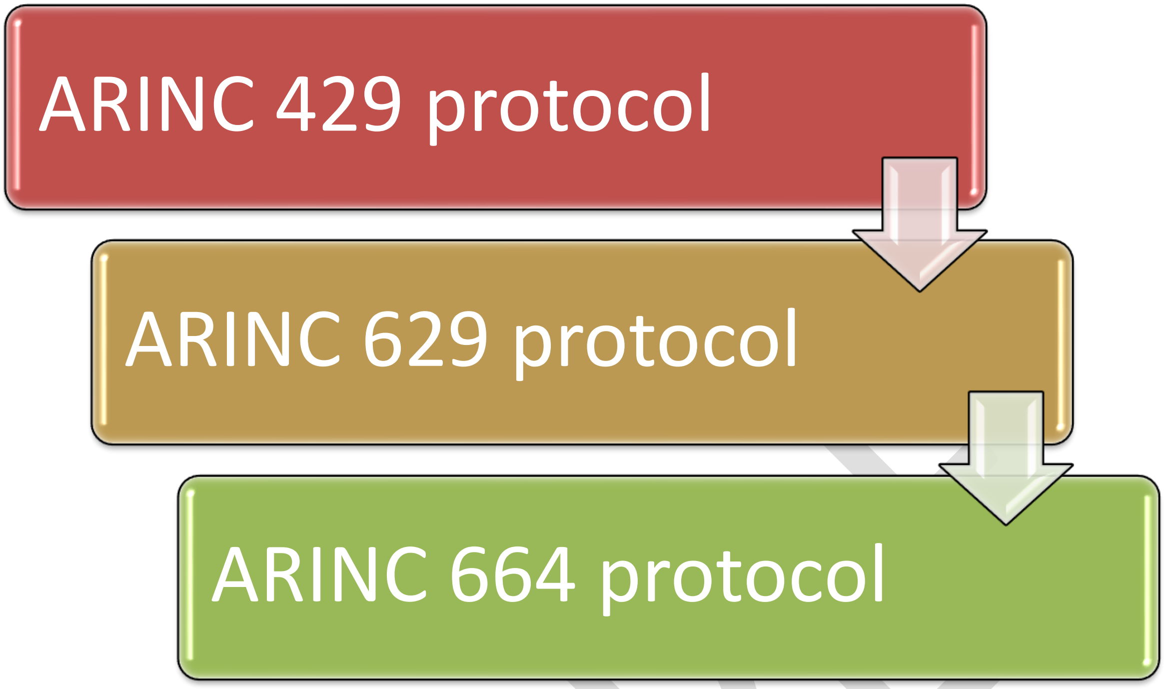


Figure 2.2.1: Conceptual Framework

(Source: created by author)

2.3 Gap in the literature

There are few types of research available which are based on evolution of ARINC protocols and its effect on aircraft maintenance. Although most of such research highlighted significance of ARINC protocols but failed to reflect the consequences they have upon aircraft maintenance. Moreover, previous research are mostly old and generally do not contain ARINC 664 or AFDX which is the latest ARINC technology that is used in most of the aircrafts.

As a result, this study would not only evaluate the changes or evolution of ARINC protocols over the ages but would also provide detailed impact that it had on aircraft maintenance as a whole. Different protocols such as ARINC 429 and 629 are used and compared along with the latest ARINC protocol, 664 is also used in this research. This would create a major uniqueness in this research and would justify the purpose behind this research.

2.4 ARINC 429 protocol

ARINC 429 is a technical standard which finds its applicability in predominant avionics data bus that is used in modern transport and commercial aircraft. It was the first ARINC protocol that defined electrical and physical interfaces of a double-wired data bus to facilitate an aircraft's avionics LAN (Balandina *et al.* 2014). It follows self-synchronising and self-clocking data bus protocol which is used for data transfer in aircraft avionics.

Twisted pairs of physical connection wires carry balanced differential signals where messages are of single data word having a size of 32 bits in length. Transmission of messages to systems that monitor bus messages occur at 100 or 12.5 kbit/s. Miller *et al.* (2014) stated that ARINC 429 transmitter has a continuous transmission of 32-bit data words where a single transmitter is limited to a single pair not exceeding 20 receivers. Self-clocking is used at receiver's end which eliminates need to transmit clocking data.

2.4.1 Network structure

ARINC 429 network has a single transmitter which is the source and is connected to a receiver which is the sink. Since ARINC 429 is a simple data bus, any sink would require its own transmitter if that equipment needs to reply (Safwat *et al.* 2014).

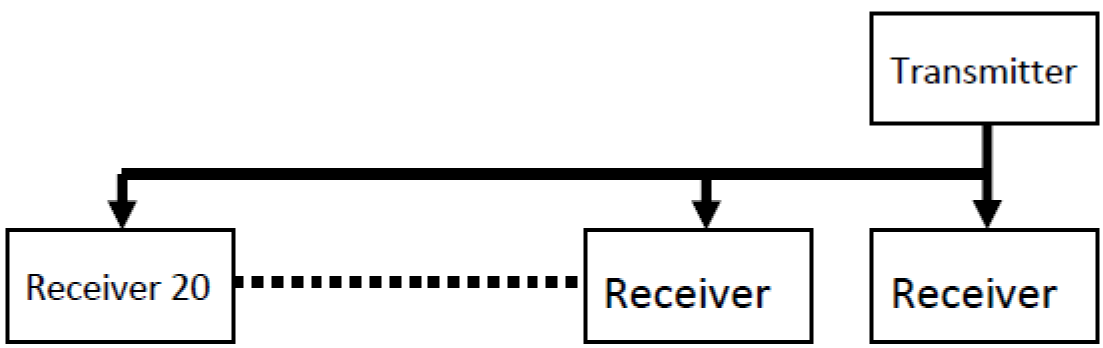


Figure 2.4.1.1: ARINC 429 layout having a single transmitter and 20 receivers

(Source: Safwat *et al.* 2014)

ARINC 429 specifies direct writing of line replacement units that use a twisted serial shielded pair-based interface capable of connecting peers that are 90 meters apart. Since it was a primitive communication system, sender sends the message to the line and responders read from it. Although the use of twisted shielded pair interface is used, one single sending station is used that has multiple recipients where if no data for sending is available, the line would be set to zero voltage.

Luckner *et al.* (2014) stated that the bus used in ARINC 429 has the flexibility of operating at both low and high speeds. High speed uses a fixed clock rate at 100 Kbit/s whereas low-speed mode has a variable clock rate with a throughput of 12.5 Kbit/s. Every chunk of word used in link data transmission is a word which are categorised into message control words and data words. Messages consisting of multiple data words are termed as records (Avionics-networking.com, 2018).

2.4.2 Working structure of ARINC 429

In ARINC 429, link control messages are implemented in the same manner as used in today's networking stacks in the following ways:

Status of listening LRU	Messages
Ready to receive data	*Request to send*
Not ready to receive data	*Clear to send*
Other status can be used as per sender or recipient criteria	*Data follows, Data received OK, Data received not OK, Synchronisation lost*

Figure 2.4.2.1: Link control messages in ARINC 429

(Source: created by author)

Such messages begin with the word for example *data follows* that are further followed by 126 data words. ARINC 429 protocol follows a simplex unidirectional bus where LRUs might not send messages related to link control to the bus which is being listened. Hierarchical layouts are found in this protocol where a station might be attached to many buses and operate as recipient or sender (Khan *et al.* 2014). In cases where bi-directional information exchange needs to be established, recipient LRUs are found to respond through a secondary interface where sender and recipient positions are interchanged. Since one ARINC 429 link can occupy only one sender role, each LRU would require only one back-channel for one participant single station.

Miller *et al.* (2014) stated that ARINC 429 transmits data using a shielded twisted cable in differential signal form. Encoding of data is done in a bipolar format that ranges till zero and the frame continuously transmits 32 bits data separated by 4-bit times of null voltage. Thus, this feature eliminates need for separate clock signal and supports self-clocking mechanism involving two speed rates. The high speed rate is of 100 kbps and low-speed rate is of 12.5kbps.

2.4.3 Protocol

As ARINC 429 uses a single transmitter on a twisted wire pair basis, it implements a simple point-to-point protocol. When data is found, ARINC 429 protocol transmitter continuously sends 32-bit data words or halts at NULL state (Carveraviation.in, 2017).

2.4.4 Word format of ARINC 429 protocol

The frame of ARINC 429 has a single 32-bit data word consists of five primary fields which can be classified as follows:

- Source Destination Indicator
- Label
- Data
- Parity
- Sign-Status Matrix

32	31	30	29 11	10	9	8 1
P	SSM		MSB DATA LSB	SDI		LABEL

Figure 2.4.4.1: ARINC 429 frame fields

(Source: Total Training Support, 2015)

As per the above figure, it can be stated that the only fault tolerance feature of ARINC 429 is the parity bit. Multiple data encoding formats that are used in avionics defined by ARINC 429 are as follows:

- Binary coded decimal
- Binary
- Discrete data
- ISO 646 character set
- Maintenance data and Acknowledgement

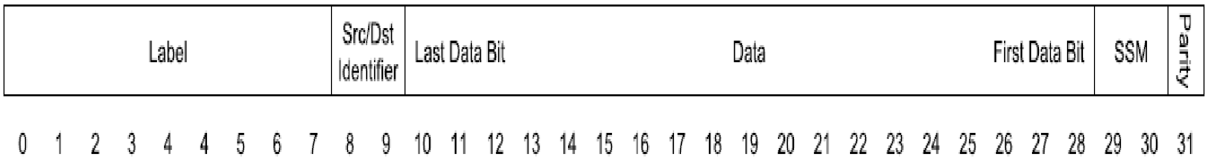


Figure 2.4.4.2: ARINC 429 data format

(Source: Total Training Support, 2015)

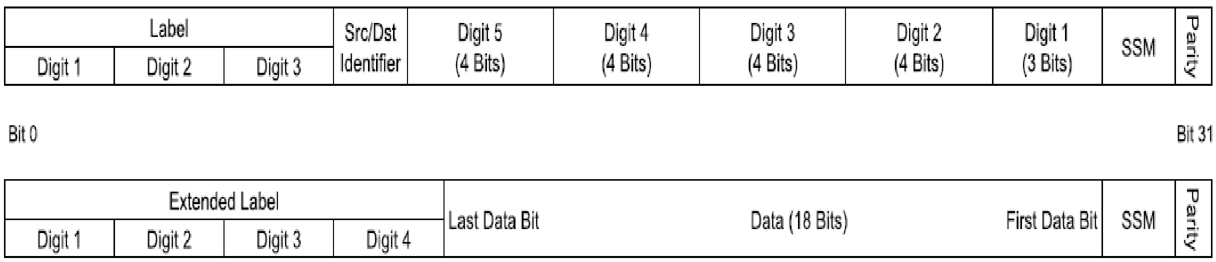


Figure 2.4.4.3: ARINC 429 BCD and binary word format

(Source: Total Training Support, 2015)

The common fields which are used in ARINC 429 are as follows:

- Label (8 bit)
- SSM (2 bit)
- Source and destination identifiers (2 bit)
- Data field (19 bit)

Small message size leads low latency that reduces delays in process timings due to the absence of transport side rescheduling of traffic. Nachlas (2017) stated that ARINC 429 achieves resilience, safety and reliability using such message sizes. However, ARINC 429 offers equal level of responsiveness that makes it a unique choice of application and is hardly found in modern day aircraft communication system. Termination of words are conducted by a single parity bit and based on a chosen data format the meaning of SSM flags are altered.

For example, BCD format is followed by assigning zero to both SSM bits. Other bit patterns have different predefined meanings which are supposed to be supported by LRUs for ensuring compatibility (Luckner *et al.* 2014). The label of a word is used as a frame header that holds information for encoding format and 3 octal numbers. This can be used by LRUs to where labels can be extended by 3 bits that serves as fourth label digit. Label digit codes are defined beforehand in a standard format and have constant meanings. The label is sent on an ordered basis where high-order-bit is sent first followed by least significant bit (Total Training Support, 2015).

2.4.5 Aircraft examples of ARINC 429

ARINC 429 is found in most of the commercial transport aircraft. ARINC 429 is also known as Mark 33 DITS which founds its applications in Boeing series of 737, 727, 757, 747 and 767. Other examples include McDonnell Douglas MD-11 and Bell Helicopters. Its unidirectional system is highly reliable that offers less wire weight and limited data rates.

2.4.6 Comparison with other protocols

Features	ARINC 429	ARINC 629	ARINC 664
Topology	Bus	Bus	Star
Medium	Dedicated	Shared	Shared
Duplex	Simplex	Half-duplex	Full-duplex
Bandwidth	2778 words/s	variable	3,000,000 frames/sec
Speed	100 kHz	2 MHz	100 MHz
Latency	Fixed	Bounded	Bounded
Quality of service	100 percent	None	Configurable

Table 2.4.6: Comparison between ARINC 429 with ARINC 629 and ARINC 664

(Source: created by author)

2.5 ARINC 629 protocol

2.5.1 Network structure

Asynchronous Full Duplex Switched Ethernet (AFDX) is a highly developed data network for avionics. King (2016) states ARINC has standardised the AFDX protocol with aircraft data networks. The topology used in the normal ethernet technology involves equal treatment of each node. In case of media collision in intranetwork packet transmission, Lopez *et al.* (2017) comment the topology allows continuous transmission till the process is complete. In order to enhance network availability, the topology applies for redundancy on its physical layers. Li *et al.* (2017) state decoupling of operation transition between data reception points uses variegated data buffers. This creates complete duplex data bridges between the end systems. ***[Refer to Appendix 4]***

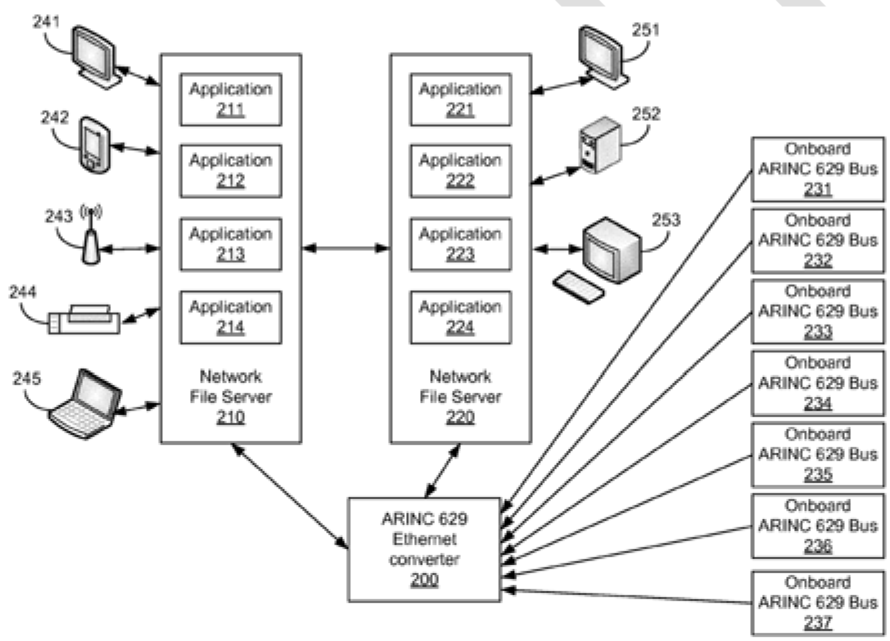


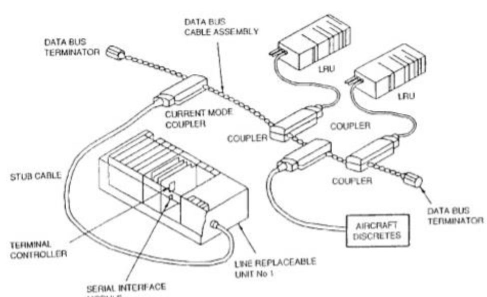
Figure 2.5.1.1: ARINC-629 network structure

(Source: Li *et al.*, 2017)

Although this facilitates data communication, bottleneck is common in the connection between several switches. The departing traffic transmission rates can be greatly enhanced than the inner switch data capacity. Fernández *et al.* (2015) have mentioned in their work that the application levels of AFDX are probably be replaced by ARINC-629 connections. As ARINC-629 represents connections between either separate single points or a single point to multiple points of hardware star, its networking structure is greatly similar to AFDX. The virtual links connect several end systems, by the representation of a point-to-point networking. According to Casquet *et al.* (2015), virtual links often connect multiple end systems. The main advantage displayed in the architecture of ARINC-629 is that it compatible with an application level. Akram *et al.* (2015) state this saves a prominent amount of cable trials through multiplexing various individual virtual links in a single wire network. ***[Refer to Appendix 5]***

2.5.2 Working structure of ARINC 629

ARINC 629 uses a linear communication series to specifically target in the avionics applications. ARINC 629 specifies LRU direct wiring with the help of a shielded, twisted pair-influenced interface which joins peers up to 90 meters apart. According to Fernández *et al.* (2015), the signalling standard of ARINC-629 transmits between the sender and the recipient in a liner format. In case, data is absent, this line is set to 0 voltages. Suthaputchakun *et al.* (2016) state the use of twisted shielded cable system pairs populates simplex connections with a single sender station and multiple recipient points, maximum of 19. The aircraft data network bus, commonly known as a multi-drop bus operates at various levels of adjustable speeds. Low speed applies variegated clock rate with a nominal throughput ranging from 12-14 kbps. In comparison, high-



speed modes need the fixed clock rates up to 100 kbps.

Figure 2.5.2.1: Components of ARINC-629

(Source: Suthaputchakun and Sun, 2015)

In the terminology of ARINC-629, all data chunks are delivered through a link called ‘word'. Suthaputchakun and Sun (2015) state in this case, transmit includes multiple data words, these are then named as records. If an active LRU is set to receive data, "Request to send" messages are transmitted through the dedicated link. "Clear to send" is applicable to an opposite task. Benammar *et al.* (2017) opine instructive phrase of “data follows” is replied with either “data received OK” or “data received not OK”. The “synchronization lost” phrase is used when issues in further interaction are denoted. ***[Refer to Appendix 6]***

2.5.3 ARINC 629 protocol

Two varieties of ARINC-629 protocols are used; basic and combined. Each of these two protocols possesses two modes, periodic and non-periodic. Spitzer (2016) states combined protocol is capable to support the prioritised information. Basic Protocol offers equal priority entry through all terminals to transmit both periodic and aperiodic information. Lopez *et al.* (2017) state in case the bus faces an overload, the terminals switch to an aperiodic mode with negligible data loss. In other times, constant transmission lengths of terminals transmit at constant intervals of periodic mode. This is because multiple terminals that use transmits for a free network bus may use clash avoidance protocols. ARINC-629 uses a similar clash avoidance method, CSMA/CA that is driven by the application of the timers. These timers are transmitted intervals, terminal and synchronisation gaps.

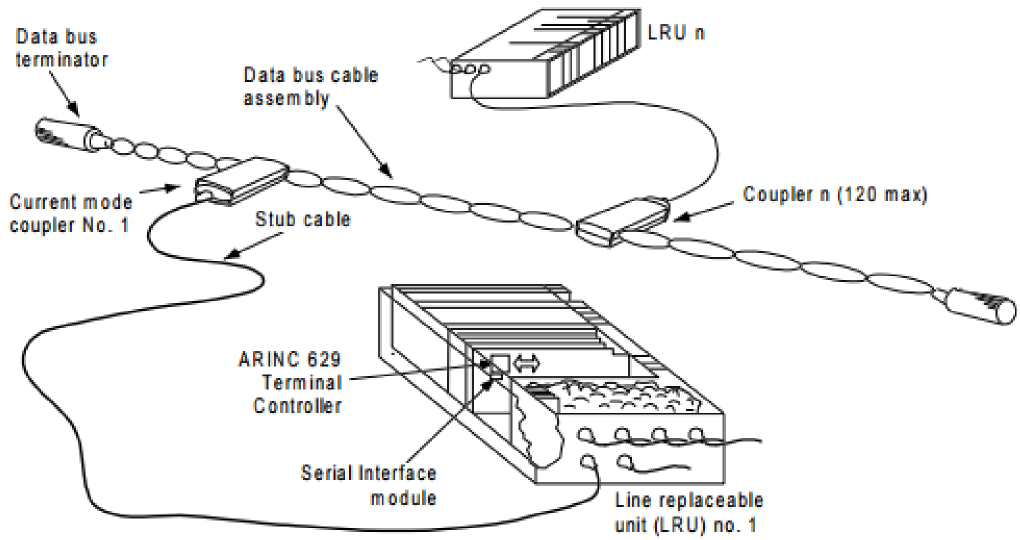


Figure 2.5.3.1: Interconnection of ARINC-629 systems

(Source: King, 2016)

Transmit Interval is a common timer that can be applicable to all the terminals in the aircraft data network bus. The minimum time required for the transmission signals sent from a single terminal. As revealed by the studies of King (2016) transmit interval is the longest timer. This is because it starts on the eve of the network transmission. In comparison to this, synchronisation gap is applicable when the traffic in the data bus is relatively lighter or quiet. The synchronisation gap is also sent from a single terminal. Casquet *et al.* (2015) comment the carries can reappear on the data bus while it undergoes a reset before its elapse. The terminal gap is unique for every single terminal in the same data bus. Terminal gap timer evaluates the transmission of terminal signals in case of multiple elapse of transmit intervals (Suthaputchakun *et al.*, 2016). The timer for terminal gap can also be reset in the availability of carrier.

2.5.4 Word format of ARINC 629 protocol

The patterns of multiple encoding formats of data are usually targeted in various usage instances. These formats are usually termed as Binary, Discrete Data, Binary Coded Decimal, Maintenance Data Acknowledgment and File transfer with ISO 646 data set. Fernández *et al.* (2015) comment the present structure of ARINC-629 words majorly conforms to next-generation standards of communication. The word format is primarily byte-aligned; however, it is optimized to reduce latency. The Word form in ARINC-629 protocol involves data transmission in chunks termed messages.

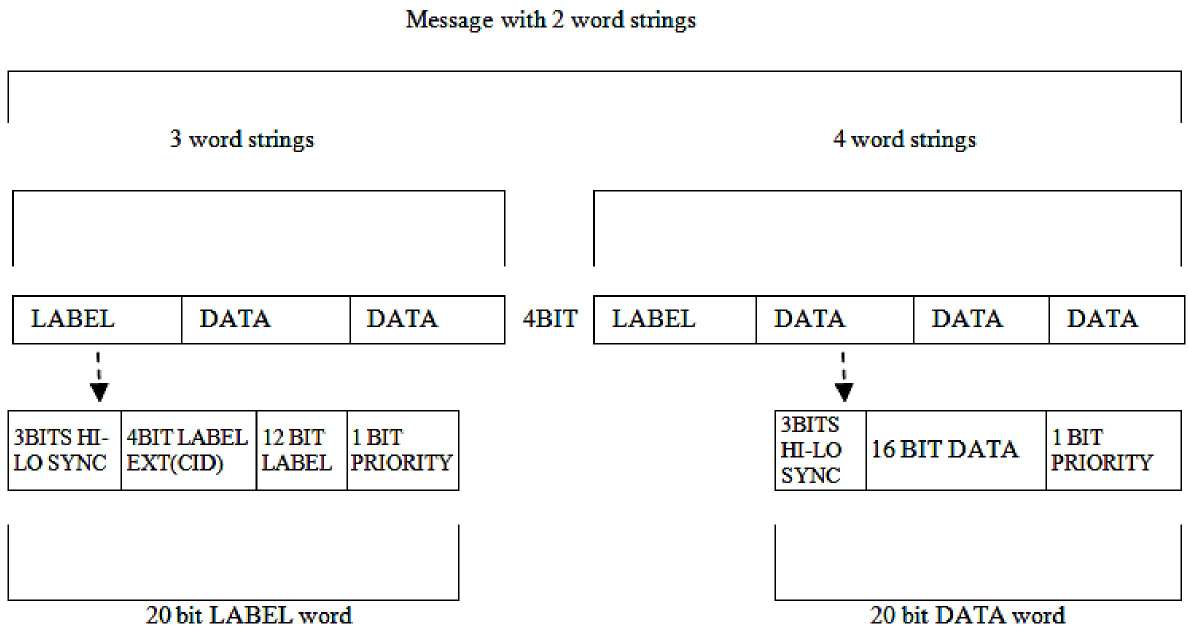


Figure 2.5.4.1: Word format of ARINC-629 systems

(Source: Szewczyk *et al.*, 2014)

This word format exists in two types, message control words and data words. Link control messages include multiple data words in advanced networking piles. However, all messages are substituted in the form of a unique terminal gap. Szewczyk *et al.* (2014) state each message is made up of maximum 31-word strings. These word strings start with a terminological label word comprised of 0 to 256 data terms. Casquet *et al.* (2015) comment a 4-bit time skip exists between simultaneous data word strings. The minimum labelled word string comprises a single label and 0 data word. In comparison, the maximum labelled word string includes 31 labels attached to 256 data words.

2.5.5 Aircraft examples of ARINC-629

ARINC-629 utilises the 100M bit bandwidth of the Ethernet connection. Demultiplexing of virtual links at destination switch and transmission to their appropriate end systems further facilitate the data. The ARINC-629 aircraft data network bus has been first initiated in 1995. This data network bus is applied to Airbus aircrafts and Boeing 777. According to Benammar *et al.* (2017), ARINC-629 topological network bus operates on the platform of multiple-sourcing and additional sink systemisation. All terminals are capable of data transmission and receipt from other terminals on the same aircraft data bus.

This facilitates more ease and freedom of data processing and exchange among several packets in the same avionics system. As revealed by Siewiorek and Swarz (2017), ARINC-629 possesses the capability to support a maximum population of 128 terminals in the network data bus. The data support rate of this bus is 2 megabytes per second. Airlines Electronic Engineering Committee developed ARINC-629 to replace its preceding data bus of ARINC 429. According to Suthaputchakun and Sun (2015), ARINC 629 network data bus is loosely based on the DATAC bus initiated by Boeing. While there has been an expectation that Boeing 777 has been the only aircraft to apply ARINC 629 network data bus. Spitzer (2016) states ARINC-629 data bus is also applied on Airbus A340 and A330.

2.5.6 Comparison with other aircraft protocols

A systematic comparison of ARINC-429, ARINC-629 and ARINC-664 is presented in this section. As commented by Li *et al.* (2017), the speed of ARINC-429 is 100 KHz in an average. This issue of speed is substantially reduced by a progress in the horsepower of the upgraded models. The ARINC-629 possess a 2 MHz speed whereas, ARINC-664 boasts of 100MHz. Casquet *et al.* (2015) state the throughput issue in which ARINC-429 has only 2778 words per second, while ARINC-629 has a variable range of throughput. In comparison to this, Suthaputchakun *et al.* (2016) state that ARINC-664 is capable of 3,000,000 words per second throughput. Similarly, the fixed latency in ARINC-429 is replaced in ARINC-629 and ARINC-664 with bounded latency.

The topology of these models is point to point in ARINC-429, while ARINC-629 and ARINC-664 use hardware and switched stars respectively. According to Benammar *et al.* (2017), the ARINC-429 is still the most reliable of all three data buses. Although, TDM and hardwire overall aspects of the later models help to improve overall reliability. The redundancy is maintained with double hardware-wire connectivity on ARINC-429. ARINC-629 applies 2 separate buses for standby and passive redundancy while ARINC-664 applies dual switches. With the help of recent subsystems, ARINC-429 communicates with other ARINC 429 interfaces. Lopez *et al.* (2017) comment ARINC-629 adds additional subsystem to couple to multiple buses and address hardwiring. Siewiorek and Swarz (2017) state this is a substantial resolution of the latency troubles. In ARINC-664 the addition of a subservient subsystem is used to establish a connection between available ports upon their relevant switches.

2.6 ARINC 664 (AFDX) protocol

Avionics Full-duplex Ethernet or ARINC 664 is a modern network protocol that is capable of meeting all new avionics requirements. Unlike other data bus networks of ARINC protocols such as ARINC 429 or ARINC 629, AFDX offers a low cost and flexible architecture along with a high-speed data transfer or 100 Mbps. According to the opinion stated by Bobrek *et al.* (2014), ARINC 664 is a well-established protocol which is based on conventional Ethernet that makes communication faster and easier. Since AFDX is based on probabilistic protocols and non-redundant architecture to the likes of Carrier-Sense Multiple Access or CDMA, it hardly meets prime avionics requirements reliability and determinism.

However, this protocol uses Ethernet that that supports low-cost parts and high-speed data transfer which is required in most of aircrafts' inter-system communication. According to the opinion of Blasch *et al.* (2015), the unique capability of ARINC 664 is to adapt conventional Ethernet and applies it to enhance modern avionics network. This data network is patented by French international aircraft manufacturer Airbus. It provides safe applications to critical operations through a dedicated bandwidth to ensure standardised quality of service. A practical and specific implementation of ARINC 664 is found in AFDX data network which defines COTS networking components and its viability in future ADNs. Following are the major aspects of ARINC 664 AFDX data network:

- Determinism
- Full duplex
- Redundancy
- Profiled network

- High-speed performance
- Switched network (Libguides.usc.edu, 2017)

2.6.1 Network structure

Bobrek *et al.* (2014) stated that the network structure of AFDX consists of three main parts as follows:

- **AFDX switch:** It interconnects source End System to destination ES and is the central component of Avionics full duplex Ethernet network. Although the links in ARINC 664 networks are in twisted pair cables, equal division of virtual links are present throughout the network.
- **End System:** It forms an interface between subsystems that is used for transmission of data and network.
- **Virtual link:** Such links are used for determination of a logical unidirectional connection that begins from a single source ES and ends at multiple destination ES. The System Integrator allocates a maximum bandwidth which is dedicated to each virtual links (Gutiérrez *et al.* 2014). ***[Refer to Appendix 1]***

AFDX follows a star topology network where each End System consists of dual AFDX ports that are connected to two redundant networks. In order to maintain availability and reliability of AFDX standard, transmission of packets and receiving packets are conducted over dual redundant channels.

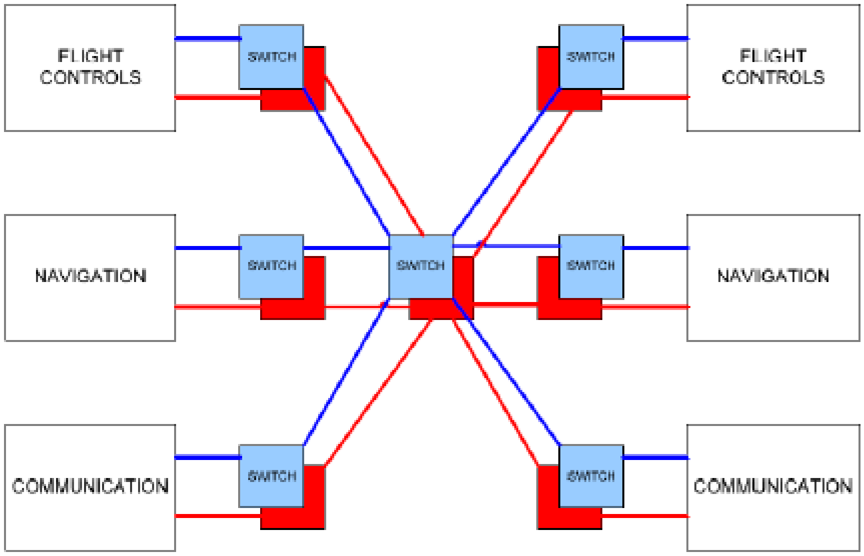


Figure 2.6.1.1: ARINC 664 physical topology

(Source: Safwat *et al.* 2014)

2.6.2 Working structure of ARINC 664 (AFDX)

The message flow control of AFDX ensures a comprehensive behaviour using network traffic control. As a result, effective traffic control is achieved through positive determination of bandwidth for each specific logical communication channel known as Virtual link or VL. This helps in providing a limited transmit latency and jitter which secures inter-system communication in aircrafts (AviftechVideos, 2012).

Virtual Link

A single physical communication link is used as a medium for communication between two Avionics full duplex Ethernet End System. According to the opinion of Safwat *et al.* (2014), AFDX implements transmission of virtual links as well as facilitates receiving Virtual Links. Using AFDX it is quite possible to establish VLs which consist of multiple communication links. Transmit virtual links can be assigned only to a single End System whereas receive VLs can be assigned to multiple End Systems. As per the opinion of Al Sheikh *et al.* (2013), the parameters of virtual links can be classified as follows:

- **Lmax:** It is the largest Ethernet frame which is capable of being transmitted on the VL and is measured in bytes.
- **Bandwidth Allocation Gap:** BAG is a timeslot which is confined to a virtual link bandwidth and defines a minimum gap time between two consecutive frames. The value of BAG should be between one to 128 ms and needs to be a power of 2.
- **Jitter:** This is an upper-bounded transmit latency that appears in the form of a time-frame offset present in bandwidth allocation gap. ***[Refer to Appendix 2]***

During transmission, maximum permissible jitter on each Virtual Link at the end point of End System needs to comply with the formula that is depicted in Appendix 3. As per the equation, *max_jitter* is measured in microseconds and *Nbw* is referred to as a medium bandwidth which is measured in bits/seconds. 40 microseconds is the minimum fixed technological jitter where *Lmax* is measured in octets. Appendix 3 also states that maximum jitter to be allowed for processing would be less for ES that consists of few virtual links along with small frame sizes. As stated by Li *et al.* (2014), in most of the cases the jitter is limited to 500 microseconds that bounds the impact on determinism upon the entire network.

Flow scheduling

Al Sheikh *et al.* (2013) stated that Bandwidth Allocation Gap regulates AFDX frames which are unique for each Virtual Link. Figure 2.6.2.1 shows a Virtual Link Scheduler which is responsible for regulator output multiplexing where a jitter is introduced when a combination of VL scheduler multiplexer and regulator outputs occurs. Furthermore, Ethernet frames experience jitter or queuing delay when they arrive at multiplexer at the input.

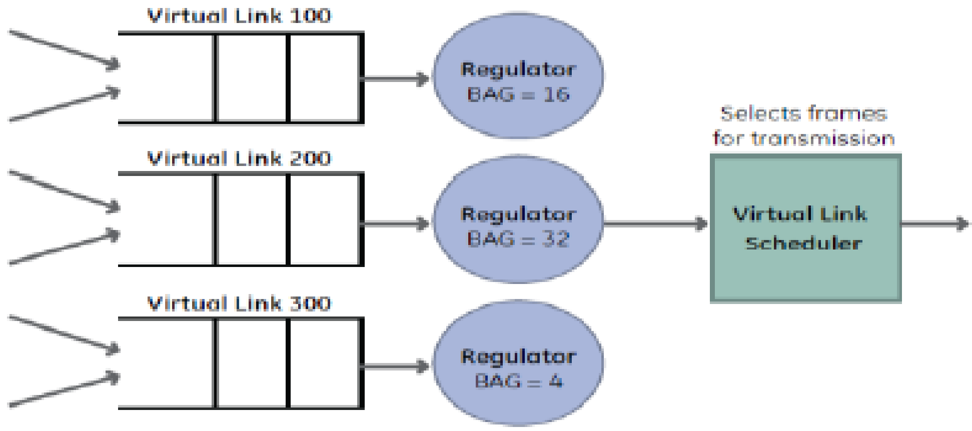


Figure 2.6.2.1: VL scheduler

(Source: Safwat *et al.* 2014)

2.6.3 Protocol

ARINC 664 consists of five layers and as a protocol derived from Ethernet, Avionics full duplex Ethernet Media Access Control data link layer is similar to that of Ethernet media access control data link layer. Safwat *et al.* (2014) stated that Sequence Number is the only difference that distinguishes Ethernet MAC from AFDX MAC. AFDX implements Internet Protocol above Ethernet layer that helps to manage frame reassembly and fragmentation along with packet forwarding. UDP or User Datagram Protocol is considered as the last AFDX protocol layer stack which is connectionless and has zero transmission error control. The selection of UDP was chosen over Transmission control protocol because UDP is more efficient than TCP. Blasch *et al.* (2015) stated that TCP is a connection-oriented protocol and facilitates transmission error control but is not required in case of AFDX. This is because the policing and redundancy management of AFDX bandwidth has the least possibility of frame loss. Moreover, UDP secures AFDX user data which ensures reliability and security of data transmission.

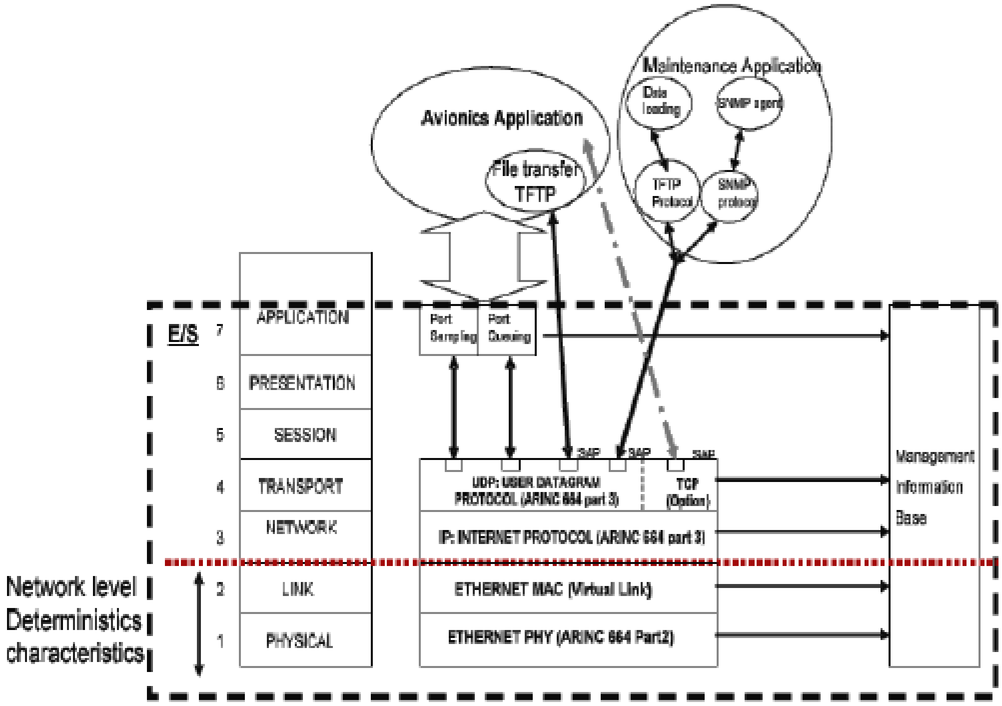


Figure 2.6.3.1: Protocol layers of AFDX

(Source: Safwat *et al.* 2014)

2.6.4 Word format of ARINC 664 (AFDX) protocol

A VL needs to be identified by a MAC destination address where MAC source address of AFDX frames needs to be MAC unicast address used for identifying physical Ethernet interface. The following table shows Ethernet MAC controller of 48 bits:

Constant field of 24 bits	**User-defined ID of 16 bits**	**Constant field of 5 bits**	**Interface ID of 3 bits**
“0000 0010 (0000)x4”	“bbbb bbbb bbbb bbbb ”	“0 0101”	“nnn”

Table 2.6.4.1: AFDX frame source address

(Source: Safwat *et al.* 2014)

Source address

As per the above table it can be stated that constant field of AFDX frame source needs to be of 24 bits in the form of binary digits. Bobrek *et al.* (2014) stated that in AFDX source address, zero is the least significant bit present in the first byte of individual address. Locally administered address is one which indicates second least significant bit present in the first byte. The user defined identification is used as a system integrator which assigns meaningful and unique IP address to the network's host. Interface ID matches the point where Ethernet MAC controller is connected to AFDX network such as 010 for Network B and 001 for Network A. The following table shows 48 bits AFDX frame destination address:

Constant field of 32 bits	**Virtual link identifier of 16 bits**
"xxxx xx11 (xxxx)x4"	

Table 2.6.4.2: AFDX frame destination address

(Source: Safwat *et al.* 2014)

Destination address

In this address frame of AFDX, each End System should receive Virtual Link Identifier and constant field from a system integrator. This constant field needs to be same for each ES in the specific AFDX network where the least significant bit present in the first byte indicates the group address which is 1. Second least significant bit present in the first byte that indicates local administered address is also 1 where MAC group addresses are used to send frames from a single ES to multiple End Systems. However, if group addresses are used in MAC layer, unicast communication can still be achieved at IP layer level through IP unicast destination address (AviftechVideos, 2012).

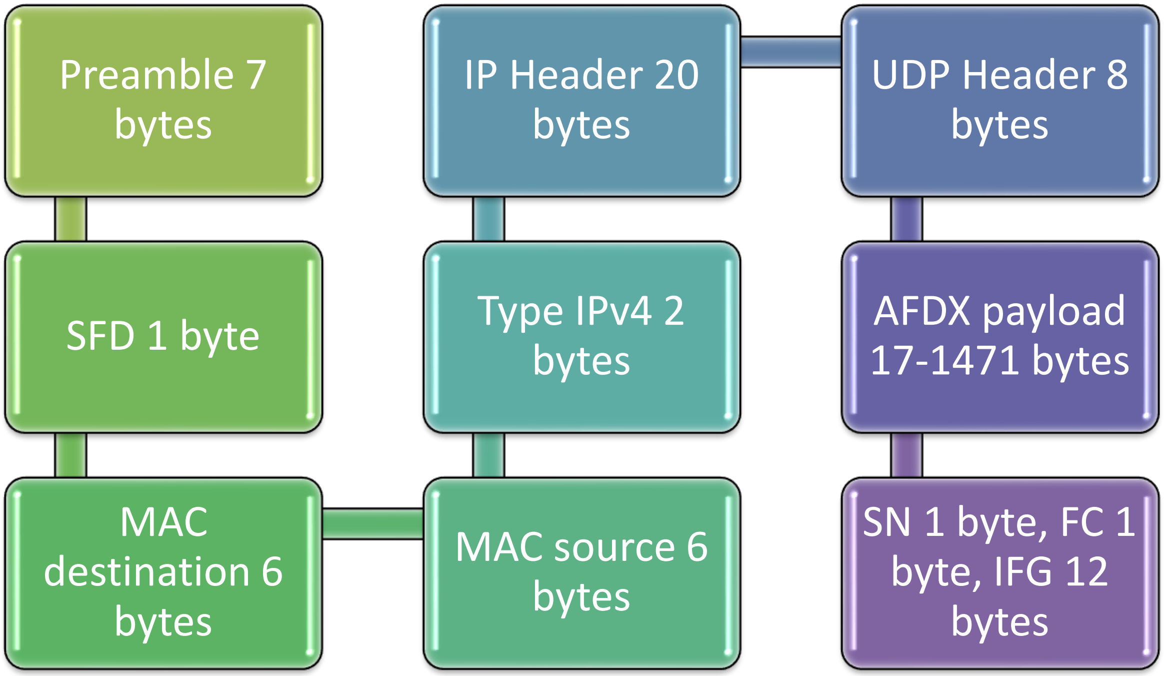


Figure 2.6.4.1: AFDX frame structure

(Source: created by author)

2.6.5 Aircraft examples of ARINC 664 (AFDX)

Following are the list of practical usage of ARINC 664 which are used in major aircrafts:

- ARINC B787
- Airbus A350, A380 and A400M
- COMAC ARJ21
- Sukhoi RRJ-100
- Bombardier Cseries and Global Express
- AgustaWestland AW149, AW101, AW169 and AH64
- Irkut MS-21

2.6.6 Comparison with other protocols

The following table compares ARINC 664 with ARINC 629 and ARINC 429.

	ARINC 664	**ARINC 629**	**ARINC 429**
Reliability	Least usage of wiring and hardware greatly	TDM usage ensures reliability of function	It is considered most reliable than other two

	improves overall reliability		
Flexibility	Addition of another subsystem is connected easily by a switch to available ports	Addition of a subsystem creates latency issues as it involves hardwiring and buses	For every new addition of subsystem, one new ARINC 429 interface needs to be added
Redundancy	Consists of dual switches with redundancy	Standby and passive buses are used for redundancy	Wiring and hardware is doubled for redundancy
Latency	Bounded	Bounded	Fixed
Topology	Switched star	Hardware star	point-to-point
Quality of Service	Configurable	Inconsistent QoS	100 percent
Speed	100 MHz (Fast)	2 MHz (Moderate)	100 KHz (Slow)
Throughput	Maximum 3 million words per second	Variable	2778 words per second

Table 2.6.6.1: Comparison of ARINC 664 with ARINC 629 and ARINC 429

(Source: created by author)

2.7 Conclusion

In this chapter of Literature Review a detailed evolution of different significant ARINC protocols have been thoroughly analysed. This would help to evaluate its impact on maintenance that would be further discussed in the later chapters of this research. As per the analysis it can be stated that ARINC 429 is the pioneer of ARINC protocols that are being used in modern aircraft. It is still one of the most reliable aircraft protocols used in modern day inter-system communication purpose. However, ARINC 629 was a modification of ARINC 429 that offered more speed and flexibility of usage but had a drawback of complex wiring that led to added weight to the aircraft. AFDX or ARINC 664 is the latest ARINC protocol and is considered the safest inter-system aircraft communication protocol.

This chapter provides conceptual framework that helps to understand the workflow and thought process used in this research. All ARINC protocols include detailed study where their network topology, physical structure, protocol, data format are evaluated. Furthermore, practical usage of such ARINC protocols in aircrafts and their comparison with each other are conducted in this chapter. All these information would be crucial for the researcher to understand the evolution of ARINC protocols and would facilitate further progress of this research through primary and secondary data analysis. Moreover, this research also includes a literature gap which helps to understand the reason behind selection of this research topic and previous research conducted on similar grounds.

Chapter 3: Research Methodology

3.1 Introduction

Research methodology is an important chapter of a research work that assists in defining a suitable approach to achieve precise and detailed research results. As stated by Singh (2015), concepts and theories used in research methodology help to achieve better and in-depth research topic analysis. This chapter would include research philosophy, design, approach and data collection analysis which would facilitate easier progress of the research and help to investigate impact of ARINC protocols on aircraft maintenance.

3.2 Method outline

Detailed research techniques are used in this chapter that would help to justify impact of evolution of ARINC protocols on aircraft maintenance. In this research positivism philosophy is used followed by deductive research approach and explanatory research design. Justification of all chosen research methods is given followed by data analysis and sampling techniques (Center for research quality, 2015).

3.3 Research onion

Research onion is a crucial research tool that enlists key divisions of a research which facilitates easy research analysis. As stated by Saunders *et al.* (2009), research onion helps to conduct research in a proper format which follows six research process categories.

- Choices
- Procedures
- Philosophies
- Approaches
- Time horizons
- Strategies

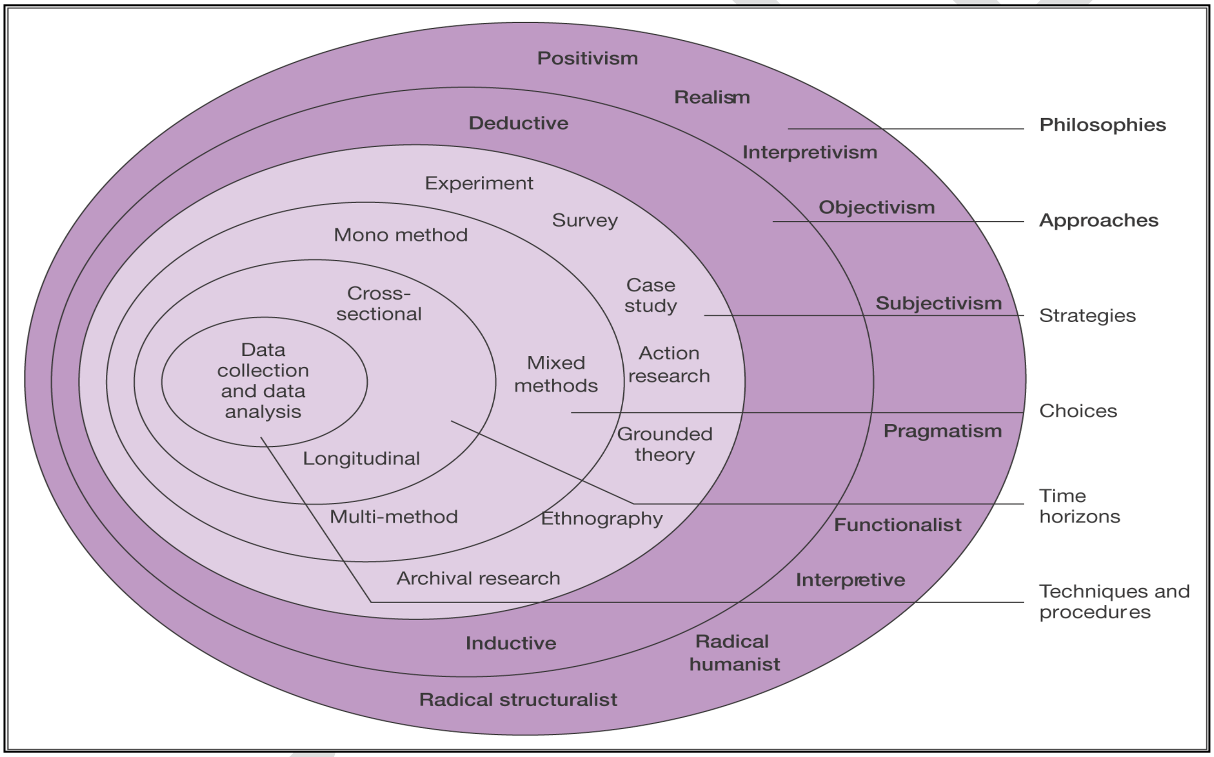


Figure 3.3.1: Research onion

(Source: Saunders *et al.* 2009)

3.4 Research philosophy

In every research, selection of research philosophy needs to be chosen wisely which should be in accordance with the research topic. The researcher has chosen positivism philosophy for this research because this philosophy aids in application of logic that analyses latent information and facts in a smooth scientific manner. (David Russell, 2014)

3.4.1 Justification for selecting positivism philosophy

Other research philosophies are not chosen for this research because they would contain mixed or multiple method designs accompanied by small samples which would be irrelevant for this research. Furthermore, positivism philosophy is highly structured, consists of large samples and would involve conceptual analysis that would achieve desired outcome of the research (Britannica.com, 2017).

3.5 Research approach

Pearl (2014) stated that most of the research follows two kinds of research approach known as deductive and inductive approach. The researcher has chosen deductive approach in this research study as it would include practical application of theories to gain in-depth access to research work.

3.5.1 Justification behind selection of deductive approach

Inductive approach uses introduction of new concepts or theories to justify a chosen research which is not required for this research. Deductive approach is chosen because it aims to support a research based on existing theories and concepts and would justify impact of ARINC protocols on aircraft maintenance (Ormston *et al.* 2014).

3.6 Research design

Research design helps to explain research topic framework that assists in understanding analysis and collection pattern. The researcher has chosen explanatory research design in this research work as it would help to describe occurence of events or incidents and evaluate the happenings that would provide a suitable outcome for this research (Adina Dudau, 2015).

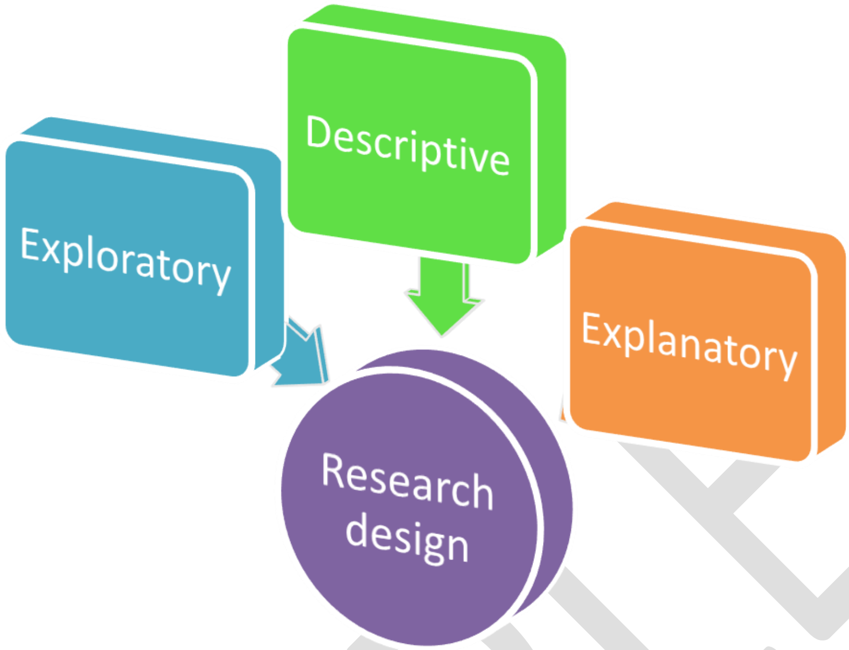


Figure 3.6.1: Types of research design

(Source: created by author)

3.6.1 Justification for selecting explanatory design

Explanatory research design has been chosen as this research would require connection of ideas to evaluate effect and cause of ARINC protocols. Exploratory predicts an outcome beforehand which is irrelevant for this research. Although descriptive can be a substitute for explanatory design but the latter is more precise and easy to understand that justifies its use over other research designs (Researchrundowns.com, 2017).

3.7 Data collection procedure

Singh (2015) stated that data collection is a useful process that supports facts and evidences which justifies research analysis. It aids in accurate result derivation and the researcher has chosen primary data sources for conducting this research work.

3.7.1 Data sources: Primary and Secondary

Primary data sources provide materials that help to gain in-depth analysis of any research topic. Primary data are raw data collected from surveys and interviews whereas secondary data are collected from newspapers, journals or other articles (Ormston *et al.* 2014). This research would include a questionnaire that would be surveyed across 61 aircraft maintenance staffs of ARINC.

3.7.2 Data techniques

The researcher has chosen quantitative data technique to conduct this research. Quantitative data would help application of statistical data from questionnaire to investigate impact of ARINC protocol evolution on aircraft maintenance (Liamputtong and Serry, 2015).

3.8 Population and sample

Population refers to the number of people who are indirectly or directly involved in a research process. In the current research 61 aircraft maintenance staffs of ARINC have been considered to evaluate impact of ARINC protocols on aircraft maintenance (Lewis, 2015).

3.8.1 Sampling technique

In this research, a sample of 61 aircraft maintenance staffs have been considered for surveying through a questionnaire working in ARINC. These data would support the impact of evolution of ARINC protocols on aircraft maintenance (Averill, 2014).

3.8.2 Sample size

Sample size is divided into quantitative technique. Quantitative research techniques include a sample size of 61 aircraft maintenance staffs where total sample size is of 61. Qualitative research would include journals, online articles, newspapers and magazines. Maintenance staffs would be surveyed based on a questionnaire likert scale (Sotiriadou *et al.* 2014).

3.9 Ethical considerations

Singh (2015) stated that a researcher needs to follow a code of conduct during a research to distinguish right from wrong. Following ethical considerations have been considered during this research:

- **Respondents involvement:** No external influence were put on respondents during their response and they voluntarily participated in this research
- **Respondents anonymity:** Researcher completely avoided any sort of mental or physical harassment to the respondents and maintained their anonymity in this research
- **Data application:** Commercial application of the data found in this research is avoided to restrict its use only for academic purpose (Woods *et al.* 2016)

3.10 Research limitations

- **Time-constraint:** As the study was cross-sectional in nature, the researcher had to complete it within a short period of time due to which certain in-depth details could not be analysed
- **Reliability:** ARINC maintenance staffs could provide biased answers that might cause issues related to reliability of the data study
- **Budget-constraint:** Due to limited budget research could not gather further data on foreign aircraft manufacturing industries and other journals which could have improved this research (Zhang and Wildemuth, 2016).

3.11 Timeline

		Name	Duration	Start	Finish
1		Selection of the topic	1 day?	12/4/17 8:00 AM	12/4/17 5:00 PM
2		Introduction Chapter	3 days	12/5/17 8:00 AM	12/7/17 5:00 PM
3		Literature Review	8 days	12/8/17 8:00 AM	12/19/17 5:00 PM
4		Research methodology	2 days	12/20/17 8:00 AM	12/21/17 5:00 PM
5		Data findings and analysis	3 days	12/22/17 8:00 AM	12/26/17 5:00 PM
6		Conclusion and Recommneda	2 days	12/27/17 8:00 AM	12/28/17 5:00 PM
7		Personal statement	1 day	12/29/17 8:00 AM	12/29/17 5:00 PM

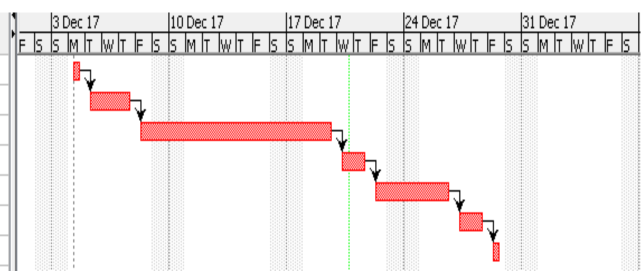


Figure 3.11.1: Timeline

(Source: created by author)

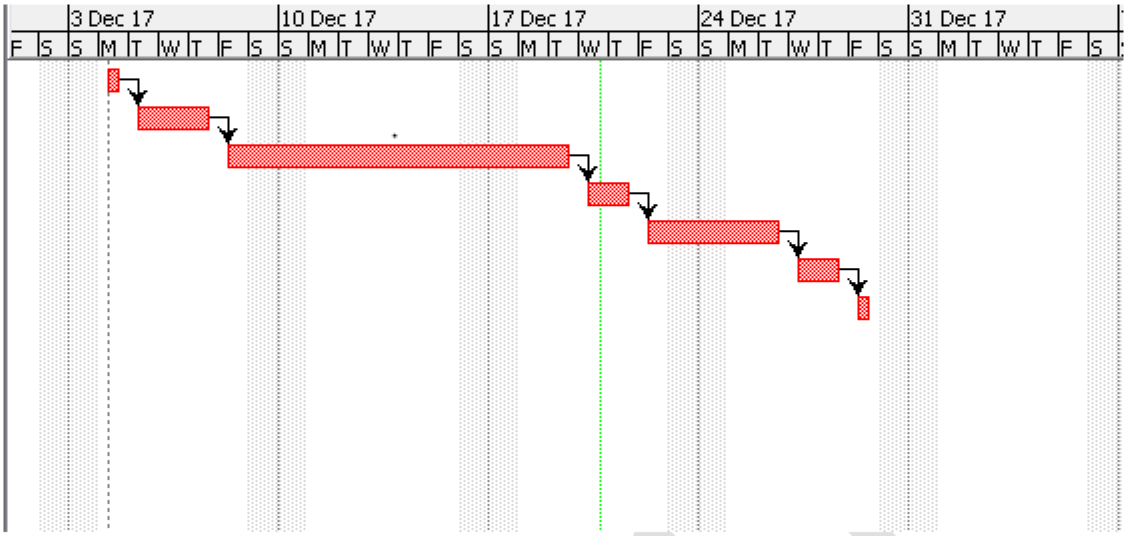


Figure 3.11.2: Gantt chart of timeline

(Source: created by author)

3.12 Summary

This chapter focused on describing different research tools that help in better research analysis. The researcher aligned the nature of study with research techniques to evaluate possible research methodology. These methodologies and tools would help to achieve justification for impact of evolution of ARINC protocols on aircraft maintenance.

Chapter 4: Data findings and analysis

4.1 Introduction

The following chapter would focus on gathering data based on questionnaire for survey which would include primary quantitative data analysis. Based on this analysis, it would help the researcher to gather data required to support the fact whether evolution of ARINC protocols had affected aircraft maintenance or not. According to the opinion stated by Ezzy (2013), quantitative or qualitative data analysis in a research helps a researcher to support the justification for a research. However, it has also been observed that data analysis involves limitations and complexities such as data manipulation or lack of genuineness. This generally occurs as employees or managers provide some biased answers either to promote a good image of the organisation or to purposely defame the organisation out of internal conflicts (Clarke and Braun, 2013). Despite all limitations every research needs to include data analysis which would form basis for evidence supporting the research work. Evolution of ARINC avionics protocols have already been discussed in this research and this chapter is solely meant to investigate impact of this evolution on avionics maintenance.

4.2 Primary quantitative analysis for avionics maintenance staffs

In this section, maintenance staffs of ARINC are considered for qualitative data analysis in the form of a survey consisting of open and close-ended questions. The number of involved respondents are 61 as others were not able to participate in the survey. The collected data helped the researcher to understand the impact of evolution of ARINC protocols on avionics maintenance.

Q.1) Which of the following best describes your current job level?

Options	**Number of responders**	**Total responders**	**Response percentage**
Internship	10	61	16%
Technician	23	61	38%
Licence Engineer	25	61	41%
Others	3	61	5%

Table 4.2.1: Response to classification of job

(Source: created by author)

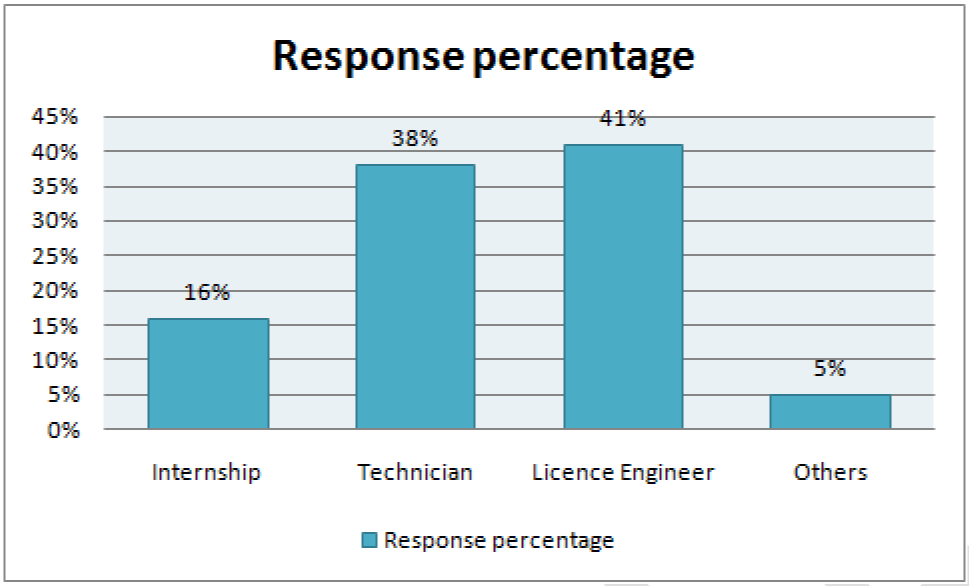


Figure 4.2.1: Graph reflecting percentage of maintenance staff positions

(Source: created by author)

Findings and analysis:

As per the survey, it can be stated that most of the maintenance staffs working with ARINC are technicians and licensed engineers. Only 16 percent are interns who aspire to work with ARINC whereas those who responded others belong to support workforce of ARINC maintenance operations such as aviation mechanic and airframe mechanic.

Q.2) On which ARINC protocol do you have working experience?

Choices	**Number of responders**	**Total responders**	**Percentage of response**
ARINC 429	10	61	16%
ARINC 629	21	61	34%
ARINC 664 (AFDX)	20	61	33%
More than one	10	61	16%

Table 4.2.2: Response to working experience of different ARINC protocols

(Source: created by author)

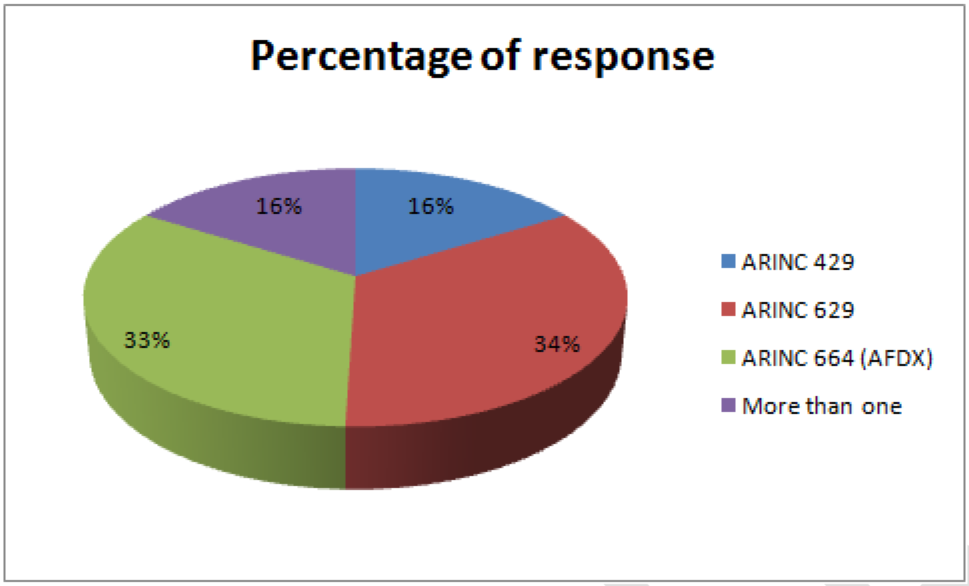


Figure 4.2.2: Pie chart showing percentage of working experience on different ARINC protocols

(Source: created by author)

Findings and analysis:

It is observed that out of the selected respondents, majority of them have experience on A629 and A664 (AFDX) whereas few have experience on ARINC 429. Only 16 percent of the total have considerable experience working with more than one ARINC protocol. However, all of these 16 percent astonishingly had knowledge about all ARINC protocols and have been working ARINC for a pretty long time. Hence, most of the answers that would be collected from this survey would be obtained from maintenance engineers who have substantial experience in any one of the protocols.

Q.3) How many years of experience do you have working with ARINC?

Alternatives	Number of responders	Total responders	Response percentage
1-2 years	10	61	16%
2-5 years	35	61	57%
Above 5 years	16	61	26%

Table 4.2.3: Response based on total experience of maintenance staffs

(Source: created by author)

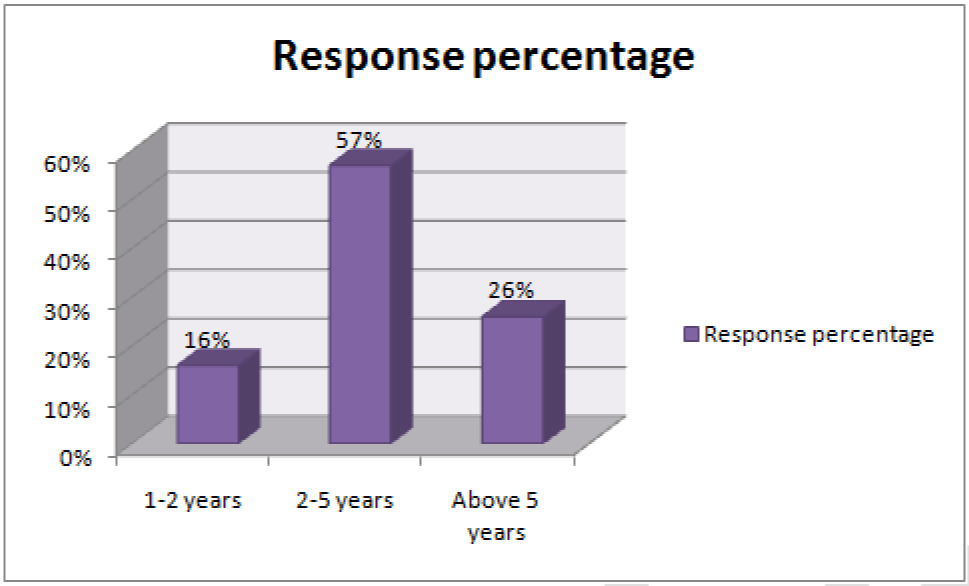


Figure 4.2.3: Graph showing experience of respondents of ARINC

(Source: created by author)

Findings and analysis:

Most of the participants had an experience ranging from 2 to 5 years followed by maintenance personnel who have more than 5 years of experience. Most of those who had above 5 years of experience also have experience working with all ARINC protocols. The least number of personnel having experience is mostly interns and new joiners who have experience only of working with A664 protocol.

Q.4) Which of the ARINC protocols have least inspection duration?

Options	**Number of responders**	**Total number of responders**	**Percentage of response**
ARINC 429	40	61	66%
ARINC 629	9	61	15%
ARINC 664 (AFDX)	12	61	20%

Table 4.2.4: Response of ARINC protocols taking least inspection duration

(Source: created by author)

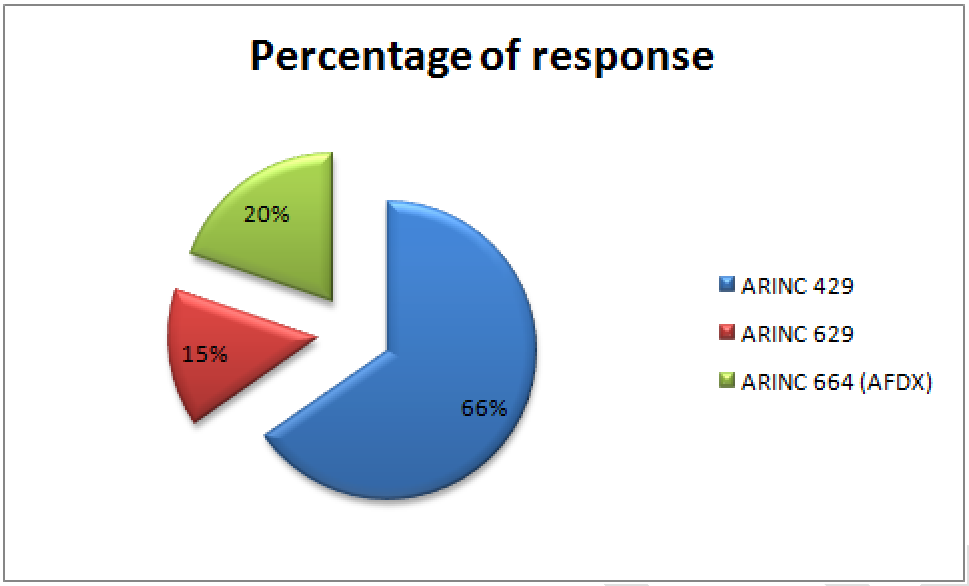


Figure 4.2.4: Pie chart showing ARINC protocols taking least inspection duration

(Source: created by author)

Findings and analysis:

Although AFDX is the latest development of ARINC protocol as per the response, A429 being the primitive ARINC protocol uses least inspection duration. This is due to the fact that A429 requires least wiring out of the other two and is based on simplex data bus architecture. Since A629 operates on multiple sources and multiple sink system unlike A429 which used single source and single sink, it requires complex wiring which increases duration for inspection. A664 uses Ethernet connection with highly complex wiring that speeds up data transfer but because of this feature it usurps a lot of inspection time.

Q.5) Are the hand tools that are used for ARINC maintenance operations apply to all ARINC protocols?

Choices	Number of responders	Total responders	Percentage of response
Yes	30	61	49%
No	31	61	51%

Table 4.2.5: Response related to hand tools used in ARINC protocols

(Source: created by author)

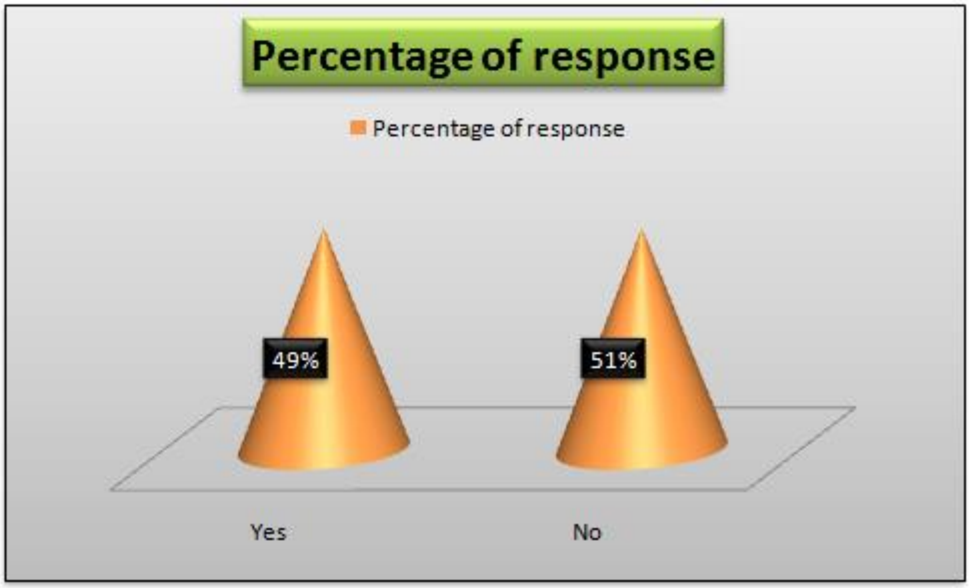


Figure 4.2.5: Graph showing response to application of ARINC protocols

(Source: created by author)

Findings and analysis:

Since most of the modern ARINC protocols are based on ARINC 429, tools are more or less the same that is used in all ARINC protocols. Since respondents belonged to varying experience levels, a mixed review was reflected on ARINC operation tools. Marginally most of them supported the fact that general operation tools do not support all ARINC protocols. For example, Hydraulic Jack J200009-78 was superseded by J200009-173 due to modification in sinks in A629 to that of A429. Hence, the older hydraulic jack would be invalid unless it is modified to operate A629. Old tools for A429 could only operate copper network interface whereas modern tools could operate both copper and fibre optics interface.

Q.6) Are there any differences in terms of using hand tools needed to repair equipment in A664 compared with A429 and A629?

Options	Number of responders	Total number of responders	Percentage of response
Agree	48	61	79%
Disagree	13	61	21%

Table 4.2.6: Differences in terms of using hand tools needed to repair equipment in A664 compared with A429 and A629

(Source: created by author)

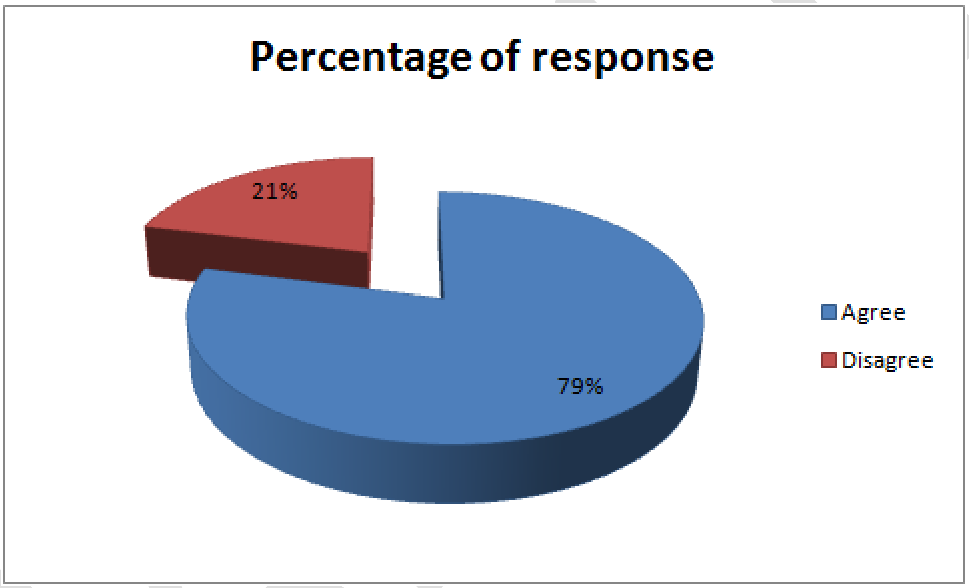


Figure 4.2.6: Pie chart showing percent of responses using hand tools for different ARINC

(Source: created by author)

Findings and analysis:

It is quite obvious that due to the evolution of ARINC protocols, evolution of hand tools to operate ARINC also developed. The tools that are used to repair equipment in A664 are quite different to those of A629 and A429 and this fact is supported by 79 percent of respondents. This difference made it easy for maintenance staffs to quickly repair A664 equipment and is quite convenient. Among the rest 13 candidates, most of them were experienced only in A664 due to which they were unable to compare previous repairing tools or equipment with the ones used in A664.

Q.7) In case of any overhaul or repair operations to ARINC protocol, which one of the protocols are easy to access the entire component?

Options	**Number of respondents**	**Total number of respondents**	**Percentage of respondents**
ARINC 429	38	61	62%
ARINC 629	13	61	21%
ARINC 664 (AFDX)	10	61	16%

Table 4.2.7: Response to repair operations of ARINC protocols

(Source: created by author)

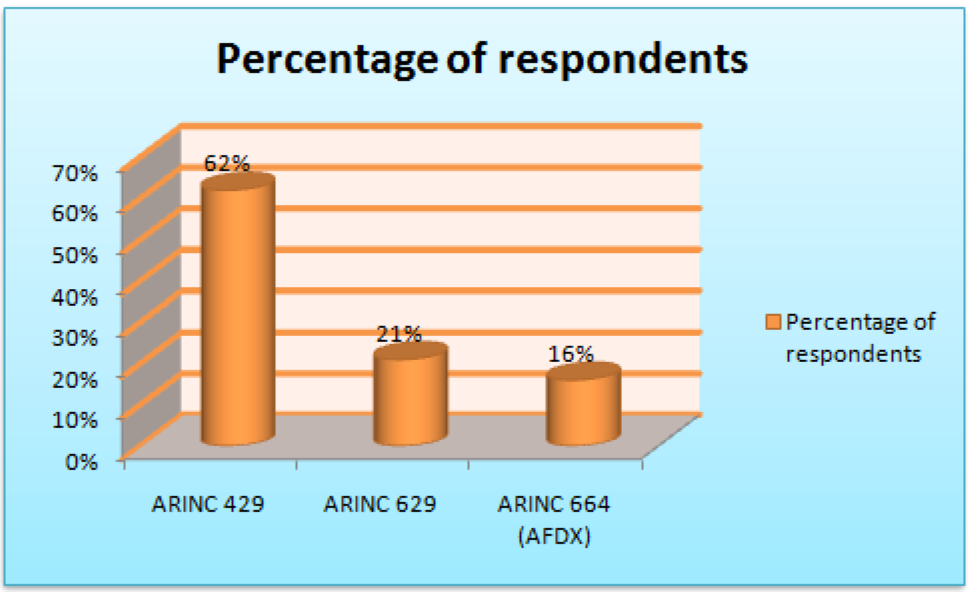


Figure 4.2.7: Graph showing percentage of responses on repair operations of ARINC

(Source: created by author)

Findings and analysis:

Since ARINC 429 follows a simple architecture, it is quite easy for maintenance engineers to access the entire component if any fault arises. A429 uses a single source and single sink architecture supported by a twisted wire pair consisting of point-to-point interface where detection of faults is easy. Furthermore, ARINC 629 and ARINC 664 follows a more complex architecture due to which maintenance staffs find it difficult to access the entire component as compared to A429.

Q.8) In which protocol is it easier to detect a fault in the system?

Choices	**Number of respondents**	**Total number of respondents**	**Percentage of response**
ARINC 429	48	61	79%
ARINC 629	6	61	10%
ARINC 664 (AFDX)	7	61	11%

Table 4.2.8: Response related to fault detection in a system

(Source: created by author)

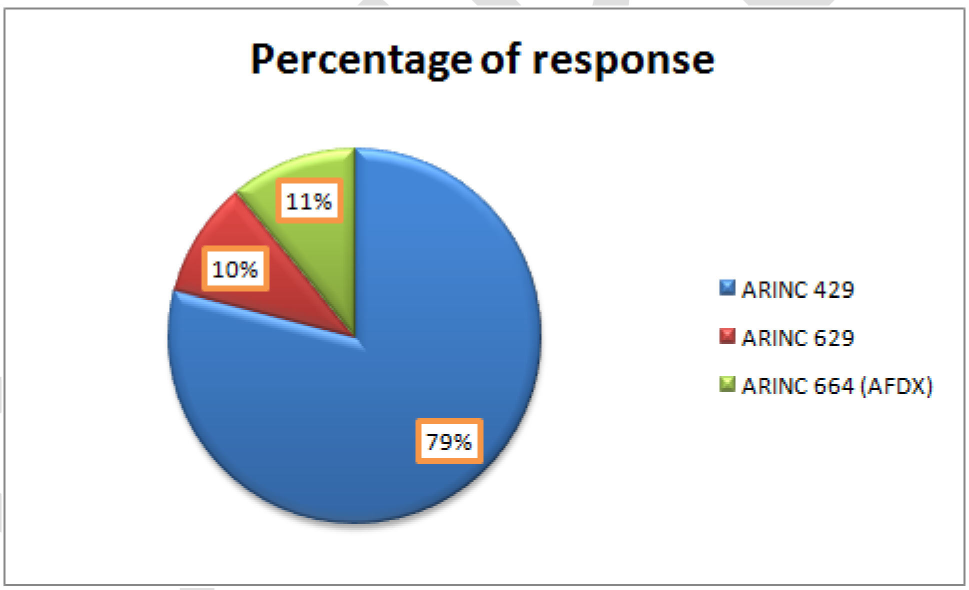


Figure 4.2.8: Pie-chart showing response percentage on detection of system fault

(Source: created by author)

Findings and analysis:

Most of the respondents supported the fact that in ARINC 429 it was easier to detect faults as compared to A629 and ARINC 664 takes a lot of time to find a fault. This is because as ARINC protocols evolved, wiring and architecture became more complex. Although 11 percent in support of AFDX stated that latest hand tools and detectors made it easy for maintenance engineers to find faults in ARINC 664 protocols.

Q.9) Which protocol might be simple in case of adding a new equipment (LRUs) to the system?

Choices	**Number of respondents**	**Total number of respondents**	**Percentage of response**
ARINC 429	6	61	10%
ARINC 629	7	61	11%
ARINC 664 (AFDX)	48	61	79%

Table 4.2.9: Response to protocol that facilitates easy addition of LRUs

(Source: created by author)

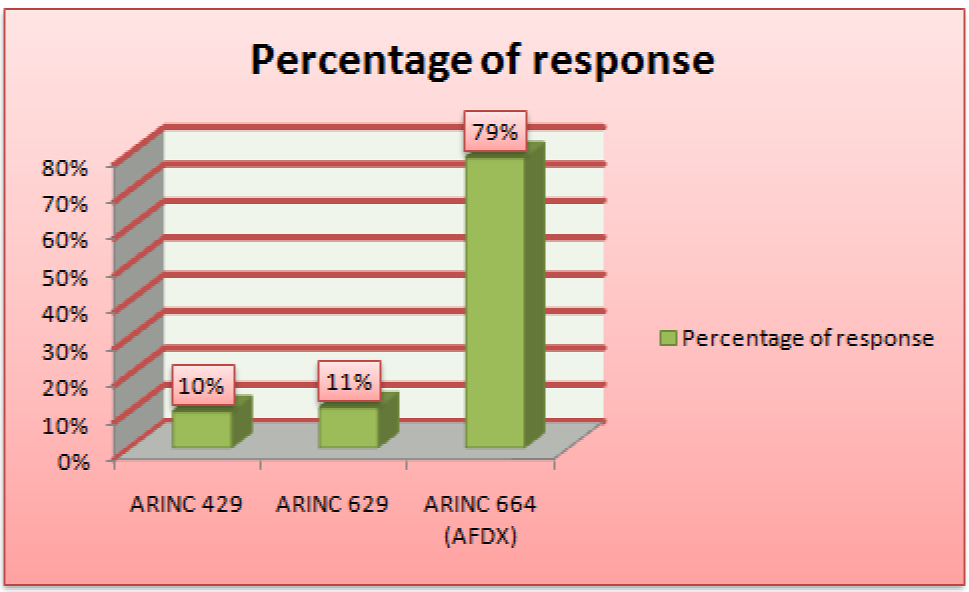


Figure 4.2.9: Graph showing response percentage in addition of LRUs

(Source: created by author)

Findings and analysis:

ARINC 664 (AFDX) is the latest modification of ARINC protocol because of which it is capable of introducing any future modifications. Additions of LRUs are also easy in case of A664 which is supported by 79 percent of the respondents. This is because ARINC 664 has a flexible low-cost architecture which is not only capable of accommodating LRUs but also provides space for future modifications. However, 11 percent supported ARINC 629 and 10 percent supported A429 as they had little working experience with AFDX.

Q.10) Which one of the ARINC protocols is safer to work on during maintenance operations?

Choices	Number of respondents	Total number of respondents	Percentage of response
ARINC 429	7	61	11%
ARINC 629	6	61	10%
ARINC 664 (AFDX)	48	61	79%

Table 4.2.10: Response to safe working protocol operations

(Source: created by author)

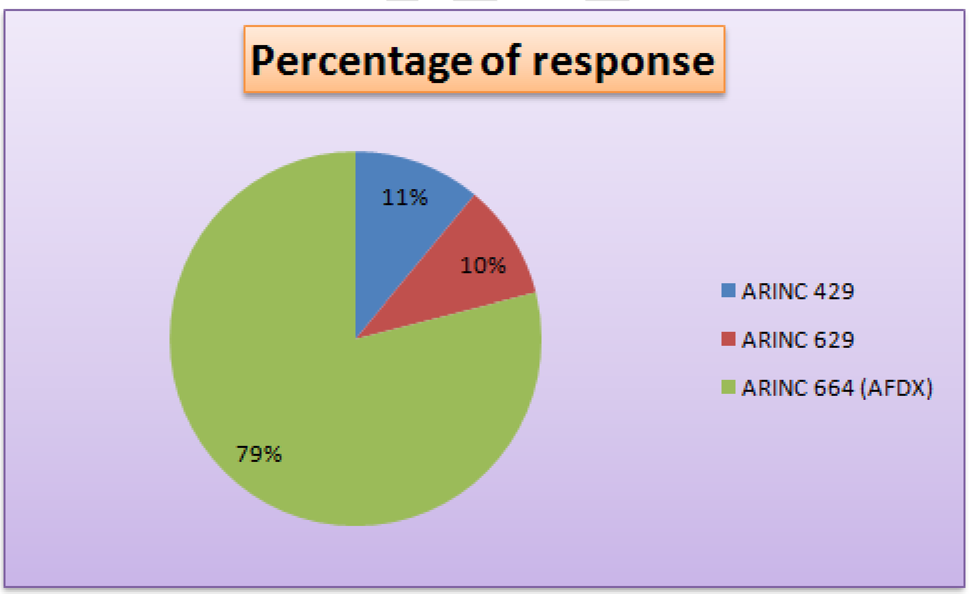


Figure 4.2.10: Pie-chart showing response percentage on safe working protocol

(Source: created by author)

Findings and analysis:

AFDX is considered to be the most reliable and safest protocol to work on in case of maintenance operations because it follows Ethernet protocol which consists of a flexible architecture. Moreover, AFDX uses end systems, links and switches which makes it safer to work with and this fact is supported by majority of candidates. Other candidates had little knowledge about AFDX and hence considered A429 and A629 safer.

Q.11) How the system operations are different from ARINC 429 to other protocols?

Choices	Number of respondents	Total number of respondents	Percentage of response
Similar	5	61	8%
Simple	16	61	26%
Complex	40	61	66%

Table 4.2.11: Response related to difference in ARINC system operations

(Source: created by author)

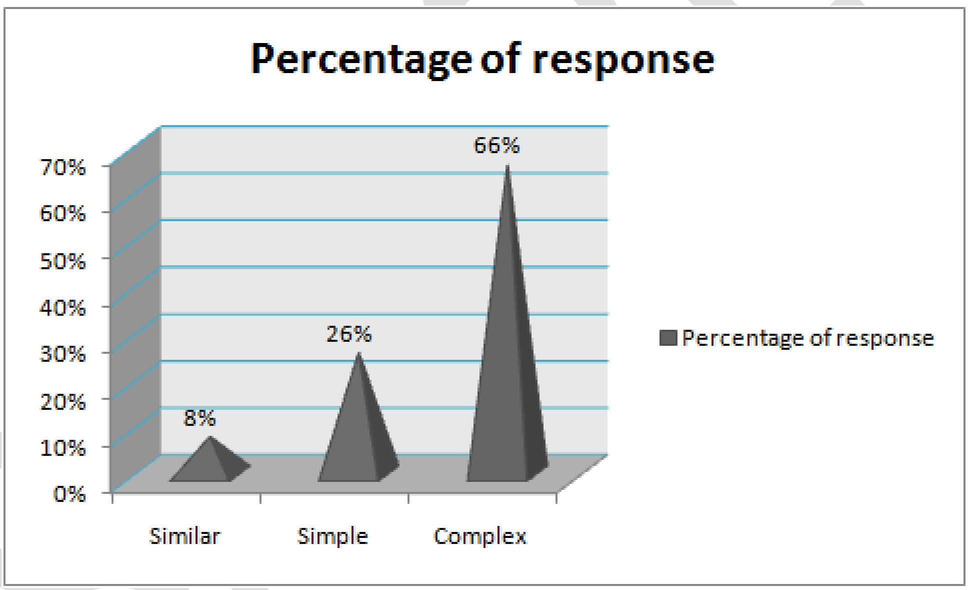


Figure 4.2.11: Graph showing response percentage on difference in ARINC system operations

(Source: created by author)

Findings and analysis:

Majority of the participants stated that system operations are complex in A629 and A664 as compared to A429 which had the simplest architecture. This is why a majority of 66 percent considered other protocols to be complex than A429. A nominal 8 percent considered it to be similar due to lack of experience and 26 percent found other protocols to be simpler than A429.

The reason for finding A629 or A664 to be simpler is because in A629 multiple sources and multiple sinks are used and in A664 Ethernet OSI model and fibre optics are used. These types of technology are the latest in industry and are easy to use if prior knowledge is present.

Q.12) How difficult is it working with different ARINC maintenance manuals?

Options	**Number of respondents**	**Total number of respondents**	**Percentage of response**
Very difficult	15	61	25%
Somewhat difficult	20	61	33%
Same	5	61	8%
Somehow simple	12	61	20%
Very simple	9	61	15%

Table 4.2.12: Response related to working with different ARINC protocols

(Source: created by author)

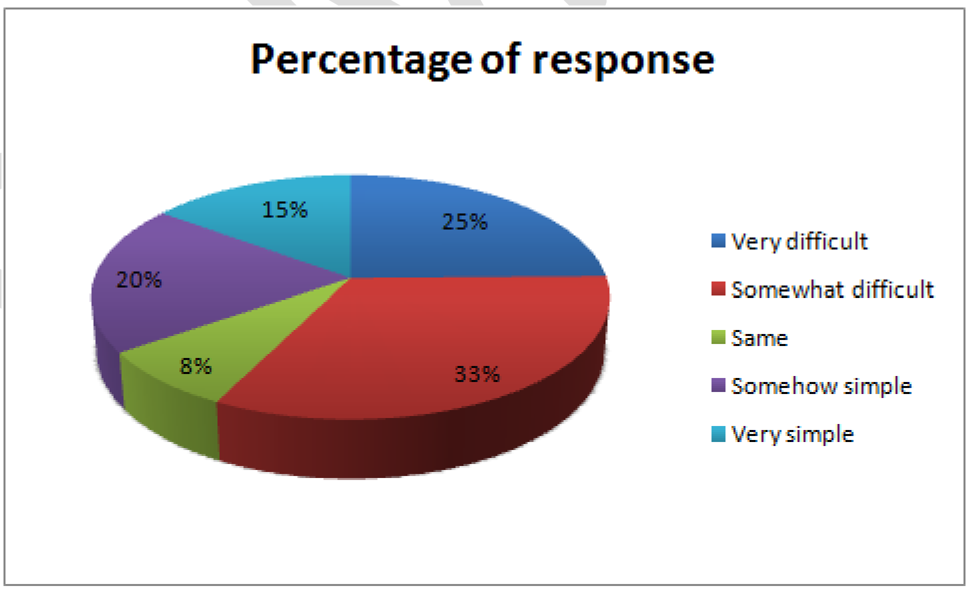


Figure 4.2.12: Pie-chart showing response percentage on working with ARINC protocols

(Source: created by author)

Findings and analysis:

A majority of the participants found that it is somewhat difficult working with different ARINC protocols as all ARINC protocols required different level of understanding and use of technology. Modern-day ARINC maintenance manuals use fibre optics technology whereas A429 had a copper network interface. Adjusting to dynamic technology is the main factor which most of the maintenance engineers find difficult to cope up with. However, a total of 35 percent found it to be somewhat simple as they had known about all protocols owing to their experience of more than 3 years.

Q.13) How has the development in ARINC 664 (AFDX) been helpful in maintenance sector?

Options	**Number of respondents**	**Total number of respondents**	**Percentage of response**
Very helpful	38	61	62%
Somewhat helpful	10	61	16%
Same	2	61	3%
Somewhat not helpful	8	61	13%
Not helpful at all	3	61	5%

Table 4.2.13: Response related to ARINC 664 in maintenance sector

(Source: created by author)

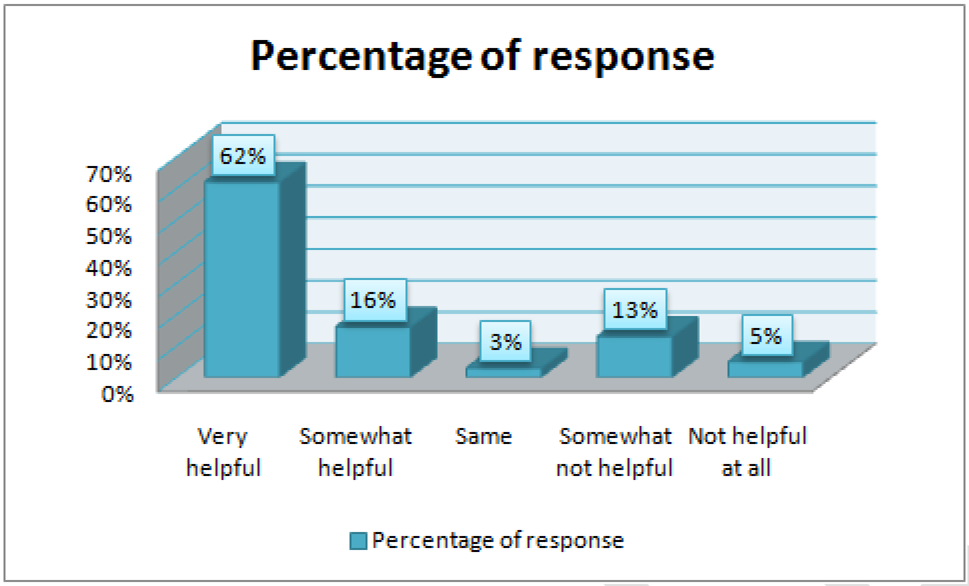


Figure 4.2.13: Graph showing response percentage on use of ARINC 664

(Source: created by author)

Findings and analysis:

Although most of the maintenance staffs consider that evolution of ARINC protocols has lead to complexity in system operations, on the other hand it has helped to detect complex problems and providing long-lasting effective solutions. Although 13 percent did not consider that AFDX helped maintenance sector as they were new and had no idea about previous ARINC protocols.

Q.14) Do you think maintenance operations of ARINC have became more complex after moving from A429 to A629/A664?

Choices	Number of respondents	Total number of respondents	Percentage of response
Yes	48	61	79%
No	13	61	21%

Table 4.2.14: Response related to complexity of ARINC evolution

(Source: created by author)

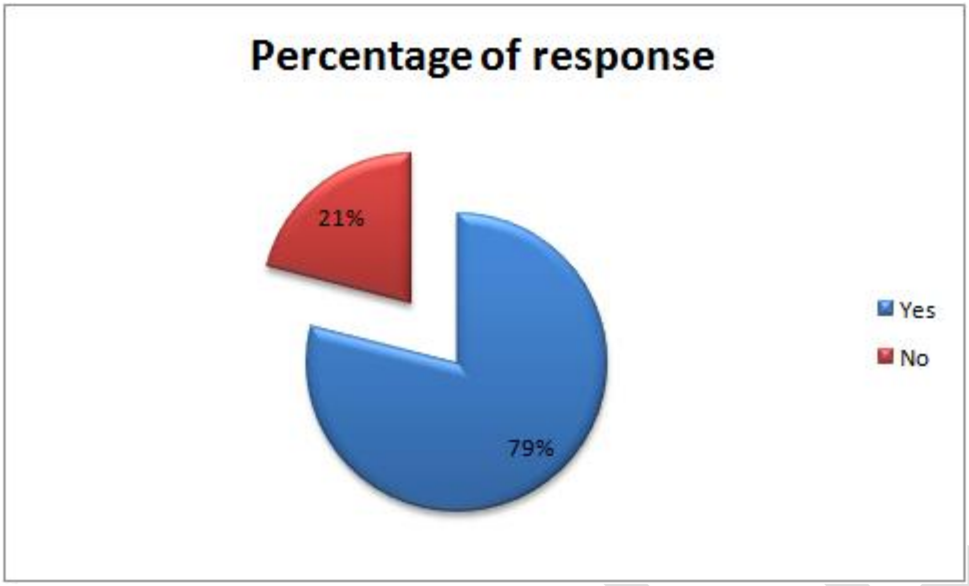


Figure 4.2.14: Pie-chart showing response percentage on impact of evolution of ARINC protocols on maintenance industry

(Source: created by author)

Findings and analysis:

More than three-fourth of the participants supported the fact the evolution of ARINC protocols led to complex avionics architecture due to wiring and physical protocol characteristics. However, the rest did not consider new protocols to be complex as they might have prior knowledge about fibre optics and Ethernet which made handling A664 easier.

Q.15) Do you think manpower required for maintenance operations of ARINC decreased after moving from A429 to A629/A664?

Choices	**Number of respondents**	**Total number of respondents**	**Percentage of response**
Yes, it has	9	61	15%
No, it has not	52	61	85%

Table 4.2.15: Response related to manpower change in ARINC operations

(Source: created by author)

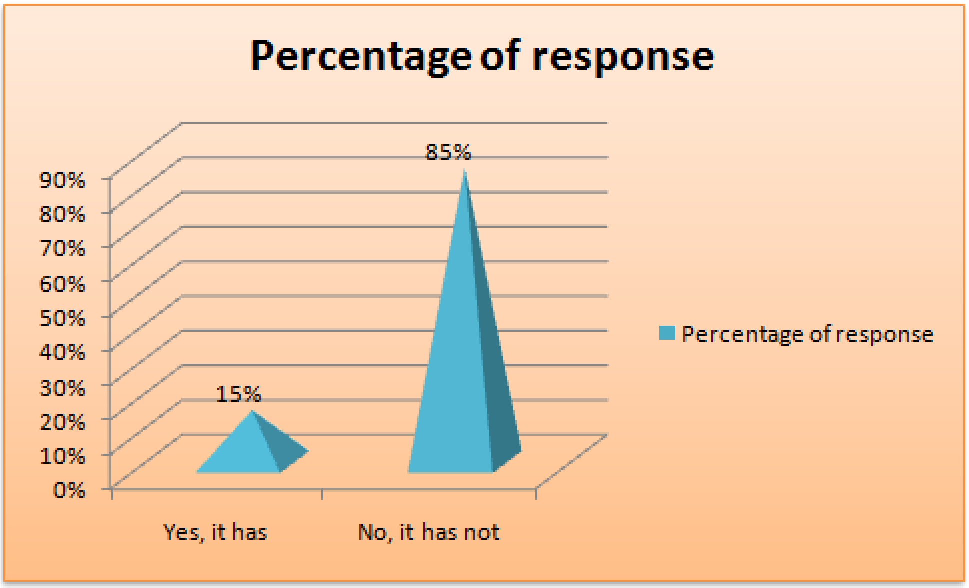


Figure 4.2.15: Graph showing response percentage on manpower change in ARINC

(Source: created by author)

Findings and analysis:

Most of the participants disapproved the fact that evolution of avionics reduced manpower in maintenance sector. This is because as technology in ARINC protocols evolved, it made complex architecture which required substantial workforce to operate and maintain the system. A mere 9 participants felt that latest ARINC protocols require less workforce because they think due to automation technology machines can auto-operate themselves which is rare.

Q.16) Do you think that maintenance cost of ARINC has decreased after moving from A429 to A629/A664?

Choices	**Number of respondents**	**Total number of respondents**	**Percentage of response**
Yes, it has	16	61	26%
No, it has not	45	61	74%

Table 4.2.16: Response related to change in ARINC maintenance cost

(Source: created by author)

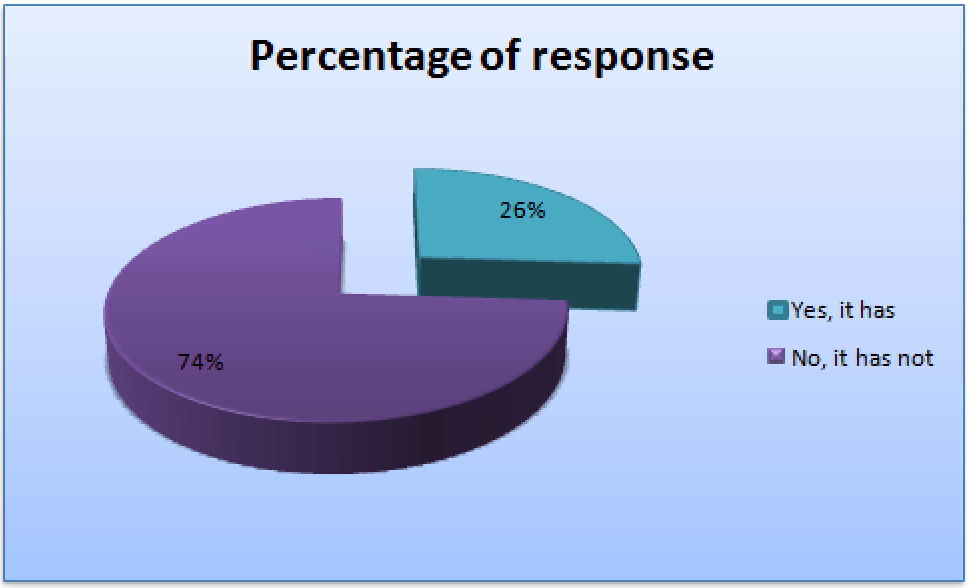


Figure 4.2.16: Pie-chart showing response percentage on change in ARINC maintenance cost

(Source: created by author)

Findings and analysis:

It is quite obvious that latest technology would be more complex and expensive than primitive ones. Although AFDX uses less cost to install, its maintenance and repair cost remains the same as compared to its previous counterparts. As a result, most of the participants supported against decreased price in latest ARINC protocols. On the contrary, 15 percent considered the initial cost of installing new ARINC protocols and based on that perspective they believed that modern avionics are cost-effective as compared to previous ones.

4.3 Conclusion

Therefore it can be concluded that evolution of ARINC protocols has a mixed impact on maintenance sector in a positive and negative way. The positive ways include a constant workforce for avionics, efficient and effective decision-making system to provide solutions to complex problems and safe working operations in latest avionics which is AFDX. However, complexity and wiring are the factors which negatively affect ARINC maintenance operations. Most of the participants who have responded to this questionnaire have pointed out the fact that latest modification of ARINC protocols is more complex than primitive ones.

ARINC 429 is still considered to be a convenient and easy protocol to be implemented in aircraft communication. However, it is not as fast and reliable as compared to AFDX because of the gap in technology that exists between these two. Furthermore, due to the evolution of ARINC protocols, hand tools required for such protocols also developed and assisted maintenance engineers to effectively operate and maintain ARINC system. The primary quantitative data analysis that has been conducted in this chapter highlighted the positive and negative factors which affected maintenance sector owing to the evolution of ARINC protocols. These data would be crucial to support an objective of this research which is to investigate the impact of evolution of ARINC protocols on maintenance sector.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

The entire research focused on series of evolution that took place with ARINC protocols and the impact it had on maintenance sector. Detailed analysis of ARINC protocols such as A429, A629 and A664 has been conducted in Chapter 2 of this research. Chapter 4 of this research deals with the impact that evolution of ARINC had on maintenance sector with respect to primary quantitative data analysis surveyed on 61 ARINC maintenance staffs. However, it can be concluded that avionics protocols have developed with technology and has eased operations in an aircraft irrespective of its function. ARINC protocols have found its place in military aircrafts and civil aviation flights that include major aircraft manufacturers such as Airbus, Boeing, MIG and Sukhoi.

As per the quantitative data analysis, it has been observed that most of the maintenance staffs preferred A429 in terms of maintenance because of its simple architecture. As technology improved, so did the requirement of aircrafts to develop automated inter-system communication. This led to evolution of avionics where A629 involved a complex architecture with increased speed. The latest is A664 or AFDX which is the safest and fastest ARINC protocol used in aircrafts. AFDX is also considered to be safest of the three as per the data analysis but the simplicity and easy-to-use feature of A429 outsmarts the other two. Hand equipment and tools used to repair and operate modern avionics also evolved with technology which made maintenance engineers' task difficult as they had to follow manuals of three different major ARINC protocols.

Linking with objectives

Objective 1: To analyse different ARINC protocols

In Chapter 2: Literature Review, the researcher has successfully established analysis of different ARINC protocols. Physical structure, network architecture, word format of A29, A629 and AFDX has been conducted followed by comparison among the three. This would help to understand the drawbacks and advantages of different ARINC protocols and its complexity in terms of wiring and hardware which would evaluate its impact on maintenance sector.

Objective 2: To evaluate evolution of ARINC protocols

The same chapter of Literature Review consists of evolution of ARINC protocols. The researcher has found a link between all ARINC protocols by comparing them which will help to understand the technology based on which A629 and AFDX evolved from A429.

Objective 3: To compare benefits and drawbacks of different ARINC protocols

The comparison between all ARINC protocols such as A429, A629 and A664 has been done while explaining each protocols in Chapter 2. This helped the researcher to highlight advantages and disadvantages among all protocols in an in-depth approach.

Objective 4: To understand the impact of various ARINC protocols on aircraft maintenance

Chapter 4 consisted of primary quantitative data analysis where 61 ARINC maintenance staffs were surveyed with the help of a questionnaire. The main purpose of this survey was to identify the impact of ARINC protocols on maintenance which would not have been possible by other methods. As per the analysis, it was found that maintenance staffs found easy to work with A429 but A664 offered safest mode of repair among the other two. Moreover, it was also found that tools and equipment also evolved along with ARINC protocols which helped maintenance engineers to operate latest communication equipment.

5.2 Recommendations

AFDX is undoubtedly the latest ARINC protocol which is majorly followed in most of the aircrafts around the world. However, the latest modification of AFDX which is the µARINC664 is the fastest, safest and the most reliable avionics that uses a simple architecture. During the survey it has been observed that many maintenance staffs preferred the simple architecture and wiring of A429 which made its maintenance easy and took least inspection duration. A6229 and A664 were complex and used extensive wiring but in µA664, this issues are resolved. It would use the latest Ethernet technology for inter-system communication and its architecture would be completely based on fibre optics. This feature would reduce wiring and would also reduce added weight on aircraft which in turn would increase aircraft’s performance and make it a light-weight vehicle capable of carrying more load. However, µAFDX is still in its development stage and this protocol is capable of changing the face of ARINC protocol in a completely different manner that would not only increase data speed but would also consist options for sustainable future development in avionics industry.

5.3 Limitations of the study

The focus of this research was limited to three protocols of ARINc which are A429, A629 and AFDX. Inclusion of other avionics protocols could have given a further in-depth analysis in this research study. Since the time was limited, it did not allow the researcher to include larger sample sizes which could have offered a better segmentation and variety of data in the research. Financial budget was also limited which also restricted the scope of this research to ARINC only or else other aircraft manufacturing companies could have been surveyed or interviewed.

5.4 Future scope of the study

Due to restrictions, the research could not exploit its potential level. Other aircraft manufacturers such as Boeing or MIG could have been included in this research and the maintenance sector military flights could also have been included. Moreover, comparative study between organisations could have provided a better data analysis of this research.

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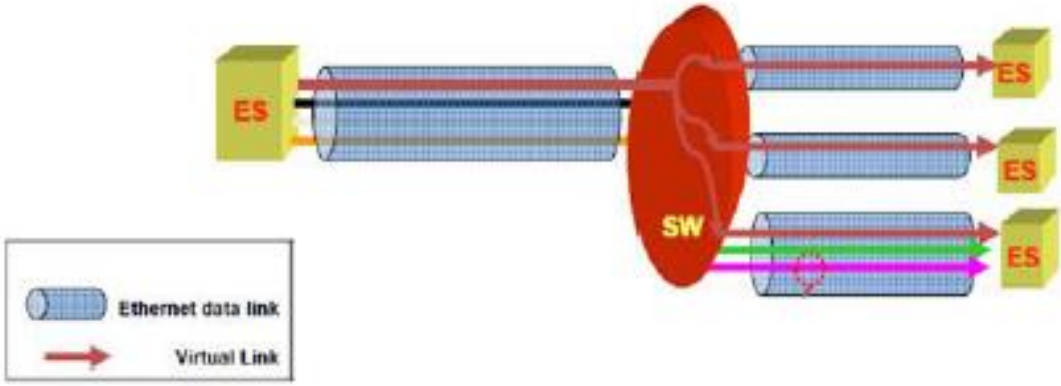
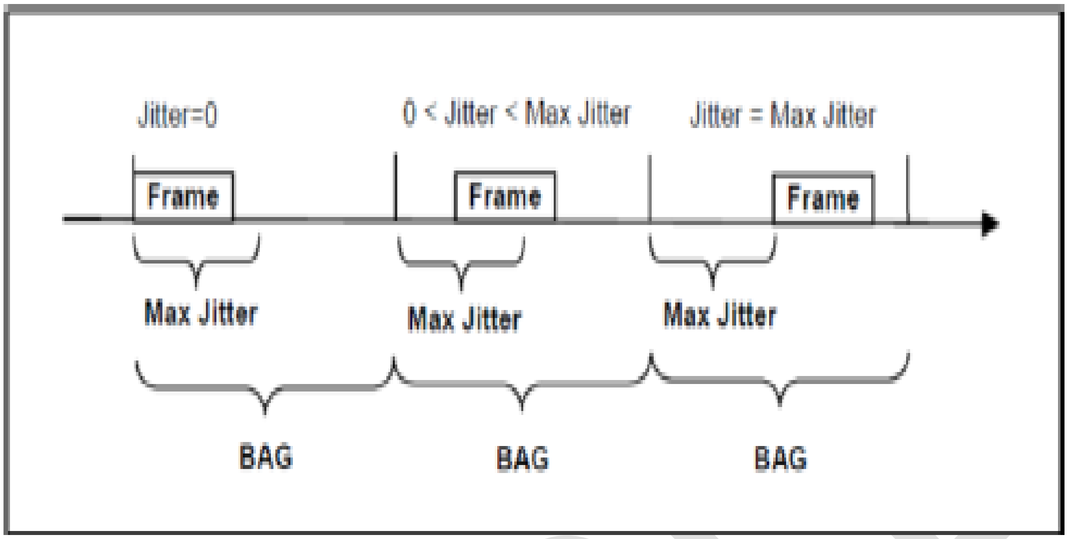
Appendices

Appendix 1: AFDX virtual links



(Source: Safwat *et al.* 2014)

Appendix 2: BAG and Jitter



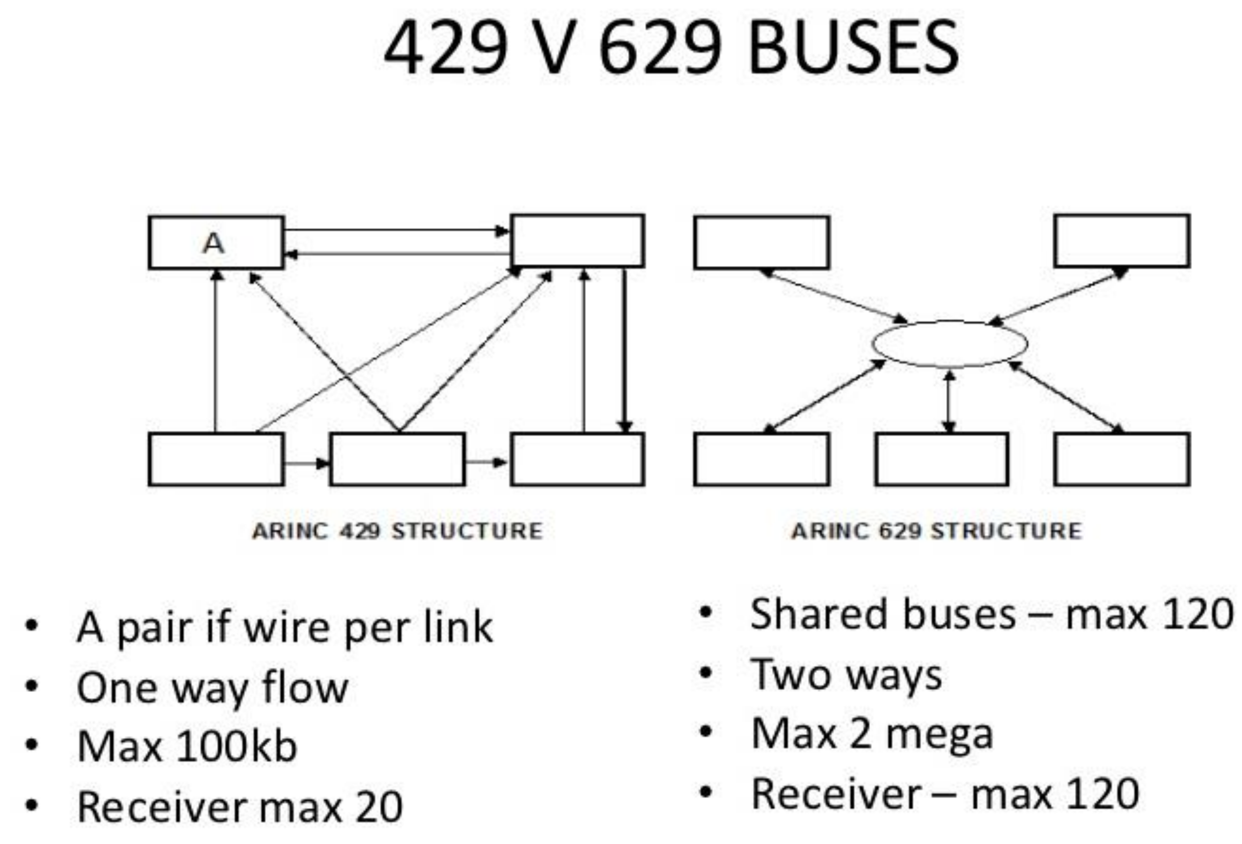
(Source: Safwat *et al.* 2014)

Appendix 3: Jitter equations

$$\begin{cases} max\_jitter \leq 40\mu s + \dfrac{\sum_{i \in \{set of\ VLs\}} \left(20_{\ bytes} + L^{max}_{\ bytes}\right) \times 8\ Bits/bytes}{Nbw_{\ bits/s}} \\ max\_jitter \leq 500\mu s \end{cases}$$

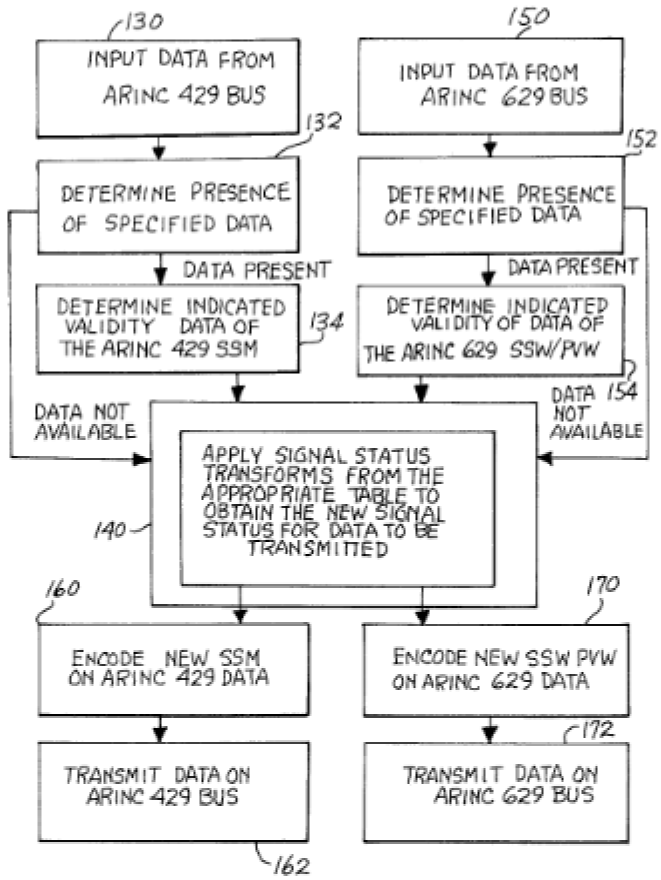
(Source: Safwat *et al.* 2014)

Appendix 4: A629 buses with A429 buses



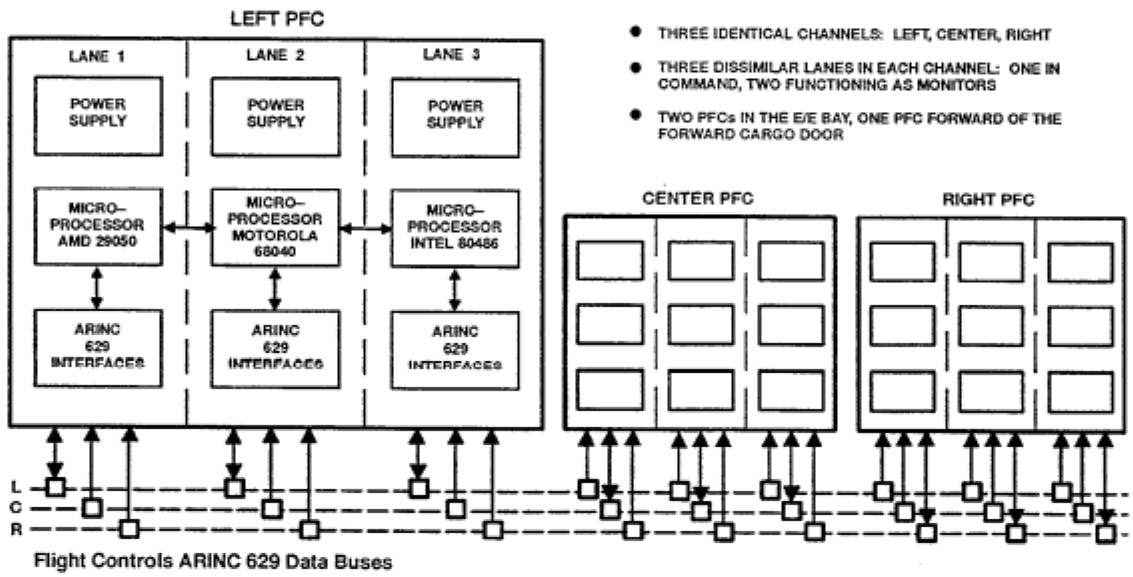
(Source: imgur.com, 2017)

Appendix 5: Data flow in A629



(Source: imgur.com, 2017)

Appendix 6: Flight controls in A629



(Source: imgur.com, 2017)