A roadmap to autonomous of airlines: specifications and communication protocols

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Abstract: The future challenge of civil aviation industries will be autonomous air lines that in addition to providing of travel requirements with full safety for passengers and cargo owners, it must has economical savings and benefits for air fleets owners too. The first step in this way is understanding and investigating safe and secure communication methods with proper data transfer speeds that are required for the autonomous airplane’s avionics and navigation systems. synchronous, with notice to existing or under developing methods to establish reliable data links for civil aviation, should also look at used technologies in unmanned aerial systems (UASs) and facilities whom provided for them in accordance with the international civil aviation organisation (ICAO) and federal aviation administration (FAA) standards. In this article, after introducing and familiarising with an autonomous airline, some of ahead challenges have been addressed and proposed for future work.

Keywords: autonomous; UAS; unmanned aerial system; data link; frequency; civil aviation; UAV; unmanned aerial vehicle; airline; communication protocols.


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1 Introduction

Certainly, the aviation (military and non-military) is the main user of sciences, as well as, it can be considered as one of the leading industries that has a driving force for sciences and researches in various fields such as electronics, navigations, communications, networks and data. Also, due to the development of automation processes in various industries and machines in order to diminish human intervention and therefore problems
with it, the aviation has been also a deep look at this field and result of this action is appearance of unmanned aerial vehicle (UAV) at various levels of automation and their usage in many critical areas especially those that are dangerous to the humans health (Holland, 2004; Siegwart et al., 2011). Also, there are frequent mistakes have been made by pilots and crew throughout history of aircrafts utilisation as means for transporting of passengers and cargo that Some of these catastrophic accidents are listed as below which more than ever identifies the importance of eliminating or minimising human intervention in involved processes (Independent, 1995; StandardDigital, 2015; Stephanie, 2015; Calhoun et al., 2002):

- On 24 March, 2015, flight 9525 of German Wings crashed in the Alps of France and the reason for this tragedy was co-pilot’s severe depression.
- Flight AF474 of Air France from Rio de Janeiro to Paris on 1 June, 2009. Evidences have indicated pilot and co-pilot’s fatal mistake that killed 228 people.
- Flight 235, Tans Asia on 4 February, 2015, pilot saw a flame on one of ATR 72-600 aeroplane’s engines and while the aircraft was able to fly with an engine, he switched off both and restarted them, that this time, aeroplane lost propulsion power, fell into river and then killed 43 people.
- On 5 January, 1995, Islamic Republic of Iran air force (IRIAF) Lockheed Jetstar, crashed near Isfahan and Iranian air force commander was killed together with a number of high-ranking officers. This incident was happened due to the pilot’s mistake in estimating the height of airports in Tehran and Isfahan.
- On 29 December, 1972, flight 401 of Eastern Airlines, when the crew were busy for landing gear's faults checking, did not pay attention to auto-pilot while it was off, as a result, 101 people were killed.
- On 28 December, 2014, flight 8501 of Air Asia flight crashed into the sea, and all 162 passengers and crew were killed because of pilot’s wrong decision to refuse flight protocols while the auto-pilot was off.
- On 6 July, 2013, the Asiana Airline’s Boeing 777-28EER aircraft type crashed, due to lack of management in altitude controlling that killed 3 people.
- On 11 September, 2001, two Boeing 767 and two Boeing 757 hijacked and struck to the Pentagon building and the New York world trade centre’s twin towers, which killed more than 2500 people.

More examples of this kind of tragedies can be Pointed out. According to research, about 70–80% of the causes of air accidents are related to human and pilot errors (Shappell and Wiegmann, 2004). Hitting by birds, entrance to bad weather, deliberately or unintentionally exiting from international ways and so, violation to airspaces and possibility of reaction by air defences, terrorist operations threats (as 11 September, 2001), faults in various aircraft systems and ignorance or carelessness of crew, Lack of awareness and readiness of the nearest airport for emergency landing and etc., are major factors and serious threats in usage of airlines and also for air travel safety. It has been seen occasionally after occurrence of air accidents, finding the black box for help to
understanding of aeroplane crash causes, is time-consuming and it is not found in some cases while, If the conversations between the flight crew are transmitted online to the ground controller or airlines, they can also use of this capability to listen and record them. On the other hand, with increasing of airlines and consequently aeroplanes number on the ground and airspaces, we have to consider special procedures to develop of discipline and to prevent the occurrence of events that are sometimes deadly. Indeed, necessary platform creating for complete flight automation will be one of the future actions of experts which should be carefully investigated and coordinated with some organisations such as federal aviation administration (FAA) and international civil aviation organisation (ICAO) to provide relevant protocols and standards. As the first step in this way, we can point out to establishing of appropriate infrastructure for communication with minimal delay together with high level of coherence and proper data transfer speeds between ground control stations and aeroplanes in flight paths and hence, providing of data exchange networks in a globalised form (Adriaan de Graaff, n.d.; Hansen et al., 2012; Vance, 2017). The rest of paper is organised as follows: in Section 2, autonomous airline’s definition is expressed and also by comparing it with an unmanned aerial system (UAS), its components are introduced. History of communications and data links for civil aviation is presented briefly in Section 3. In Section 4, type of communications for civil aviation and UAS are discussed. Some key points that are useful for choosing suitable communication protocols and data links are proposed in Section 5. Results of the evaluation and future works provided in Section 6.

2 UAS technology and autonomous airline definition

Let consider a civil aeroplane that do all flight procedures consist of getting travel plan, engines start and taxi, take off, cruise, approaching and landing, arriving to park zone and finally engines shut down, full automatically as a big unmanned aircraft with a crew that he or she is only responsible for surveillance on systems and intervening in emergencies. So, fleets that use these type of aircrafts can be called full automatic or autonomous airlines (Adriaan de Graaff, n.d.; Jenkins, 2016).Because all matters relating to flight and control of the aircraft will be completely automated from passengers departure at origin until dismounting them at the destination. To speed up to their development, the best way can be proposed as a technology that is used for a UAS. Components of a UAS are (Gupta et al., 2013): an aircraft that is capable to fly with no boarded pilot or personnel that is required for its control and guidance or unmanned aircraft (UA), a ground control station (GCS), a load; and an information and navigation system (Figure 1).

If we want to generalise this system for our subject, the civil aeroplane is called UAV, the payload is cargos with passengers weight or without it, the GCS can be considered as air traffic controls (ATC) along with flight paths, navigation and communication systems that have their own task. So, according to Figure 1 and above-described materials, this configuration can be corrected in Figure 2 for an autonomous airline. On the other hand, classifications for the unmanned aerial vehicl e (UA V) are based on flight altitude and take-off weight. Thus, an example of these categories can be found in Table 1.
According to this table, we can find that a civil aircraft belongs to medium altitude long endurance (MALE). Therefore, characteristics of an aeroplane that can operate in these airlines can be summarised as follows:

- From the start of aircraft’s engines until reaching to destination and engines shutting down, all work is done autonomously. So, the role of the pilot only can be considered as system’s manager and for acting in urgent situations (losing communication, failure in avionics or navigation system and etc.).

- Increasing flight safety (human mistakes decrease to zero, choosing of optimum and safe flying paths with suitable speed, avoidance of birds hitting and accident with other aeroplanes together in the sky and ground, flight on international airspaces,...)

- There is an adequate coordination between all avionics components, even with aircrafts that have not any flight automation system.
• Preventing of terrorist operations due to the impossibility of aircraft hijacking and rapid detection of unauthorised flights.

• Online errors detection in aircraft’s various systems and sending to control centres or airline repair and maintenance teams.

• Early warning systems to report to ground control centre as soon as occurrence and observation of an abnormal situation in aircraft’s flight condition, automatic preparation of nearest airport for emergency landings.

• Sending of crew’s online conversation to airlines and flight control centres, as a result, recording and listening to it and therefore reducing the dependency to the black box.

• In a plane crashing tragedy, determining the exact location of the crash for increasing aid speed and understanding of passengers’ conditions.

As regard to these eight items, it is clear, without establishing a permanent connection and secure data link for data exchanging between autonomous aeroplane and ground control as well as other aircrafts in the ground and the sky, achieving of this goal is impossible.

Table 1 Classification of UAVs

<table>
<thead>
<tr>
<th>Category</th>
<th>Weight of UAV</th>
<th>Normal operating altitude</th>
<th>Radius of mission</th>
<th>Endurance</th>
<th>Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICRO</td>
<td>&lt;2 kg</td>
<td>Up to 200ft</td>
<td>5 km (ILOS)</td>
<td>A few hours</td>
<td>Very low altitude</td>
</tr>
<tr>
<td>MINI</td>
<td>2–20 kg</td>
<td>Up to 3000ft</td>
<td>25 km (ILOS)</td>
<td>Up to 2 days</td>
<td>Low altitude</td>
</tr>
<tr>
<td>SMALL</td>
<td>20–150 kg</td>
<td>Up to 5000ft</td>
<td>50 km (ILOS)</td>
<td>Up to 2 days</td>
<td>Low altitude</td>
</tr>
<tr>
<td>TACTICAL</td>
<td>150–600 kg</td>
<td>Up to 10,000ft</td>
<td>200 km (ILOS)</td>
<td>Up to 2 days</td>
<td>Low altitude</td>
</tr>
<tr>
<td>MALE</td>
<td>&gt;600 kg</td>
<td>Up to 45,000ft</td>
<td>Unlimited</td>
<td>Days/weeks</td>
<td>Medium altitude</td>
</tr>
<tr>
<td>HALE</td>
<td>&gt;600 kg</td>
<td>Up to 65,000ft</td>
<td>Unlimited</td>
<td>Days/weeks</td>
<td>High Altitude</td>
</tr>
<tr>
<td>STRIKE/ COMBAT</td>
<td>&gt;600 kg</td>
<td>Up to 65,000ft</td>
<td>Unlimited</td>
<td>Days/weeks</td>
<td>High Altitude</td>
</tr>
</tbody>
</table>

Source: Gupta et al. (2013) and Kakar (2015)

3 History of communications and data exchange for civilian aircraft

In the early days of the advent of aircraft, communication had been made by visual equipment such as lights, flags or even fire and the first radio connection was created by the Morse code. With introduction of radio frequency (RF) in 1929, aeronautical radio inc
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ARINC (ARINC) was formed for allocation of frequency requirements which has become an independent company now whom has been called aviation spectrum resources (ASRI). Demand for production enhancement of aircrafts and air transport development and this fact that all companies wanted to use their own dedicated frequencies, air transportation faced with spectrum depletion. As a result, along with high-frequency (HF) air-ground voice, very high frequency (VHF) also appeared. So today, usage of VHF is the most common way for communication between aircraft and ground control and is currently used as a base system for ATC. Because of technology development and digitisation of communication, necessity for data exchange and data link between planes and ground controls was created so for the first time in 1978, airlines introduced air-to-ground data transmission with VHF, the link was called ARINC communication addressing and reporting system (ACARS) but Later, ARINC changed its name into Airborne Communication Addressing and Reporting System. For this reason, the Boeing used controller-pilot data link communication (CDLC) link together with automatic dependent surveillance (ADS). Then future air navigation system (FANS) born and the Boeing called this configuration as FANS-1. In same effort, the Airbus introduced FANS-A and thus a combination of these two, FANS-1/A, has been used in all of the world’s air traffic controls (Cary r. Spitzer, 2015). On the other hand, due to ICAO planning to move towards full automation and autonomy of air navigation or global air navigation plan (GANP) program, defined blocks (block0-block3) must be completed since 2013 to 2031 (ICAO, 2016). Also at the twelfth air navigation conference has been mentioned to aeronautical automation systems so It is clear, serious efforts are doing to complete autonomy and automation of airlines that will be seen their initial results after 2019 (ICAO, 2016). The important feature of the reliable communication system is aircraft availability for all times in both inline of sight (ILOS) and beyond line of sight (BLOS) positions. So, exchange of information and data, can accomplish with least delay (Çuhadar and Dursun, 2016). For example, during taxi on runway, takeoff or landing in an airport or in general in an ATC contact zone, it is ILOS position and ground control is capable to make a direct radio data link without using of any relay or an additional amplifier station (Morgenthaler et al., 2012). In BLOS, we will need to establish a satellite communication (SATCOM) or relay stations that in this situation an aeroplane can be itself as a communication booster (Pongrácz and PALIK, 2012; Burdakov et al., 2009). However, first issues for UAS communication technology are flexibility, adaptability, safety and security, bandwidth, frequency, data/information flow. Like any new system, until to replacement of older with it, should have: adequate versatility for a stable connection with them, very low permeability so high security against hacking and malicious attacks, suitable bandwidth and frequency for full flow transmission and required information speed with minimal delay (Gupta et al., 2013). Data that has been sent by ATCs is got by aeroplane receivers and is transmitted through a modem to the central processing unit in a system with an integrated modular architecture (IMA) and thus transfer it to other modules for appropriate actions. Also, to exchange data between modules, sensors, actuators, processors and other hardwares; databases according to ARINC or military standard (MIL-STD) protocols with fibre optic mediums can be used (Boeing, 2005; Cary r. Spitzer, 2015; Moir et al., 2006, 2013).
Communication and data transmission in civil aeroplanes and UASs

Communication systems, as well as data transfer, for an aerial vehicle are divided into four categories:

- air-ground (A-G)
- air-air (A-A)
- air-space (A-S)
- airport.

Various organisations are working on a comprehensive plan to establish universal communications. One of them is the Boeing Company, which has developed the mobile communication network architecture (MCNA) program for organizing this project and has published a document (Boeing, 2005). A-G type are used for ILOS communications and A-A and A-S can be used by both ILOS and BLOS, but as far as possible in ILOS position, A-G is preferred because of its economical and cost-related issues. Available air-ground communication systems for civilian aircraft can be found in Figure 3. Undoubtedly, the most important means for voice communicating between pilot or crew with a ground controller is VHF voice. VHF band for airborne applications varies in 118.000 MHz to 135.975 MHz frequency ranges. However, in facing from barriers such as mountains, can cause confusion and mask it which is the most important limiter factor. Most long-range planes have 3 types VHF equipment which one of them must be connected to the ACARS at 131.5 MHz frequency. Plain old ACARS (POA) is preferred system for data messaging whom has designed to support ACARS protocols. Hence, it uses 2.4Kbps data transfer rate and for many years has been only data link system. Air traffic services (ATS) such as flight information service (FIS) and departure clearance (DCL) have performed with POA. VHF data link mode2 (VDLM2) with data exchange rate of 31.5 Kbps, has the highest bandwidth efficiency and is rapidly developing.

Figure 3  Air-Ground communication protocols

![Air-Ground Communication Diagram](image)

This system has not yet provided ICAO requirements for ATS, but both Europe and the US are planning to use aviation VHF link control (AVLC) data link for this purpose. F data link mode3 (VDLM3) is a data link protocol from the VHF family that developed for FAA and is used simultaneously for data and voice support. Maximum data rate for this protocol is 19.2 Kbps (Matolak and Branstetter, 2004) and is based on voice digitalisation and time division multiplexing (TDM) to increasing its performance. VHF
data link – Broadcast (VDLB) from the physical layer of VDLM2 does not support the transmission of any network packet. Thus, it is used to publish data such as FIS. HF sound can be called the first successful experience for air-to-ground communication that utilises high frequency, 3 MHz to 30 MHz which for propagation, uses both the sky waves and the ground waves (Moir et al., 2013). The main disadvantage of HF is a weakness against weather conditions and hence is usually accompanied by noise. However, its data links have more resistance to these shortcomings. For this reason, ARINC has formed HF Data Link (HFDL) with 1.2 Kbps rates at 13 station over worldwide for civilian aircraft (Moir et al., 2013) (Figure 4). With the proliferation of cellular networks, there is a high potential for using 3G/4G protocols as wireless connections for data rates at several tens of megabytes per second (100 Mbps for download and 50 Mbps for uploads). The disadvantage of this approach is that in crowded places due to high network consumption, usage of this method is with unacceptable delay. Therefore, this utilisation for aviation purposes is still under investigation (Kubica, 2015; Tse and Viswanath, 2004).

Air-to-air is another kind of communication that used in aviation and can be listed it as follow:

- 1090-ES
- Universal access transceiver (UAT)
- VHF data link mode4 (VDLM4)
- Broadband VHF (B-VHF)
- P-25
- P-34.

**Figure 4**  HFDL ground stations (see online version for colours)

1090-ES that has 1090 MHz frequency, can provide 4Mbps bandwidth, it has been used by both FAA and EuroControl as automatic dependent surveillance – broadcast (ADS-B) service for civilian aircraft. Therefore, the main traffic of it is related to this service. UAT
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was developed by the MITRE that has been used by FAA to transmit ADS-B message in general aviation (GA). Because it did not accept any network protocols, it has not been used by civil aviation. Unlike the US, in some European countries, VDLm4 with 1 Mbps maximum rate (Matolak and Branstetter, 2004) which is from VDL family, is used to support ADS-B and also has the ability to support air-to-ground communications. So, there is a disagreement between FAA and Eurocontrol for choosing of UAT or VDLm4 as a candidate link for ADS-B service in GA. Three protocols, B-VHF, P-25 and P-34, have new research backwards so that B-VHF is being developed for new air-to-ground communications such as airline operational communications (AOC) and air traffic safety (ATS) and P-25 and P-34 are based on internet protocol (IP) technology and also being considered for local safety applications but these two protocols are not in MCNA subsets. Following systems have been developed for satellite communications:

- Inmarsat Aero-H
- Inmarsat Swift-64
- Inmarsat Swift-Broadband
- Satellite data link system (SDLS)
- Iridium
- Connexion by Boeing (CbB).

The Aero-H service is very comprehensive in ocean airspace that with 10.5 Kbps data transfer rate makes FANS's foundation. This service includes CPDLC and automatic dependent surveillance –addressable (ADS-A) whom is selected by demand assigned multiple access (DAMA) to satisfy ICAO requirements but with a slight delay that the reason for this delay is providing a data coverage and support service in future. This service has the ability to provide selectively addressed services. But, its major disadvantages are a large-scale antenna, high cost of hardware and support services. Accordingly, it is not used in areas where other cheaper protocols provide same services. Swift 64 is designed for passenger services with 64 Kbps data transmission rate. Swift-Broadband service is the next generation of swift64 and can support 500 Kbps data transfer rate also has the ability to use the universal mobile telecommunication system (UMTS). In addition to providing services for passengers, this system has also paid attention to safety services. SDLC is also proposed by European space agency (ESA) and Eurocontrol for ATS data link within Europe. Iridium is a global satellite communications system that covers throughout the world, even in polar areas that create voice and data services at 2.4 Kbps channel. CbB is also developed by the Boeing, which creates broadband bandwidth services for passengers and maybe use for AOC and ATS. Hence, is one of the main components for the Boeing’s MCNA program. Its main drawback is high cost and weight of avionics system, large antenna and consequently produces high drag force. As regards to mentioned items in satellite communications, the most important problem for the development of this technology is the cost of both avionics equipments and provided services by SATCOM, that for this reasons, ARINC 781 is developing some ways to reduce these costs. Airport communications between aeroplane and ground controller take place during setting of flight plan, engines starting until to take off, landing to parking zone and engines shut down. Existing services to make these connections are:
airport data link (ADL)
IEEE802.11
IEEE802.16
IEEE802.20
Terrestrial trunked radio (TETRA) I/II.

The ADL is similar to the B-VHF and is based on the modulation / multiple code division multiple access (MC-CDMA) technology. IEEE802.11 has been used by some airlines, also known as Gate Link, it has a data transfer rate of 1–2 Mbps and its usage is developing for airline, industry and medical applications. However, disadvantage of this protocol is a limited range (about a few hundred metres). IEEE802.16 has the highest range in the 802.XX family, has been defined according to global standard but has not yet been officially approved. Protocol range with working frequency between 3 GHz to 11 GHz is about 50 km so it has the greatest chance to become comprehensive and also, it can work with IP as a data link. IEEE802.20 comes with a combination of 802.16 and 3G protocols and can support higher speeds at frequencies bellow 3.5 GHz but it still needs time to evolve. TETRA I is used for voice production and TETRA II is undergrowth (Boeing, 2005). Along with developed or under developing communication protocols for civil aeroplanes, it is not a bad idea to look at technologies that used by UASs. Connection between UAS’s control centre and UA is performed by two links that are called Up-Link to transfer data from the control centre to aircraft and Down-Link to send received information by sensors or Payload from the aircraft to control centre, which to this data that explains system’s status, ‘housekeeping’ is also referred (Austin, 2011; Valavanis and Vachtsevanos, 2014). Generally, communication between the control centre and aircraft in a UAS is carried out by three different mediums:

- laser beam
- fibre optic
- radio frequency (RF).

Due to limits, because of absorption by the atmosphere and then a loss of reliability, the laser beam is not currently within the researches’ scope (Carrasco-Casado et al., 2015; Austin, 2011). The second method, fibre optics, is only suitable for flying at low altitudes and vertical takeoff and landing (VTOL) systems that are limited to few km. Therefore, the best communication medium for UASs is a radio frequency (RF) too (Austin, 2011; Valavanis and Vachtsevanos, 2014). In USA, RF communications and related topics are investigated by FAA and also are being developed by radio technical commission for aeronautics (RTCA). But in Europe, European aviation safety agency (EASA) has this responsibility. When there is a need for high-rate data transfer, only high frequencies can transmit it. To the understanding of this, we can refer to the Shannon Hartley’s law which calculates maximum data rate for a bandwidth and a signal-to-noise ratio as equation (1):

\[
\text{Bit/Second} = \text{Bandwidth} \times \log_2 \left( 1 + \frac{\text{signal}}{\text{Noise}} \right)
\]  

(1)

If bandwidth is as HZ, KHZ, MHZ or GHZ, the data rate will be calculated in bps, Kbps, Mbps, Gbps, respectively. As shown in equation (1), the main factor for determination of
data transmission is $\frac{\text{signal}}{\text{noise}}$ ratio. Which is strongly influenced by environmental conditions and barriers existing along signal’s path (Lundheim, 2002). Certainly, there are other parameters who are effective in quality and quantity of data transmission that is beyond of this paper’s scope. So the popular frequency bands for UAS applications can be described as follows and Table 2 (Gupta et al., 2013):

- **Ku band**: This band is used for high-speed links with a wavelength that is short and has a high frequency. It has a high propagation depth and then can overcome too many obstacles and cover a very large amount of data.
- **K band**: It has a high-frequency range that can cover large amounts of data. Its greatest disadvantage is a dependency to strong transmitters and also is very sensitive to environmental conditions.
- **L and S bands**: The data link speeds do not exceed 500 Kbps. Its wavelengths have the ability to penetrate underground installations, requiring less power than K band bandwidth.
- **Band C**: requires a large transmitter and receiver antennas.
- **Band X**: It is used for military purposes.

Also, with appearance of mobile ad-hoc network (MANET) where each unit acts as a communication repeater or relay, so that, data goes to next node and finally forwards to destination, we can expect sustainable and cheaper communications for military and civil applications in future (Grodi, 2016; Gupta et al., 2013).

### Table 2  Common radio frequencies for UAS

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>3–30 MHz</td>
</tr>
<tr>
<td>VHF</td>
<td>30–300 MHz</td>
</tr>
<tr>
<td>UHF</td>
<td>300–1000 MHz</td>
</tr>
<tr>
<td>L</td>
<td>1–2 GHz (General) 950–1450 MHz (IEEE)</td>
</tr>
<tr>
<td>S</td>
<td>2–4 GHz</td>
</tr>
<tr>
<td>C</td>
<td>4–8 GHz</td>
</tr>
<tr>
<td>X</td>
<td>8–12 GHz</td>
</tr>
<tr>
<td>Ku</td>
<td>12–18 GHz</td>
</tr>
<tr>
<td>K</td>
<td>18–26.5 GHz</td>
</tr>
<tr>
<td>Ka</td>
<td>26.5–40 GHz</td>
</tr>
</tbody>
</table>

*Source*: Gupta et al. (2013)

## 5  Key points for choosing a network and data link

Selection of protocol type and data links for autonomous airlines involves several main factors who the most important of them can be listed as several tips:

- **Hardware and avionics**: Data transfer ability is related to hardware, avionics
architectures and their components as well as databases that have been used by the system. Benefits of integrated modular architecture and fibre optic are known in modern aircrafts.

- **Economic profitability**: Total avionics cost and data exchange services must be cost-effective for airlines so will play a decisive role in encouraging or disappointing of them. This cost must be compensated with benefits of autonomy, for example, optimal path selection and consequently fuel consumption reduction. Therefore, fuel cost or a slight increasing in price of passenger or cargo tickets, should not be compared with its advantages such as speed, convenience, safety and lower maintenance costs and etc.

- **Data link and network security**: Undoubtedly, security is one of the main challenges that airline autonomy will face with it. When a data link is being selected, special attention should be paid to hackers and possibility of data theft and even aeroplane hijacking by saboteurs or terrorist groups. So, all their access way, must be blocked. For example, sending a copy of all commands whom will be received by aeroplane to control centre before achieving any malicious action can be detected quickly and the controller will be able to take necessary actions. So far, permanent solutions for civilian purposes have not been identified and this field requires extensive researches.

- **Citizens’ health**: Certainly, if frequencies with wavelengths that are harmful to human body, urban and environmental health are used, there will be irreparable damages to the health of citizens especially those who live close to airports and air control centres. For this reason, comprehensive research has to be carried out on different frequencies effects on urban and environment life (Coontz-McAllister et al., 2014).

- **Redundancy and automatic data recovery**: System must have the ability to retrieve data and it must be able to access at the same time to all possible connection ports and data link for obtaining the required information. As regards to algorithms whom are defined based on strength and weakness of the signals, cost and security issues for choosing the port and data link, a system can determine suitable selection priority of protocols (Gupta et al., 2013).

### 6 Conclusion and future work

Autonomous of airlines is inevitable in future. In addition to sensible increasing in dominance on aeroplanes for airlines and control centres and reduction of human error rates to zero, if a suitable roadmap be made, it will improve economic efficiency with safety and security. The first step is to determine communication protocols for data exchange between aircraft and ground control centres. These protocols must be selected so that not only have no data disconnected during flight, but also minimise total services cost. For instance, for airport communication IEEE802.16, air-ground in ILOS position VDML2 or VDML3; and for BLOS, iridium or air relays that seems the final cost of this system is lower than iridium, can be used. At first glance, Air-to-air communications may be given less attention because other navigation systems like traffic collision avoidance system (TCAS) do their job well and if the process of full automation and precise ground
control is implemented, there will be no chance of collision in the sky. Importance of this connection will be appeared when the aircraft wants to exchange data with other aerial vehicles, especially when will be used as air relay. Hence, UAT and VDLM4 protocols can be considered. But, when we need to transfer data at higher speeds, such as video, we can utilise the protocols that used in UASs, that types of K or Ku can be proposed. Otherwise, bands L and S are suited for speeds below 500 kbps. Of course, with increased data transfer speeds, total service costs will also grow that this should be carefully considered with regard to economic issues. Also, topics related to network safety, frequency pollution in urban environments are some of the important problems ahead of this work. As for the last point, it should be recalled that all of the above protocols must be fully inspected in accordance with the ICAO and FAA’s Civil Aviation laws and will be revised if necessary. In order to make this change in the civil aviation industry, the puzzle pieces should be dealt with as the main topics. All of which require detailed research and may be basis for the emergence of new research fields and even more modern sciences.

These issues can be expressed by several questions and items for future work. For example, how can airline send flight plans to related locations and aircrafts, automatically? What hints should be considered to perform engines start-up steps, passenger or cargo loading, determining the path for taxiing, preparing for movement on the runway with appropriate timing? What methods are available for automatic movement on runway depending on airport’s traffic to take-off point and after landing to parking zone? automatic methods for estimating flying paths of birds and preventing of aircraft entrance to bird groups especially near airports, how can do automatic take-off and put the plane at an appropriate speed and height up to the destination airport? full automatic methods for determining of presence or absence of bad weather and cumulonimbus (CB) clouds, how to establish multiple air connections with a control centre without diminishing its ability to provide automated control services, what methods can be used for data exchanging between aeroplanes and ground control centres in flying paths? fault diagnostics in aeroplanes various systems, simultaneous recording of voice and data whom is sent from aeroplane to related ground centres, automatic navigation methods, network security, anti-hacking and anti-sabotage operations, the effect of used frequencies for data transfer on human health and urban environments, required redundancy for data links recovery. Surely, with the progress of work, new items will be added to this list.

References

