

Development Of Communication System for UAV Ground Control Station with ATC Based On Controller Pilot Data Link Communication

Andri Kristanto*^{1,2}, Toto Indriyanto¹

¹Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung
ITB Kampus Ganesha Jl. Ganesha 10, Bandung, Jawa Barat, Indonesia 40132

²Advanced Master in Unmanned Aircraft System, Service and Management - Ecole Nationale de l'Aviation Civile
7, Avenue Edouard Belin, 31400, Toulouse, France

E-mail: *andrinavigasi@gmail.com

Diterima: 17 Januari 2023, disetujui: 27 November 2023, diterbitkan online: 29 Desember 2023

Abstrak

Teknologi UAV (*Unmanned Aerial Vehicle*) atau pesawat tanpa awak berkembang sangat pesat dari tahun ke tahun, dengan berbagai misi yang diemban seperti pengiriman, pertanian, pemetaan, pengawasan, pemadaman kebakaran, dan lain sebagainya. Dengan semakin berkembangnya fungsi drone, maka wilayah operasi sebuah UAV akan semakin luas, namun ada lokasi-lokasi yang menjadi area terlarang dalam mengoperasikan UAV, salah satunya adalah bandara. Mengoperasikan UAV di area kontrol ruang udara membutuhkan izin dari pemerintah dan regulator setempat. Selain itu, sistem komunikasi yang baik sangat penting untuk mendukung operasional agar tidak terjadi kegagalan. Pada makalah ini akan dibahas pengembangan sistem komunikasi antara pilot UAV *Ground Control* dengan operator ATC (*Air Traffic Control*). Sistem ini akan menggunakan pesan strategis dan taktis, mengembangkan arsitektur sistem komunikasi UAV berdasarkan prosedur operasi standar pesan strategis (CPDLC) yang melibatkan desain sistem komunikasi UAV *Ground Control Station* (GCS) dan analisis daya pancar. CPDLC sistem ini merupakan sistem komunikasi menggunakan text based, dimana menggunakan media internet untuk mengirimkan pesan kepada ATC di suatu bandara. Metode yang digunakan didalam penelitian ini yaitu melakukan studi literatur, mengumpulkan pesan CPDLC berdasarkan dokumen (GOLD), pembuatan arsitektur sistem komunikasi UAV, pembuatan standard operating prosedur komunikasi strategis, pembuatan desain interface sistem komunikasi pada GCS dan melakukan perhitungan power menggunakan link budget analisis. Hasil penelitian menunjukkan bahwa daya pancar dengan menggunakan perhitungan link budget pada jarak 100 km adalah 17 dBm untuk komunikasi payload dan 15 dBm untuk komunikasi telemetri, yang masih memenuhi standar minimum link margin 15 dBm.

Kata kunci: UAV, ATC, CPDLC, Pesan Taktis, link budget.

Abstract

UAV (Unmanned Aerial Vehicle) technology is growing very rapidly from year to year, with various missions carried out such as shipping, agriculture, mapping, surveillance, fire fighting, and so on. With the development of drone functions, the operating area of a UAV will be wider, but there are locations that are prohibited areas in operating UAVs, one of which is the airport. Operating a UAV in an airspace control area requires permission from the government and local regulators. In addition, a good communication system is essential to support operations to prevent failures. This paper will discuss the development of a communication system between UAV Ground Control pilots and ATC (Air Traffic Control) operators. The system will use strategic and tactical messages, developing a UAV communication system architecture based on strategic message standard operating procedures (CPDLC) involving UAV Ground Control Station (GCS) communication system design and transmit power analysis. This CPDLC system is a text-based communication system, which uses internet media to send messages to ATC at an airport. The methods used in this research are conducting a literature study, collecting CPDLC messages based on documents (GOLD), creating a UAV communication system architecture, creating strategic communication standard operating procedures, creating a communication system interface design at GCS and calculating power using link budget analysis. The results show that the transmit power using link budget calculation at a distance of 100 km is 17 dBm for payload communication and 15 dBm for telemetry communication, which still meets the minimum link margin standard of 15 dBm.

Keywords: UAV, ATC, CPDLC, Tactical messages, link budget.

1. Introduction

Technology in the world of aviation is currently developing very quickly. Starting with the Wright brothers (Wilbur and Orville), the inventors of the first effective aircraft design that used heavier-than-air and controlled engines, then continued with the development of passenger aircraft to space shuttle technology. In addition to manned aircraft currently, the development of unmanned aircraft or commonly called Unmanned Aerial Vehicles (UAV) has also increased significantly.

UAVs, commonly called drones, are operated without a human pilot on board. They are usually operated remotely using remote control to manoeuvre or autonomously using pre-programmed flight plans or artificial intelligence. The advantage of UAVs or drones compared to manned aircraft is that UAVs can be used in certain mission situations with high risk without the need to endanger human life.

doi: <http://dx.doi.org/10.25104/warlit.v35i2.2308>

0852-1824/ 2580-1082 ©2020 Sekretariat Badan Penelitian dan Pengembangan Perhubungan.

Artikel ini *open access* dibawah lisensi CC BY-NC-SA (<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Nomor akreditasi: (RISTEKDIKTI) 10/E/KPT/2019 (Sinta 2).

An example of its use is inspecting of a nuclear power plant. It is very dangerous if humans carry out inspections due to nuclear radiation itself. By using UAVs to conduct such inspections, it will become safer (low risk) and faster.

UAV is one of the technologies in the world of aviation that is widely developed today. UAVs or drones have various missions, including surveillance, mapping, agriculture, defence, firefighting, delivery, and many more [1]. With the various functions of UAVs, their operations are getting bigger. Likewise, for the operating area of the UAV itself, the airspace will be increasingly dense, and it is possible to operate in restricted areas and will intersect with the operating area of manned aircraft. Therefore, regulations governing the operating area of UAV are needed.

Areas that become restricted to operate drones are military areas, airports, densely populated areas, power plant areas, and so on. The airport or Controlled Airspace area is restricted to operate UAV because it is the operating area of aircraft carrying passengers and is prone to crime. To operate in such area, a permit is required from the Airport Authority or the authorised agency, as well as from the regulator.

In addition to permission from the Directorate General of Civil Aviation and related agencies in each country, operating UAVs in Controlled Airspace areas also requires communication system between Ground Control Station (GCS) or drone pilot and ATC at an airport to support flight safety and security. Aeronautical communication is usually carried out in forms of voice and data communication. The communication is performed to coordinate between UAV GCS and ATC regarding the altitude, position and drone manoeuvres.

In addition to communication system, UAV also have control and navigation systems. The control system serves to control the movement manoeuvre of drone by GCS. The tool used is a remote control system using C2 Link Communication and navigation system using GPS. In the future, navigation systems such as GPS will support the use of ADSB (Automatic Dependent Surveillance Broadcast), so that UAV monitoring will become easier.

The development of UAV technology has to consider safety and security factors, so that the drone or UAV can be operated safely and there are no conflicts that can endanger humans and the surrounding environment [2]. Currently, the International Civil Aviation Organization (ICAO) focuses on regulating the operating system of UAV. The goals are to maintain safety and avoid conflicts with passengers and other drones. In the future, UAV operations will use Unmanned Aircraft System Traffic Management (UTM) to regulate UAV operations [3].

CPDLC (Controller Pilot Data Link Communication) systems are already in use on manned aircraft today. Current CPDLC system is a communication service provided by an aviation communication provider called SITA (Société Internationale de Télécommunications Aéronautiques). SITA is a multinational information technology company that specializes in providing communication and information technology solutions primarily for aviation industry.

The problems in the research are what messages will be used in data communication between the UAV pilot and ATC, how the communication system works, what are the procedures for operating the CPDLC data communication system, what components are in the Ground Control Station to support the UAV communication system with ATC, and how to calculate the Ground Control Station power in operating the UAV at a distance of 100 Km based on the UAV technical specifications.

The objectives of this research is to develop data communication systems that have never been done in UAV operations. In addition, this system will facilitate communication between ATC and UAV pilots when operating in controlled airspace. More than that, the purpose of this research is collect CPDLC messages as strategic messages, create Strategic and Tactical message communication architectures, create CPDLC Communication Standard Operating Procedures, design communication system interfaces at the Ground Control Station, and calculate power control for telemetry and Payload communication systems at the Ground Control Station.

This research was carried out at PEN Aviation company, a UAV service company operating in Malaysia. It aims to create a communication system between UAV GCS and ATC operator at an airport that operates at a distance and in the Control Space Area. In this research, communication system in which GCS sending messages via internet and connecting to SITA server to ATC will be developed and analysed.

2. Research Methodology

The following is the methodology used in designing a remote UAV communication system between the UAV Ground Control Station and the Air Traffic Controller operator. In this research process there are several stages carried out. The stages of developing a communication system between UAV GCS and ATC are summarised in the flowchart Figure 1 below.

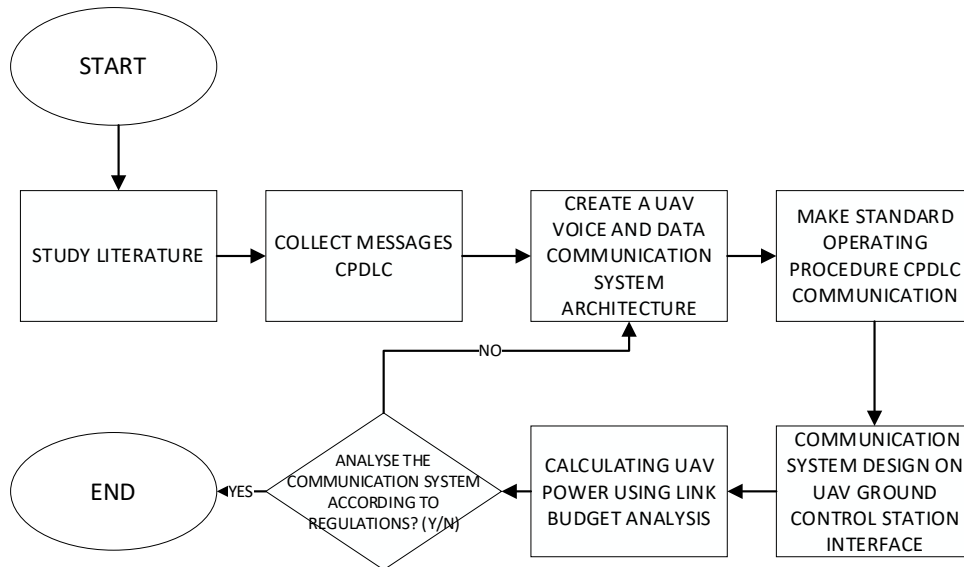


Figure 1. Flowchart of research methodology

2.1. Literature Study

Literature study is conducted by consulting various literatures and related regulatory documents. The objects studied in this research are long-range UAV communication using data transmission via internet and Beyond Visual Line-of-Sight (BVLOS) drone control.

Global Operational Data Link Document and Document 4444 on procedures for Air Navigation Service Air Traffic Management are the references to determine procedures and operations of UAV communications using CPDLC

2.2. Collect CPDLC messages

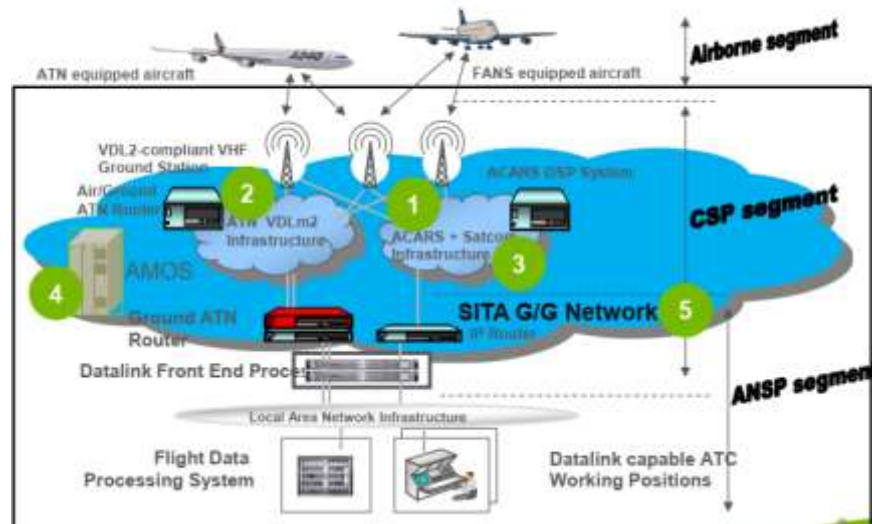
The first step to take when creating a CPDLC message list is to search the literature on CPDLC systems Communication. Some documents as references are the Global Operation Data Link Document (GOLD) [4], Document 4444 [5] and the CPDLC end to end description document [6]. From these documents, CPDLC messages are summarised and can be applied in UAV Communication operations between ATC pilots and UAVs.

2.3. Strategic and Tactical Messages System Architecture on UAV

Communication system architecture was created by collecting CPDLC message data and understanding CPDLC system that has been applied to data and voice communication on an aircraft. The CPDLC architecture is a description of how the communication system works and what are the components or equipment in it. CPDLC communication architecture also provides information on the relationship between devices starting from GCS to ATC. The working principle of the CPDLC communication system is divided into 3 segments. The first segment is the Airbone Segment, the

second segment is the Communication Service Provider segment, and the third segment is the Air Navigation Service Provider (ANSP) segment. After all CPDLC systems are active and connected, the pilot makes a request to ATC in the form of a text message, for example is request to ATC in the form of a text message, for example requesting a certain altitude using the Flight Management System equipment in the aircraft cockpit. The message is sent via VDL mode 2 or satellite if it cannot be covered by VDL mode 2. After that, the text message will be distributed through the Communication Service Provider, SITA. The data will be encrypted and recorded on the SITA server. After that the text messages will be forwarded to ATC.

The Figure 2 is the architecture of the CPDLC system communication between the aircraft and the Air Traffic Controller



Source : [7]

Figure 2. CPDLC architecture on manned Aircraft

Strategic messages are used for standard communications such as take-off, cruise, landing, and so on. Tactical messages are used for voice communication in case of emergency conditions, for example operation near controlled airspace.

2.4. Standard Operating Procedure Strategic Messages of GCS Communication with ATC.

Designing a communication Standard Operating Procedure on a long range UAV is performed by applying the phrasology that has been done on data communication on an airplane between Pilot and ATC. In making Standard Operating Procedure Strategic messages, CPDLC operation manual book from Honeywell company (Pepitone et al., 2011) is used as a reference.

2.5. Design Interface Ground Control System of UAV Communication

The next project is to conceptualise the communication interface that will be installed in the GCS. In determining the items in it, this research uses references from the Ground Control Station owned by the PEN AVIATION company and the CPDLC system found in FMS equipment on manned aircraft. Because there are not too many interface references for communication systems on UAVs at this time. The process of determining interface items in the communication system at GCS is described in Concept of Operation below.

The Concept of Operation in making the Ground Control Station communication system interface design requires several components to support the UAV pilot communication system with ATC. The Figure III.4 is part of the Communication Section of the UAV Ground Control Station.

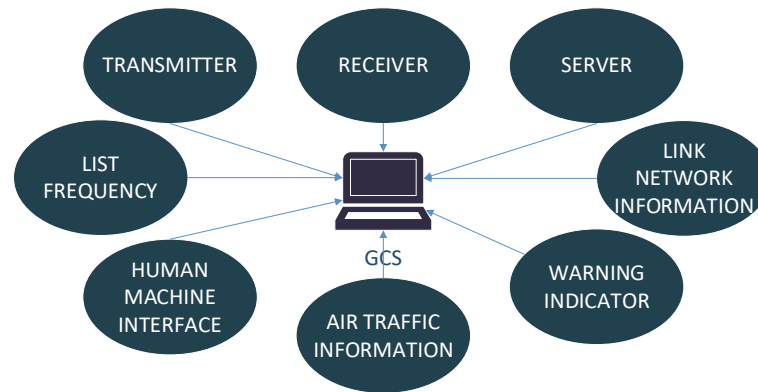


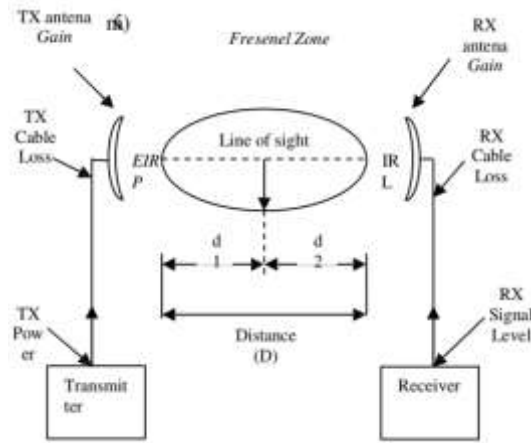
Figure 3. Communication Ground Control Station Part

The part Ground Control Station of UAV includes:

- Transmitter is the part of the Ground Control Station UAV that functions to send information of data or voice to the ATC or UAV receivers.
- Receiver is the part of the Ground Control Station UAV that functions to receive the information of data or voice from ATC and UAV sensor (camera, ADSB).
- The server is the part of the UAV Ground Control Station that serves to store data and voice communications between the atc and the UAV pilot as they coordinate with each other for takeoff, cruise, manoeuvre and landing.
- Link Network Information is part of the Ground Control Station which functions to provide information in the form of communication network conditions both RF radio and Internet networks.
- Warning indicator is part of the Ground Control Station to provide information that the UAV position is outside of the UAV operational boundary or other objects in close proximity to the UAV operation. So that the UAV Pilot needs to take action against the UAV.
- Air Traffic Information is a data and voice information about the conditions between ATC and manned aircraft operating around the UAV operating area, so that the UAV pilot knows the conditions around the UAV operation area through Air Traffic Information.
- The Human Machine Interface (HMI) is a UAV pilot interface used to monitor UAV operational conditions. The UAV Human Machine Interface contains telemetry information, sensor information, and so on.
- List Frequency is a part of the UAV Ground Control Station that contains a list of UAV communication frequencies with ATC. with this list the UAV pilot can select the channel frequency that will be used to coordinate with ATC at an airport. The frequency used for uav pilot communication with ATC is 118 - 137 Mhz.

2.6. Link Budget Calculation

Link budget is a fundamental concept in telecommunication, especially in wireless communication systems. It is a calculation that helps engineers or researchers determine the overall performance and feasibility of a communication link between two points, such as a transmitter and a receiver [8]. Link budget takes into account all the advantages, disadvantages, and factors that affect signal strength and quality of transmission. Figure 4 shows block diagram of link budget calculation method.



Source : [9]

Figure 4. Link budget block diagram

Parameters in link budget calculation are [10] :

- Transmit Power (P_{Tx}): The power level that the transmitter uses to transmit the signal.
- Free-Space Path Loss (L_{fs}): Signal loss that occurs when electromagnetic waves propagate through space. Depends on the distance between the transmitter and receiver and the frequency of the signal.
- Transmitter Antenna Gain (G_{Tx}) and Receiver Antenna Gain (G_{Rx}): Directional gain of the antennas used at the transmitter and receiver. This gain amplifies the signal in the desired direction.
- Cable Losses (L_{Tx} and L_{Rx}): Losses that occur when signals travel through transmission lines and cables between the transmitter and antenna, and between the antenna and receiver.
- Atmosphere Attenuation (L_m): Signal loss due to absorption, scattering, and other atmospheric effects.
- Receiver Sensitivity (R_x): The minimum signal power level required at the receiver in order to accurately detect and demodulate the signal.
- Margin (FM): An additional power margin added to account for uncertainties and fluctuations in communication link.

Equations used to determine the link budget are:

$$PRx = PTx + GTx + GRx - LTx - LRx - Lfs - Lm \tag{1}$$

Free-space losses can be determined using equations as follows:

$$Lfs = 32.45 + 20Log10(D) + 20Log10(f)dB \tag{2}$$

After all the data is fulfilled, it will calculate the fade margin, the System Operating Margin is to ensure that the system we are working on will work correctly. Basically, the Fade Margin calculates the difference between the received signal and the receiver's sensitivity:

$$SOM = PRx - Receiver\ Sensitivity \tag{3}$$

Fading is the fluctuation of signal amplitude. Fade margin is the power level that must be reserved which is the difference between the average power reaching the receiver and the sensitivity level of the receiver. Fading occurs due to the phenomenon of more than one path, and even multiple paths (multipath fading). Multipath fading that occurs because signals have different phases, thus causing the effect of eliminating each other. The effect of fading on the received signal can strengthen or weaken, depending on the phase of the resultant signal between the direct signal and the indirect signal. Fade Margin can be calculated with the Barnett-Vigniant Equation, which is described as follows.

$$FM = 30\log D + 10\log(6ABf) - 10\log(1 - R) - 70 \quad (4)$$

Where FM is the fade margin, D is the distance (km), f is the wave frequency (GHz), R is the objective reliability, A is the roughness factor, and B is the factor for fade margin. reliability, (1-R) is the objective reliability, A is the roughness factor, and B is the factor for converting the worst month probability to a generalised probability. The fade margin value criterion is highly depends on the desired link reliability. However, generally a good fade margin is 20 – 30 dB [11]. The purpose of the link budget in this research is to determine the maximum distance between the UAV and ATC and losses in the transmission system

2.7. Analysis of Operating System

Analysis of the communication system is carried out to ensure that the capabilities of the GCS communication system is in accordance to specifications of The UAV Regulations. Standard specifications used are:

- 1) PEN Aviation's UAV Technical Specifications [12].
- 2) Global Operational Data Link Document (GOLD), which contains CPDLC standards and list messages.
- 3) Standard Operating Procedure of CPDLC by Honeywell [13].
- 4) Document Regulation part 107 by FAA "Small Unmanned Aircraft Systems (UAS) Regulations".

Regulation (EU) 2019/947 by EASA "The Rules and Procedures for the operation of unmanned Aircraft".

3. Result and Discussion

3.1. List of CPDLC Messages

List of CPDLC messages is obtained from literatures on CPDLC system, such as the Global Operation Data Link Document (GOLD) [4], Document 4444 [5] and the CPDLC end to end description document [6]. From these documents, a summary of list of CPDLC messages that can be applied in UAV communication can be produced.

CPDLC equipment contains text messages in the form of ATC commands to pilots. The text message consists of 2 formats, namely:

1. Downlink Format : Text message transmitted from the pilot to Air Traffic Control
2. Uplink Format : Text message sent from ATC to the pilot.

Messages sent by GCS to ATC or vice versa are text-based messages, the message model is regulated in the Global Operational Data Link Document (ICAO, 2013). In this research, the focus is on the downlink format. Messages are sent from the Ground Control Station to ATC. downlink format examples are shown in the table 1.

Table 1. Downlink Format Messages CPDLC

No Ref #	Messages Elements	Messages Intent/use
DM 0	WILCO	The instruction is understood and will be complied with
DM 1	UNABLE	The instruction cannot be complied with
DM 2	STANDBY	Wait for a reply.
DM 3	ROGER	Message received and understood.
DM 4	AFFIRM	Yes
DM 5	NEGATIVE	No
DM 6	REQUEST	Request to fly at the specified level
DM 7	REQUEST BLOCK [level] TO [LEVEL]	Request to fly at a level within the specified vertical range.
DM 8	REQUEST CRUISE CLIMB TO [LEVEL]	Request to cruise climb to the specified level

Source : [4]

3.2. Architecture of CPDLC and Tactical Messages

The architecture design of communication system between UAV pilot and ATC begins with study of CPDLC system on manned aircraft. The system is then compared with CPDLC system that will be applied in UAV operations in airport area. Figure 5 shows the designed strategic messaging architecture using CPDLC system on UAV. The communication architecture system begins with the Ground Control Station sending data messages processed on the GCS server to be forwarded to the SITA provider via the Internet. SITA will continue to ATC the strategic message to be responded and reply to the message via the Internet to the UAV Ground Control Station.

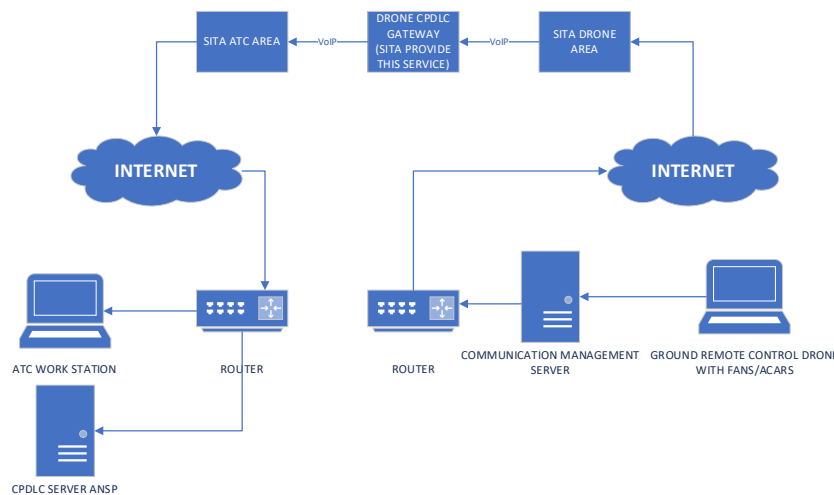


Figure 5. Strategic Messages Architecture

The architecture determination also considers several components in supporting the communication system. Among other things, hardware, transmission media and input and output of this system. So that the communication system architecture of strategic messages and tactical messages can be understood. The UAV communication system architecture between ATC and GCS consists of 2 systems, namely strategic and tactical, where the strategic architecture system is carried out using internet media to be sent to ATC through the SITA navigation provider and for tactical using VHF media by being sent to the UAV, from the UAV sent to ATC or aircraft around the UAV operation area. The Figure 6 is an overview of the architecture that will be applied in Long range UAV communication operations.

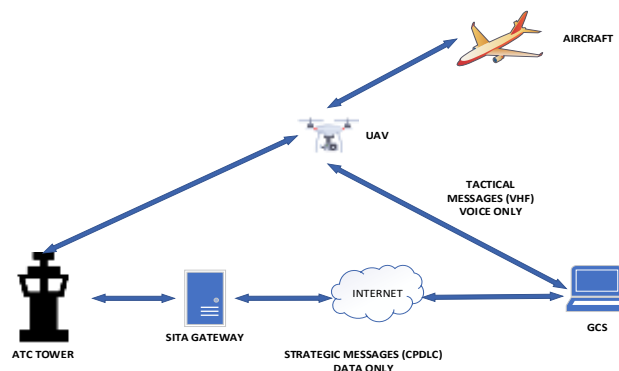


Figure 6. Communication architecture of UAV using strategic and tactical messages.

3.3. Standard Operating Procedure of CPDLC System

CPDLC standard operating procedure is used to initiate the strategic messaging operation between UAV Pilot and ATC. There are several steps to perform this operation described below.

1. **System Activation:** ATC and pilots ensure that the CPDLC system is activated and ready for use. This involves selecting appropriate data link service or aviation communication provider and establishing a connection.
2. **Logon System:** Here pilot initiates logon process by sending CPDLC system entry request to ATC. This includes identifying aircraft and its associated data link address. Controller verifies the login request and establishes the data link connection.
3. **Communication:** Once the data link connection is established, ATC and pilots can exchange messages using predefined codes and templates. The messages can be permissions, instructions, requests for information, or acknowledgments.
4. **Message Format:** Both ATC and pilots use standardized message formats to ensure clear and concise communication. These formats may include predefined codes for specific instructions or requests.
5. **Readback/respons:** Pilots are responsible for re-reading important instructions or clearances received through the CPDLC to ensure their understanding. Controllers review the readings and provide appropriate responses.
6. **Message Termination:** After completing the message exchange, the controller or pilot ends the communication session by sending a termination request. This ensures that both parties realize that the interaction has been completed.
7. **Monitoring:** Supervisors and pilots continue to monitor the CPDLC system for incoming messages and remain alert to any updates or changes in flight operations.

The Flowchart Standard Operating Procedure for operating of CPDLC system is shown in Figure 7.

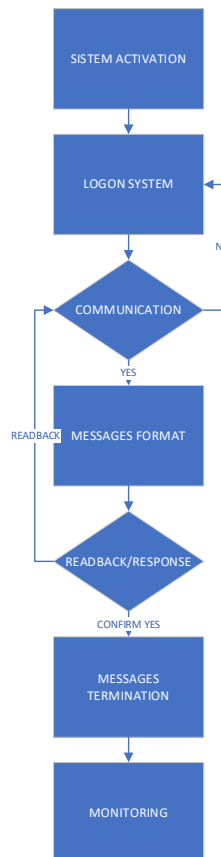


Figure 7. Flowchart of standard operating procedure for CPDLC system

3.4. Interface Design for UAV GCS Communication

This is the conceptual design of the communication interface that will be installed in the GCS. To determine its subsystems, GCS reference from PEN Aviation and the CPDLC contained in the FMS equipment of a manned aircraft are used.

Based on this reference, CPDLC file messages, network status indicators, transmission systems and receiving systems are included as parameter items in strategic messages. For tactical messages, parameters that need to be included are list of frequency, transmission system, receiving system and storage.

3.5. Calculation of GCS Transmitter Power

3.5.1. Link Margin Analysis

In calculating the power required in UAV operations, the Link Budget calculation method is used. The method requires several parameters from PEN Aviation UAVs [14]. The parameters used include TX power, TX cable loss, TX Antenna Gain, RX Antenna Gain, RX Cable Loss, RX sensitivity, and distance.. The parameters used are telemetry communication and payload communication, namely:

Table 2. Link specification for payload communication

No	Parameter	Value	Unit
1	TX Power	32	dBm
2	TX Cable Loss	3	dB
3	TX Antenna Gain	30	dB
4	RX Antenna Gain	2.1	dB
5	RX Cable Loss	3	dB
6	RX Sensitivity	-100	dBm

Source: [14]

Table 3. Link specification for telemetry communication

No	Parameter	Value	Unit
1	TX Power	36	dBm
2	TX Cable Loss	3	dB
3	TX Antenna Gain	30	dB
4	RX Antenna Gain	2.1	dB
5	RX Cable Loss	3	dB
6	RX Sensitivity	-100	dBm

Source: [14]

Based on Tables 2 and 3, fade margin can be determined using telemetry frequency of 5034 MHz and payload frequency of 2400 MHz at distance of 100 km. First, free space loss for payload and telemetry communication is calculated based on equation (2).

Free space loss for payload communication:

$$L_{fs} = 32.45 + 20\text{Log}_{10}(100) + 20\text{Log}_{10}(5034) = 140.1 \text{ dB}$$

Free space loss for telemetry communication:

$$L_{fs} = 32.45 + 20\text{Log}_{10}(100) + 20\text{Log}_{10}(2400) = 146.53 \text{ dB}$$

Then, the Receiver Power or EIRP (effective isotropic radiated power) is determined using equation (1). Setting the value of L_m or miscellaneous losses as "0", EIRP for payload communication:

$$PRx = 32 \text{ dB} + 30 \text{ dB} + 2.1 \text{ dB} - 3 \text{ dB} - 3 \text{ dB} - 140.1 = -82 \text{ dB}$$

EIRP for telemetry communication:

$$PRx = 36 \text{ dB} + 30 \text{ dB} + 2.1 \text{ dB} - 3 \text{ dB} - 3 \text{ dB} - 146.53 = -84.43 \text{ dB}$$

To ensure that the communication link can run properly, then the operating margin or link margin needs to be calculated based on the formula (3).

Operating margin for payload communication:

$$SOM = -82 - (-100) = 18 \text{ dBm}$$

Operating margin for telemetry communication:

$$SOM = -84.43 - (-100) = 15.57 \text{ dBm}$$

Table 4 shows the link margin of telemetry and payload UAV from 0.1 -100 Km where the increasing distance of the link margin will decrease.

Table 4. Payload and telemetry link margin

No	Distance	Lfs Payload	Lfs telemetri	Prx payload	Prx telemetri	Link Margin Payload	Link Margin telemetri
1	0.1	80.10	86.54	-22.00	-24.44	78.00	75.56
2	5	114.08	120.52	-55.98	-58.42	44.02	41.58
3	10	120.10	126.54	-62.00	-64.44	38.00	35.56
4	15	123.63	130.06	-65.53	-67.96	34.47	32.04
5	20	126.12	132.56	-68.02	-70.46	31.98	29.54
6	25	128.06	134.50	-69.96	-72.40	30.04	27.60
7	30	129.65	136.08	-71.55	-73.98	28.45	26.02
8	35	130.99	137.42	-72.89	-75.32	27.11	24.68
9	40	132.15	138.58	-74.05	-76.48	25.95	23.52
10	45	133.17	139.60	-75.07	-77.50	24.93	22.50
11	50	134.08	140.52	-75.98	-78.42	24.02	21.58
12	55	134.91	141.35	-76.81	-79.25	23.19	20.75
13	60	135.67	142.10	-77.57	-80.00	22.43	20.00
14	65	136.36	142.80	-78.26	-80.70	21.74	19.30
15	70	137.01	143.44	-78.91	-81.34	21.09	18.66
16	75	137.61	144.04	-79.51	-81.94	20.49	18.06
17	80	138.17	144.60	-80.07	-82.50	19.93	17.50
18	85	138.69	145.13	-80.59	-83.03	19.41	16.97
19	90	139.19	145.62	-81.09	-83.52	18.91	16.48
20	95	139.66	146.09	-81.56	-83.99	18.44	16.01
21	100	140.10	146.54	-82.00	-84.44	18.00	15.56

Normally, the standard value of operating margin or link margin is above 15 dBm. Thus at maximum distance of 100 km, the communication specifications of the UAV system can be used. Table 3 shows the link margin values for payload and telemetry communication systems from distance of 0 to 100 km. Based on payload and telemetry link margin on Table 3, there are no values that are much different and above 15 dBm. As the distance increases, the link margin value will decrease. This condition is depicted in the payload and telemetry link margin graphs in Figures 8 and 9.

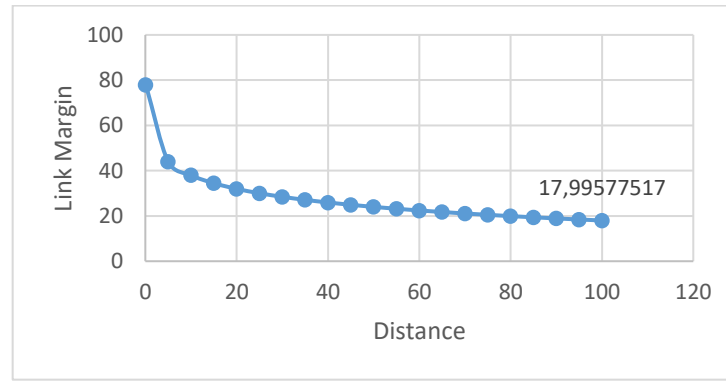


Figure 8. Link margin for payload communication

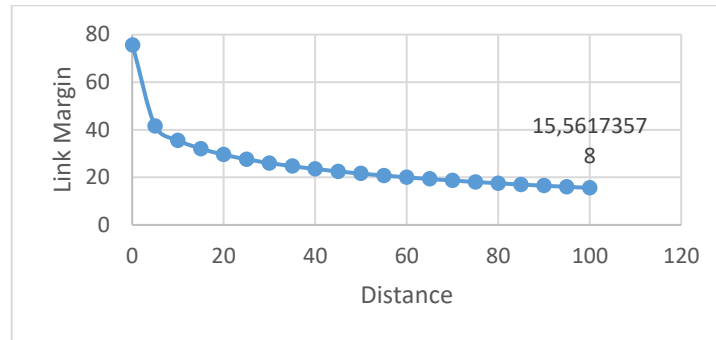


Figure 9. Link margin for telemetry communication

In Figure 7 and Figure 8 there is a similarity in the graph, the further the distance of the UAV operation with GCS, the Link Margin value will decrease. At a distance of 100 km the link margin value for payload and telemetry communication is above 15 dBm, so it is still within the tolerance of the communication system.

3.5.2. Fade Margin Analysis

The purpose of fade margin is to account for GCS communication network with UAV in the event of adverse weather conditions. To determine fade margin value, the Barnett-Vignant equation is used in formula (4). This calculation is based on the worst weather conditions by entering an A value of 3 which indicates smooth terrain and a B value of 0.5 which indicates hot areas. Tables 4 and 5 shows fade margin for payload and telemetry communication.

Table 5. Fade margin for payload communication

Frequency Payload (GHz)	D (km)	A	B	Reliability y	FM Payload (dB)
2.4	100	3	0.5	0.98	20.33

Table 6. Fade margin for telemetry communication

Telemetry Frequency (GHz)	D (km)	A	B	Reliability	FM Payload (dB)
5.030	100	3	0.5	0.98	23.55
5.031	100	3	0.5	0.98	23.55
5.032	100	3	0.5	0.98	23.55
5.033	100	3	0.5	0.98	23.55
5.034	100	3	0.5	0.98	23.55
5.035	100	3	0.5	0.98	23.55
5.036	100	3	0.5	0.98	23.55
5.037	100	3	0.5	0.98	23.55
5.038	100	3	0.5	0.98	23.55
5.039	100	3	0.5	0.98	23.56

In Table 5, the payload frequency that is in the 2400 MHz frequency range has a fade margin of about 20.33 dB with a distance of 100 km for the worst simulation condition shown with parameters A and B. The magnitude of the fade margin has met the standards in a communication channel which is considered good, which is when the value is 20 - 30 dB. Furthermore, the analysis of the fade margin in the telemetry shown in Table 6, the frequency range from 5030 to 5039 MHz has a fade margin of 23.55 dB with a reliability of 98%.

Communication system between UAV GCS and ATC is one of the communication systems used in addition to payload communication and telemetry communication, especially if the UAV operating area is in the Controlled Airspace area [15].

4. Conclusions

In this project it can be concluded that:

1. Data collection of CPDLC messages using references from the Global Operational Data Link Document (GOLD) issued by ICAO and Document 4444 "Procedures For Air Navigation Services Air Traffic Management". These messages have been implemented in aircraft CPDLC communications system and are planned for use in UAV communications.
2. Architecture of UAV systems, namely strategic and tactical communication systems, Strategic messages are used for non-urgent messages (data only), and tactical messages are used for urgent messages (voice only).
3. The Standard Operating Procedure for Strategic Communications aims to guide the operation of the CPDLC system for strategic communications. The operation of this UAV is planned to be conducted with BVLOS and conducted in controlled airspace areas. Therefore, special permission from local authorities and ATC is required before operating the UAV. In operation, strategic messages using the CPDLC system will be sent via the internet to ATC using a navigation provider (SITA) and tactical messages using VoIP will be sent via VHF to the UAV, after which it is sent to ATC at an airport.
4. From the results of the link budget calculation above, it can be concluded that in order to fulfil the regulation of UAV operation safety regulations and smooth mission payload data with a range of 100 km then on the telemetry and telecommand side, a power of 36 dB or equal to 4 Watts is required while the payload requires a power of 32 dBm or equal to 1.6 Watts. On the payload, power is required 32 dBm or equal to 1.6 Watts. These results are based on the minimum standard value of link margin of 15 db.
5. This project is a concept of the communication system that will be applied in UAV operation. UAV communication system architecture, standard operating procedures for operating strategic messages, UAV communication interface design, and UAV link budget calculation are the first steps for the communication system between ATC and Ground Control Station. Further research is needed to make this system more reliable and applicable in UAV communication systems.

Acknowledgement

The authors appreciate the supports from PEN Aviation Company, Malaysia in conducting research for this topic and thanks to Badan Pengembangan Sumber Daya Manusia Perhubungan for providing the opportunity to carry out the ITB and ENAC Double Degree scholarships.

References

- [1] G. Singhal, B. S. Bansod, and L. Mathew, "Unmanned Aerial Vehicle Classification, Applications and Challenges: A Review," New Delhi, 2018. doi: 10.20944/preprints201811.0601.v1.
- [2] A. A. Pandey and Dr. R. Prabhakar, "Integration of Drones/UAV in Civil Aviation airspace in India: Challenges and Job complexities," *Social Science Journal*, vol. 12, no. 6, 2022.
- [3] T. Jiang, J. Geller, D. Ni, and J. Collura, "Unmanned Aircraft System traffic management: Concept of operation and system architecture," *International Journal of Transportation Science and Technology*, vol. 5, no. 3, pp. 123–135, Oct. 2016, doi: 10.1016/j.ijst.2017.01.004.
- [4] International Civil Aviation Organization, *Global Operation Data Link Document (GOLD)*. Montreal, Quebec: International Civil Aviation Organization, 2013.

- [5] ICAO, *Procedures for Air Navigation Services (PANS) - Air Traffic Management (Doc 4444)*. ICAO, 2016.
- [6] Data Comm Implementation Team, *CPDLC END2END DESCRIPTION*. Data Comm Implementation Team, 2020.
- [7] SITA, "Session 4.6 ADS CPDLC Workshop SITA v 2.0-1.Lagos," Nigeria, 2015.
- [8] C. Yan, L. Fu, J. Zhang, and J. Wang, "A Comprehensive Survey on UAV Communication Channel Modeling," *IEEE Access*, vol. 7, pp. 107769–107792, 2019, doi: 10.1109/ACCESS.2019.2933173.
- [9] S. Attamimi and R. Rachman, "Perancangan Jaringan Transmisi Gelombang Mikro Pada Link Site Mranggen 2 Dengan Site Pucang Gading," *Jurnal Teknologi Elektro*, vol. 5, no. 2, May 2014, doi: 10.22441/jte.v5i2.764.
- [10] A. Chabory, R. Douvenot, and C. Morlaas, "Antennas and Propagation," Toulouse, 2023.
- [11] I. N. Y. Putro, N. Chasanah, and Sunar, "Desain Link Budget Dengan Metode Free Path Loss Model Untuk Analisis Jarak Jangkauan LSU 02 LD," in *Seminar Nasional Iptek Penerbangan dan Antariksa XXI-2017*, Jakarta: LAPAN, 2017, p. 7.
- [12] Cavok UAS, "Cavok UAS - Professional drone solutions." [Online]. Available: <https://cavok-uas.com>
- [13] D. Pepitone, J. Fugedy, and E. Letsu-Dake, *CPDLC Procedures: Recommendations for General System Performance Requirements, Design of Standard Operating Procedures and Operating Limitations for CPDLC*. Washington, D C: Honeywell, 2011.
- [14] Pen Aviation, "PEN UAS." [Online]. Available: <https://penaviation.com/services/pen-uas/>
- [15] NATO Standardization Agency, "Standardization Agreement," Brussels, Belgium, 2009.