ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

INSTITUTE OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Feasibility study of network planning for domestic flight in the Air of Ethiopia using LDACS-1

By

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Advisor

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Place: Addis Ababa

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This thesis has been submitted for examination with my approval as a university advisor.

Dr. Yalemzewd Negash ____________________

Advisor's Name Signature

Abstract

The digital communication system which has been used in aeronautical communication field is based on VDL-2 (VHF Data Link Mode 2) system. This system provides a transmission of text messages with a maximum bit rate of 31.5 kbps for a distance up to 375 KM. However, as the air traffic dramatically increased over the last ten years, the air space becomes more congested. Due to this, it becomes too difficult to assignee VHF spectrum channel for each aircraft. Thus, the VDL-2 system does not accommodate large aircraft traffic load and high bandwidth requiring services. In addition, the VDL-2 system has several limitations: it does not support high capacity services for the communication between the aircraft and the air traffic controller (ATC). And also it is not providing data services during long flights. These phenomena occur when the communication distance between the aircraft and the control is more than 375 KM.

These problems in aeronautical communication forced the aviation community to evaluate and prepare new air to ground communication system. In order to cope with the increasing demand of communication capacity in the aeronautical sector, the future communications infrastructure has been proposed in L-band frequency spectrum. Currently two candidates are considered for the L-band Digital Aeronautical Communications System (LDACS). The two competing digital data link technologies are LDACS type 1 and 2. Both L-band systems are the air-to-ground data link technology within the Future Communications Infrastructure (FCI).

From this perspective, this study investigated the LDACS-1 specification, Ethiopia airlines vision 2025 and perform network planning to serve the estimated data traffic load for the year 2025. Moreover, by deploying LDACS-1 system for domestic flight in Ethiopia a feasibility study has been made. Based on two different cases, the simulation is done for cell radius of 75 km with 30 base stations (BS) and cell radius 150 km with BS 12. In both scenarios the study assumed all aircraft generate the same data rate and travelling the same speed. The performance matrices considered in this work are: coverage by signal level, coverage prediction by transmitter, coverage prediction by overlapping zones and prediction by QoS. The performance indicator matrices show that, by implementing scenario I, the system can accommodate, up to 780 aircrafts. Whereas implementing scenario II the system can serve up to 312 aircrafts at a time. Thus in terms of traffic load, the system capacity in scenario I is higher than that of scenario II.

Finally, simulation results show that the network planning based on LDACS-1 system can be implemented in Ethiopia. Consequently, the proposed network planning is able to fully serve the expected traffic load, with sound QoS and it provides full coverage of the continental Ethiopian airspace. Thus the deployment of LDACS-1 system can be possible in Ethiopia.

Key words: **Aeronautical communications, Ethiopia airlines vision 2025, aviation community, VDL2, ATC, LDACS, LDACS-1, FCI, BS.**

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Addis Ababa, December 23, 2016

List of abbreviations

Acronym	**Description**
A/A	Air-Air
A/G	Air-Ground
ACAS	Airborne Collision Avoidance System
ACB	Adjacent Cell Broadcast
AeroMACS	Aeronautical Mobile Airport Communications System
AM	Amplitude Modulation
AM(OR)S	Aeronautical Mobile (off Route) Services
AM(R)S	Aeronautical Mobil (Rout) Service
AMS	Aeronautical Mobile Service
AS	Airborne Station
ATC	Air Traffic Controller
ATM	Air Traffic Management
B-AMC	Broadband-Aeronautical Multi Carrier Communications
BC	Broadcast
CCCH	Common Control Channel
CINR	Channel to Interference plus Noise Ratio
CSMA	Carrier Sense Multiple Access
D8PSK	Differentially encoded 8-Phase Shift Keying
DCCH	Dedicated Control Channel
DLS	Data Link Services

DME	Distance Measuring Equipment
ELT	Emergency locator transmitter
ET	Ethiopia Airline
FAA	Federal Aviation Administration
FCI	Future Communications Infrastructure
FCS	Future Communication Study
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiplexing Access
FL	Forward Link
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Geostationary Navigation Satellite System
GPS	Global Position System
GS	Ground Station
GSM	Global System for Mobile Communications
ICAO	International Civil Aviation Organization
ILS	Instrument landing system
ITU	International Telecommunication Union
LDACS	L-band Digital Aeronautical Communication System
LDACS 1	L-band Digital Aeronautical Communications System Type one
LDACS 2	L-band Digital Aeronautical Communications System Type Two
LLC	Logical Link Control
LME	Link Management Entity
LOS	Line of Sight
LTE	Long-term evolution

LT	Local Time
MAC	Medium Access Control
MF	Multi Frame
MIDS	Multifunctional Information Distribution System
NASA	National Aeronautics and Space Administration
OFDM OR	Orthogonal Frequency Division Multiplexing off- route
PDUs	Protocol Datagram Units
QoS	Quality of Service
RA	Radio altimeter
RL	Reverse Link
SARPs	Standards and recommended practices
SATCOM	Satellite communication
SF	Super Frame
SIB	System Identification Broadcast
SNDCP	Sub Network Dependent Convergence Protocol
SSR	Secondary Surveillance Radar
TCS	Terminal cellular system
TWLU	Terminal wireless local area network unit
UAT	Universal Access Transceiver
UMTS	Universal Mobile Telecommunications System
VDL	Very High Frequency Data Link
VDL-2	Very High Frequency Data Link Mode 2
VHF	Very High Frequency
VI	Voice Interface

VNAV	Vertical Navigation
VOR	VHF Omni-directional ranging
WXR	Weather radar

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1

Introduction

The concept of aeronautical communication system can be addressed by analog and digital systems. The analogue communication system which has been applicable for voice transmission has been in use for more than 75 years [1]. As the need of more service and higher data rate services demand increase, the concept of digital communication system emerged in 1978. This system is known as VDL-2 (VHF Data Link Mode 2) [2]. The digital communication system was applicable for transmission of text messages with a maximum data rate of 31.5 kbps between aircraft and Air Traffic Controller (ATC) system, called Aircraft Communications Addressing and Reporting System (ACARS) [3]. It has been used regularly as part of civil aviation operations for messaging services. As the information exchange between aircraft and ground station increase, the air traffic channels become congested. As a result, the VDL-2 system is not accommodating an increasing amount of data traffic. Therefore, the growing problems in aeronautical communication have forced the aeronautical community to upgrade the existing technology.

The researchers along with related organizations, such as International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA) and National Airspace System (NAS) are currently preparing new infrastructure for next generation air to ground system. This infrastructure is called NextGen [4]. The NextGen system has the ability to accommodate much larger air traffic comparing to the current system's capability. It also reduces the aircraft controller and pilot workload [5].

L-band Digital Aeronautical Communication System (LDACS) is a recent technology with an improved performance in service delivery and system simplicity. It has an ability to provide a high speed communication between the aircraft and air traffic controllers at the airport as well as the areas nearby the airport. So by adapting LDACS system it is possible to transmit higher data rate in less time. The LDACS system is designed for the time frame of 2015 – 2030 and intended to handle the future aeronautical data traffic demands [6]. The system technical specifications which includes system parameters, basic cell planning and site deployment are available.

LDACS network planning process refers to determining the locations, estimated capacity and size of the cell sites (coverage and capacity planning), and assigning frequencies to them by examining the radio-wave propagation environment, link budget calculation and interferences among the cells.

1.1. Problem Statement

The communication system which has been used in aeronautics field is primarily based on analog voice communication. It is a widely known communication system, which provides both voice and data services and operates on HF and VHF bands. Table 1 shows the list of available HF and VHF data rate. Though, the VHF based voice communication system used for analog radio system with Amplitude Modulation (AM) scheme, its mode of communication can be easily affected by noise or other interference. In addition, it doesn't serve best in terms of spectral efficiency and power managements [7].

Band	Technology	Access Scheme	Modulation	Data Rate
HV	HF Data Link	TDMA	MPSK	1.8 Kbits/s
VHF	VHF Data Link 2	CSMA	D8PSK	31.5 Kbits/s
VHF	ACARS	CSMA	AN MSK	2.4 Kbits/s

Table 1.1 HF and VHF digital aeronautical data links [8]

According to aviation authorities [9], the air traffic is estimated to grow 3% per year. This implies that the traffic load in early 2030 is twice as compared to the load in 2012. It is expected by 2030 that the number of flights will almost double to 48.7 million. Passengers will also be travelling further (In 2012, over 4.9 trillion passenger kilometers were flown by airlines, one passenger flying one kilometer is a 'passenger kilometer'). By 2030, forecasts suggest that 13.5 trillion passenger kilometers will be flown [10]. Based on these estimations, the current system will suffer from severe congestion around the globe and this band (VHF) is already saturated.

The number of aircrafts at busy airports in the near future will be larger than system capacity in the next decade [11]. The problem can only be solved by adopting new Air Traffic Management concepts (ATM).

Figure 1.1 The highest aircraft densities [12]

1.2. Motivation

As it has been mentioned in the above section, the connection link between the aircraft and Air Traffic Control can be established via VHF or HF communication system. Currently these systems are facing frequency scarcity problem and the VHF band is already saturated. More over the system is not secured and easily affected by noise or interference. Furthermore, the communication system does not serve best in terms of spectral efficiency. While technology has rapidly advanced there exist technological gaps between communication system available in the cabin for passenger services and in the cockpit for ATC.

It is commonly agreed that future aeronautical communication services include the provision of broadband services on-board of the aircraft. Different airlines have shown interest to provide mobile and internet services to their flight passengers in fleets. This will make the flight time more pleasant and more constructive to the passengers. Due to various technological requirements, international regulations, long life-cycles for aeronautical systems, and security requirements; the use of mobile phone and internet services in aircraft during flight time is prohibited. But researchers have been investigating ways to determine how the data services are available to passengers. To mitigate such problems, the aircraft authorities and regulatory bodies have developed an L-band Digital Aeronautical Communications System (LDACS).

The improvement requirement, in 2002 the National Aeronautics and Space Administration (NASA) and the European Organization for the Safety of Air Navigation (EUROCONTROL) launched the project Future Communication Study (FCS) to develop a new air-ground communication system capable to fulfill this goal [13]. The airborne solution is referred to as the Future Radio System. These efforts cover several fields, area of future aeronautical data links. At the end of this project, two candidates have been selected by the International Civil Aviation Organization (ICAO) for future digital air-ground communication systems. Those candidates are L-band Digital Aeronautical Communications System, Type1 (LDACS-1) and Type 2 (LDACS-2).

The main target of L-DACS is to make air travel more convenient, predictable and environmentally friendly. L-DACS is expected to help guide and track aircrafts more precisely and on more direct routes. Among other needs, L-DACS has to cover very long distances (nearly 400km) and to support very high mobility (up to 1080km/hr) [14]. Hence it is important for the future aeronautical communication systems to provide fast, high-speed, high data rate and reliable communications not only between the aircraft and ground infrastructure but also between airplanes directly.

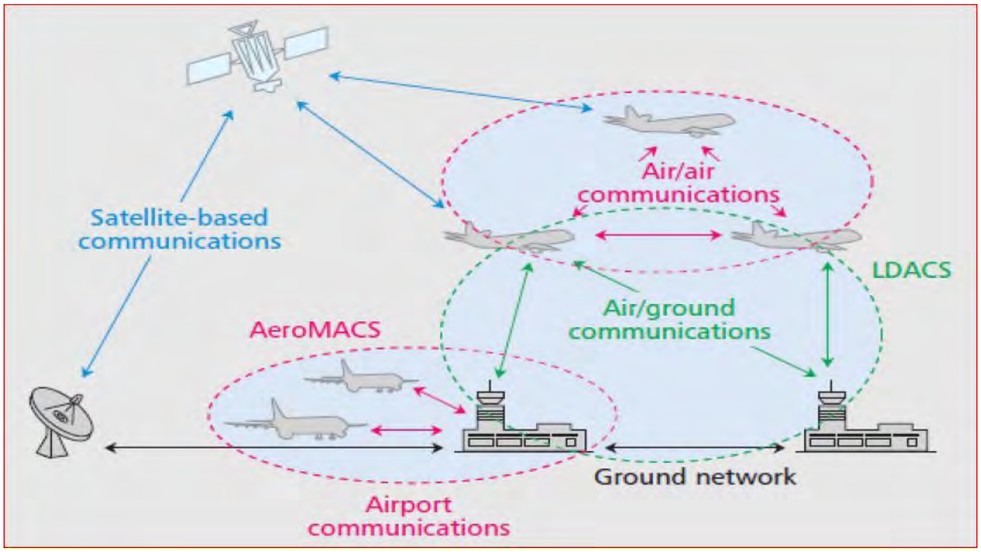


Figure 1.2 Future Communications Infrastructure of the ATM [EUROCONTROL]

As we have seen Figure 1.2 FCI comprises three segments: a ground-based high-capacity airport surface data link system, referred to as the Aeronautical Mobile Airport Communications System (AeroMACS), remote and continental environments and a ground-based terrestrial data link system for continental airspace in general, referred to as the L-Band Digital Aeronautical Communications System (L-DACS) and a satellite-based data link system (SATCOM) for the oceanic.

Thus, these highly driven commercial interests in aeronautical communication system motivated this study of network planning for use in Ethiopia using LDACS-1.

1.3. Literature Review

Several studies have been conducted on the aeronautical communication system. Among there, the Joint Euro-American Project was launched in 2003 to provide solutions adapted to the future aeronautical scenario. This project is entitled aeronautical Future Communication System (FCS) and is composed by researchers, industrialists and aeronautical authorities from many countries around the world. Inside the scope of this project, it has been developed a system called L-band Digital Aeronautical Communication System (L-DACS) to face the saturation of the current continental aeronautical communication system that operates in the VHF band. Since 2007, the L-DACS is being developed and two candidates were pre-selected: LDACS-1 and LDACS-2 [15].

LDACS1 for an Alternate Positioning Navigation and Time Service project investigate the navigation performance of the future communication system LDACS-1 applied for aviation using Geostationary Navigation Satellite System (GNSS) positioning technique [16].

Modeling DME Interference Impact on LDACS-1, in this paper, an algorithm for modeling the Distance Measuring Equipment (DME) impact on LDACS-1 is presented. This enables to determine whether LDACS-1 can cope with DME interference for a certain area and channel frequency. The performance evaluation is based only on the positions; pulse rates, and transmit frequencies of the DME stations, without carrying out extensive simulation. Results for Europe indicate that a reliable operation of LDACS-1 can be achieved [17].

In [18], the authors give detailed feature of LDACS-1 and discussed issues such as channel coding, physical layer specifications, antenna transmission, scheduling, quality of service, handovers and modulation schemes. Moreover, LDACS-1 spectral efficiency for forward link (FL) and reveres link (RL) are described.

High level protocol operations and functions are discussed in [19]. This document explains LDACS-1 impact onto DME, quality of service and possible extension for long-term evolution (LTE). This paper mainly focuses on the impact off different features of LDACS-1 on performance and interference.

In [20], a brief overview of the LTE- based A/G system for air traffic management services is studied. The main focus of this study is using the existing terrestrial LTE network the users in the aircraft are expected to avail broadband connectivity.

[21], On their journal, D. Medina and F. Hoffmann established the idea that new innovations for in-flight connectivity based on the concept of mesh networking. Which began in 2009, deals with an airborne mesh networks which uses self-organizing wireless networks formed by aircraft via direct air-to-air radio communication links.

[22] which began in 2007, deals with the feasibility of aeronautical ad-hoc network with the aircrafts flying including all the means of communications of an aircraft, even connections between two aircrafts, to transport all data for the air traffic control, the airlines and passengers. However, it does not consider the effect of the routing protocols because of aircrafts travels to the high speed and have a very dynamic topology.

As explained [23], in LDACS deployment, different frequency planning schemes can be used. This document explains in details the deployment of frequency planning of B-AMC. In the consequence, the study shows that the B-AMC frequency planning can be used for LDACS system.

1.4. Objective of the Thesis

1.4.1. The general objective

The general objective of this thesis is to investigate future Aeronautical Communication system based on LDACS-1 system for the case of Ethiopia.

1.4.2. Specific Objective

According to predictions of the growth of air traffic in the year 2025, this study accomplishes the following specific objectives:

- The feasibility study of network planning for domestic flight in the air of Ethiopia using LDACS-1 system.
- Estimation of data traffic load and cell planning to implement LDACS-1 base stations.
- Designing frequency plan, base station lay out and cell arrangements.

1.5. Methodology

With the above mentioned objectives for the research, the thesis will primarily study and analyzes the theoretical background of existing Aeronautical communication system and emerging solution that are usable for this purpose. The data supporting this study is derived from relevant current aeronautical communication journals, different manuscript, different IEEE articles, previous studies on this subject and online literatures. By analyzing these resources, we have gained insight into the connectivity behaviors of LDACS-1 system, commercial aircraft connectivity route and Ethiopian Airlines Vision 2025 plan for domestic flight traffic load. The analysis gives an important baseline to determine the location of ground stations and the range of each cell. With the objectives and the theoretical knowledge in the subject matter clear, simulation data is taken. This data will be analyzed and simulated based on different performance parameters using ATOLL simulation environment.

1.6. Limitation of the Thesis

Considering the fact that LDACS is a new technology in Aeronautical communication, the introduction and implementation of LDACS is in early stages. This lead to some of the following limitations:

- Finding information related to digital map of some domestic airports were a challenging task. Thus to fill this gap the study consider an automatic network planning.
- It became too difficult to obtain an aircraft distribution data for different domestic flights. Thus the thesis roughly assumed an approximated value of: Number of aircraft in a cell and the data rate generate by each aircraft.

- Since the frequency spectrum allocation in L band is not available in Ethiopia, this study directly uses the frequency planning of Broadband Aeronautical Multi Carrier Communications System (B-AMC).

1.7. Thesis Outline

The thesis is divided into 5 chapters including the introduction. The paper is outlined in Figure 1.3. First we will begin with a brief description of the LDACS-1 communication system in terms of architecture and characteristics. A second part will present the target plan of Ethiopia Airlines for domestic flight, including the location of all Airports and airport to airport distance. And also provide a detailed explanation of the network planning, and the presentation of preliminary results for the cell planning and frequency planning. In the fourth section we present the scenario of our simulations and the results obtained. We will then conclude our paper giving some directions of future work.

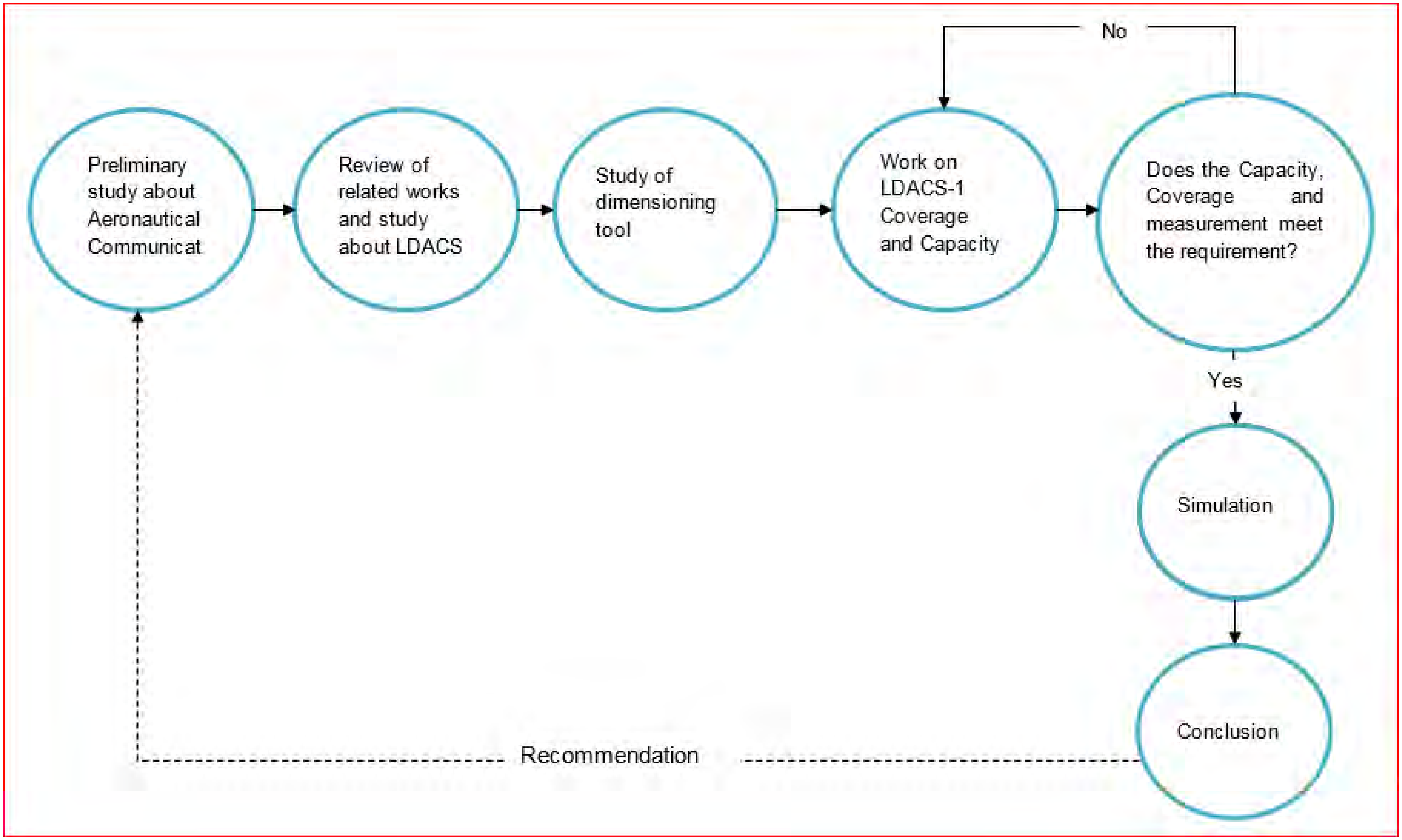


Figure 1.3. Structure of the thesis

2

Theoretical background of aeronautical communication system and emerging solution

This chapter discusses the existing communication system which has been used in the aeronautical field and future's air/ground candidate solution. It briefly introduces about the potential applications of the L-band Aeronautical Communication System type 1 (LDACS-1) which could be employed in future. The chapter also provides the technical specifications of the LDACS-1 system which is used for the simulations and evaluation.

2.1. Existing Communication Systems on an Aircraft

Traditional aircraft communications are based on analog voice on either a High Frequency (HF) or Very High Frequency (VHF) radio waves. Those communication systems are far from meeting the demands of increasing air traffic volume. Furthermore, newer aircrafts are equipped with satellite communication system. However, HF and VHF systems are still the primary means for pilots to communicate with air traffic controllers. Based on the relative position of the aircraft in different phases of the flight, the Air to Ground (A/G) communication can be classified into;

- Line-of-sight communication
- Non- line-of-sight communication (NLOS)
- Take-off or landing
- En-route communication as shown in Figure.2.1 [24] [25].

The next sections will explain in detail information of existing aeronautical communication system.

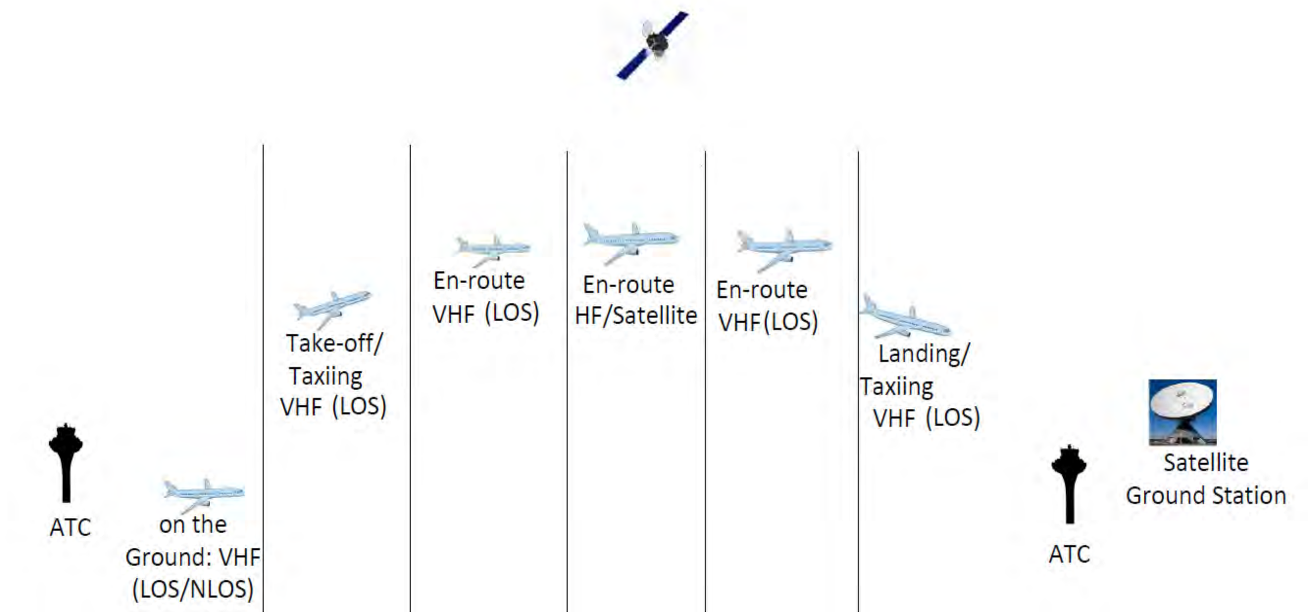


Figure 2.1 Aircraft in different phases of flight and preferred operating bands [26]

2.1.1. HF Communication System

High frequency (HF) radio communication system provides an effective means of communication between distant aircraft and ground ATC. The operating frequency range is between 3 - 30MHz. The aeronautical HF radio band covers the Aeronautical Mobile (Route) Service and Aeronautical Mobile (off Route (OR)) Services.

The AM(R)S covers a total of 1301 KHz bandwidth. This band is widely used for the civil on-route HF radio communication in airplanes and for flight communications where VHF communication systems cannot be employed. As shown in Figure 2.2, the large commercial aircraft type contains two HF systems. Actually, the communication services through satellite system are expensive and have long delay. Therefore, for oceanic and polar flights HF communication system allow the aircraft to send its reports to ground station. However, HF communication system is the only means of communication system between a distance aircraft and ATC for some aircraft [27].

AM(OR)S covers a total of 1125 KHz bandwidth within the frequency range 3025 – 23,350KHz, which is mainly used for the off-route service. However, the performance of HF system depends on solar physics. As a result, it normally takes about 2 minutes to setup a communication.

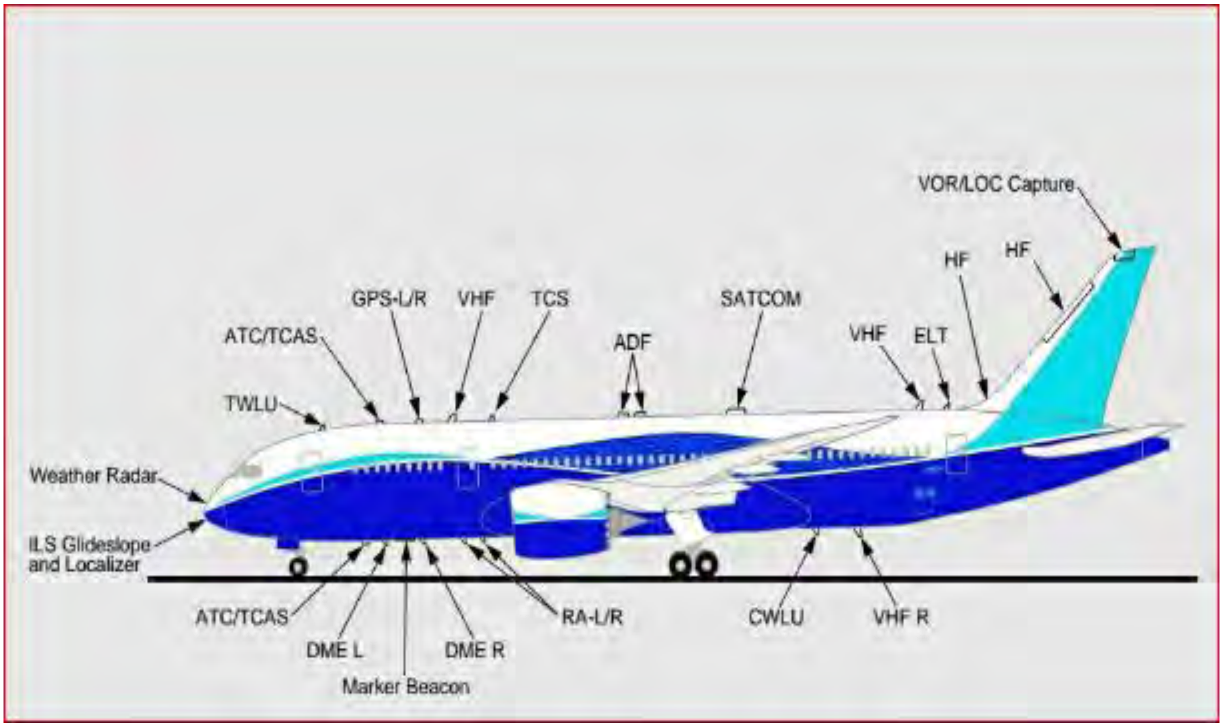


Figure 2-2 Antenna location on commercial aircraft [28]

2.1.2. VHF Communication System

Globally the communication between an aircraft and a ground Air Traffic Control (ATC) usually uses Very High Frequency (VHF) based communication system [29]. This band is used to support all phase of flight between the pilots and air traffic controllers, the arrival and departure of the flight to and from the terminal area and the ground movement of aircrafts. The VHF band is a congested area of the spectrum which is shared by many terrestrial systems and uses line-of-sight communications to ground stations. The system provides both voice and data services for aeronautical communication. The VHF communication spectrum ranges from 118 –137 MHz has been allocated for aeronautical safety communications over continental areas. This spectrum is organized in voice channels of 25 kHz or 8.33 kHz and a unique voice VHF channel is assigned to each Air Traffic Control (ATC) sector.

Relatively small parts of the spectrum have been allocated to the aeronautical data links like ACARS (Aircraft Communications Addressing and Reporting System) and VDL (VHF Digital Link). VDL technology provides effective and reliable communications between pilots and ATC. For data communication the modulation schemes are the D-8PSK (Differential – 8 Phase Shift Keying) is used. The data bit rate is usually at 31.5kbps [30]. There are three competing VHF based data communication technologies for ATC, such as VDL mode 2, 3 and 4 [31].

Regarding to the aircraft type different VHF communication systems are installed inside an aircraft. For large commercial aircraft three VHF systems are installed, two of which are used for ATC voice communications and one is used for the data communications.

2.1.3. Satellite Communication System

Satellite systems are capable of providing more bandwidth than the aeronautical VHF networks can provide. It is very well placed to cover the large oceanic and remote airspaces. Its services have to be up and running all the time for critical purposes. Currently, there are two ICAO standards for satellite communications, the INMARSAT3 and IRIDIUM systems. However, the performance requirements in the current ICAO satellite standards (AMS(R)S standards and recommended practices (SARPs)) are insufficient to meet the quality of service (QoS) requirements of the applications supporting the future operating concept. There is therefore a need to update the satellite SARPs to include more stringent performance requirements, to select a new technology and to develop the required standards to meet the updated requirements.

The need to select a new technology does not constitute an undesirable proliferation of technologies, as by the 2020+ timeframe all current aviation satellite systems will be reaching the end of their lifetime and new system s will have to be reconsidered in order to continue supporting the oceanic areas [32].

Also for general aeronautical communication satellite would be very costly. There is also the latency issue with GSO (Geostationary Satellites). Taking this into account most of the time satellites are not used for ATC communication.

2.2. Future Aeronautical Communication System

Based on the result of the future aeronautical communications research, the new generation air to ground system should have high capacity to support high traffic for all phases of a flight. Research has identified two technology options for the L-band Digital Aeronautical Communication System (LDACS).

2.2.1. L-band Digital Aeronautical Communication System (LDACS)

LDACS is a ground-based communication system based on line-of-sight communications principle. To support air/ground communication, in particular for en-route and TMA communications in continental airspace.

Over the past several years, EUROCONTROL has funded two projects for developing new data links for aeronautical communications. These projects resulted in two proposals named LDACS-1 and LDACS-2. Initial specifications for both technologies have been published by EUROCONTROL [18].

The first option, named (LDACS-1), represents the state of the art in the commercial developments employing modern modulation techniques, and may lead to utilization/adaptation of commercial products and standards like Long-Tern Evaluation (LTE) [33], Wireless Local Area Network, Wi-Fi and WiMAX [34]. LDACS1 is based on a frequency division duplex (FDD) configuration utilizing Orthogonal Frequency Division Multiplexing (OFDM) modulation techniques which enables the use of Adaptive Coding and Modulation (ACM) and higher order modulation schemes.

The second option, named (LDACS-2), capitalizes on experience from current aviation systems and standards such as VDL3, VDL4 and Universal Access Transceiver (UAT). LDACS-2 is based on a time division duplex (TDD) configuration utilizing a binary modulation derivative of the implemented UAT system (CPFSK family) and existing commercial systems such as Global System for Mobil Communications (GSM) [18].

This thesis focuses on LDACS-1 and the next section will present it in detail.

2.2.2. LDACS-1

2.2.2.1. Spectral deployment of LDACS-1

LDACS-1 is intended to operate in the lower part of the L-band (960-1164 MHz) without causing interference towards or being influenced by the interference from existing L-band systems. Currently, several other systems are already operating in the L-band, as shown Figure2.3.

Distance Measuring Equipment (DME) operating as a Frequency Division Duplex (FDD) system on the 1 MHz channel grid is a major user of the L-band. Parts of this band are used in some countries by the military Multifunctional Information Distribution System (MIDS). In addition, several fixed channels are allocated for the Universal Access Transceiver (UAT) and for Secondary Surveillance Radar (SSR)/Airborne Collision Avoidance System (ACAS) systems. Fixed allocations have been made in the upper part of the L-band for Global Position System (GPS), Global Orbiting Navigation Satellite System (GLONASS) and GALILEO channels. Universal Mobile Telecommunications System (UMTS) and Global System for Mobile Communications (GSM) commercial systems are operating immediately below the lower boundary of the aeronautical L-band (960 MHz). Moreover, different types of RSBN systems may be found in some parts of the world, operating on channels between 960 MHz and 1164 MHz.

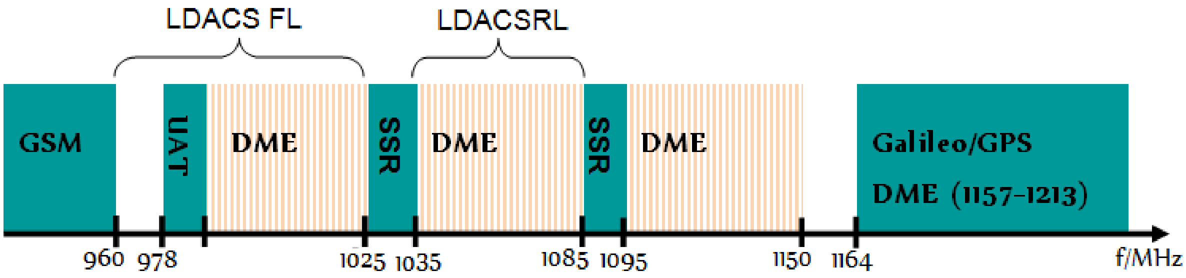


Figure 2.3. Current L-band Usage [18]

LDACS1 designed for a frequency-division duplex system, enables a GS to transmit continuously at a certain frequency, while the AS transmit at the same time but at a different frequency. For LDACS1, the frequency spacing between FL and the RL is set to 63 MHz [18].

For the LDACS1 deployment in the L-band different scenarios are possible. For the inlay scenario the frequency ranges from 985.5 to 1008.5MHz is foreseen for the FL whereas the RL should be placed in the frequency range from 1048.5 to 1071.5MHz. This spectral deployment minimizes the mutual interference between LDACS-1 and other L-band systems, mainly SSR Mode S.

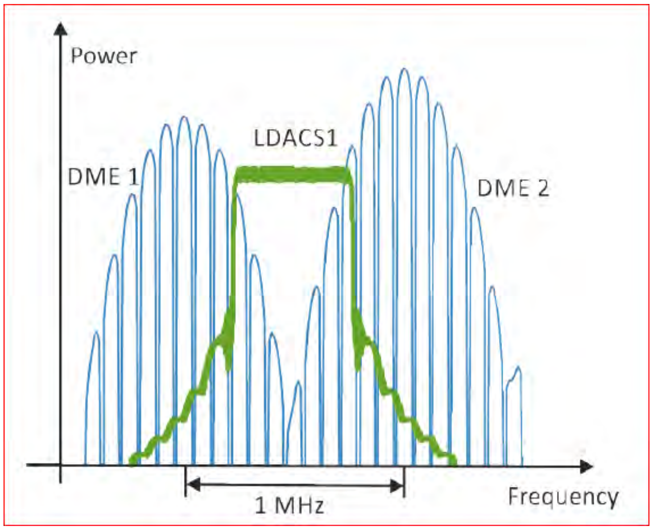


Figure 2.4 LDACS-1 spectrum and DME interference in the inlay deployment scenario [35]

2.2.2.2. LDACS-1 system architecture

This section, presents a brief overview about the fundamental parameters of LDACS-1 system. Details are available in [18]. LDACS-1 knows two different modes of operation, an air-ground (A/G) and an air-air (A/A) mode. However, the A/A mode has not been specified yet, therefore this paper focuses on the A/G mode as specified in [18].

LDACS-1 originated from the Broadband-Aeronautical Multi-Carrier Communications (B-AMC) system and WiMAX standard of the Association of Public Safety Communications Officials (PSCO). It is designed for the transmission of both digital voice and data. Physical layer allocation maps and allocation units (tiles and chunks) are from WiMAX. LDACS-1 is a cellular system based on a network of ground stations (GS). It is designed as a frequency division duplex (FDD) system, which enables a GS to transmit continuously at a certain frequency on the forward link. The communication between a GS and an aircraft, here referred to as airborne station (AS), employs orthogonal frequency division multiplexing (OFDM) [36]. While the AS transmits at the same time but at a different frequency on the reverse link.

Two different links exist; the forward link (FL) incorporates transmissions from the GS to the AS while the reverse link (RL) is employed in the opposite direction. Both directions are separated FDD.

In the RL, a combination of Orthogonal Frequency-Division Multiple-Access (OFDMA) and Time-Division Multiple-Access (TDMA) is used, whereas in the FL, Orthogonal Frequency-Division Multiplexing (OFDM) is applied. The TDMA component in the RL is selected in order to minimize the possibility of interference with legacy systems which are operating on board on aircraft in the L-band, e.g. the distance measuring equipment. This is important since an LDACS-1 transmitter operates close to other receivers on board, so it should only be active for a short time, reducing these receivers' exposure to interference.

The modulation and coding scheme of LDACS-1 can be adapted to the channel state and, thus, implements adaptive coding and modulation on both the FL and the RL. Eight different coding and modulation schemes have been defined. With that, the data rate varies between 303 kbit/s - 1373 kbit/s on the FL (assuming 24 data channel physical layer Protocol Datagram Units (PDUs) and 3 common control channel physical layer PDUs per multi frame (MF)) and 220.3 kbit/s - 1038.4 kbit/s in the RL (assuming average dedicated control channel duration of 15.84 ms per MF) [37].

2.2.2.3. Topology

LDACS-1 operating in the A/G mode is a cellular point-to-multipoint system. The A/G mode assumes a star-topology (Figure 2.3) where Airborne Stations (AS) belonging to aircraft within a certain volume of space (the LDACS-1 cell) are connected to the controlling GS. The LDACS-1 GS is a centralized instance that controls the LDACS1 A/G communications. The LDACS-1 GS can simultaneously support multiple bi-directional links to the ASs under its control. Prior to utilizing the system an AS has to register at the controlling GS in order to establish dedicated logical channels for user and control data. Control channels have statically allocated resources, while user channels have dynamically assigned resources according to the current demand.

Logical channels exist only between the GS and the AS. Direct voice and data transmissions between AS of the same cell cannot be performed without a relay function operating at the GS.

Due to its broadcast like nature the FL employs a time continuous transmission received by all AS. The different GS are separated in the frequency domain. In the RL a combined orthogonal frequency / time division multiple access approach is employed, dynamically allocating certain blocks of subcarriers for a certain time to an AS. Each GS uses a 500 KHz channel.

Both transmission modes use frequencies in the L-band and are separated in frequency by a spacing of 63 MHz. For the FL the frequency band from 985.5 to 1008.5 MHz is currently considered while the RL is to use the band from 1048.5 to 1071.5 MHz [18].

Currently deployed link technologies provide data rates in the range of 3–30 kbps per cell. However, future radio access technologies like LDACS-1, which this paper focuses on, provide data rates in the range of 291–1318 kbps in the Forward Link (FL) and 270–1267 kbps in the Reverse Link (RL) per cell depending on selected modulation and coding scheme. Although LDACS-1 increases the data rate beyond that provided by current aeronautical links, the link capacity is still far behind that of consumer electronics. Another difference is the cell size and the number of aircrafts in a single cell. However, typical cell radiuses are in the range of 150–370 km and each cell is providing services for up to around 512 aircraft.

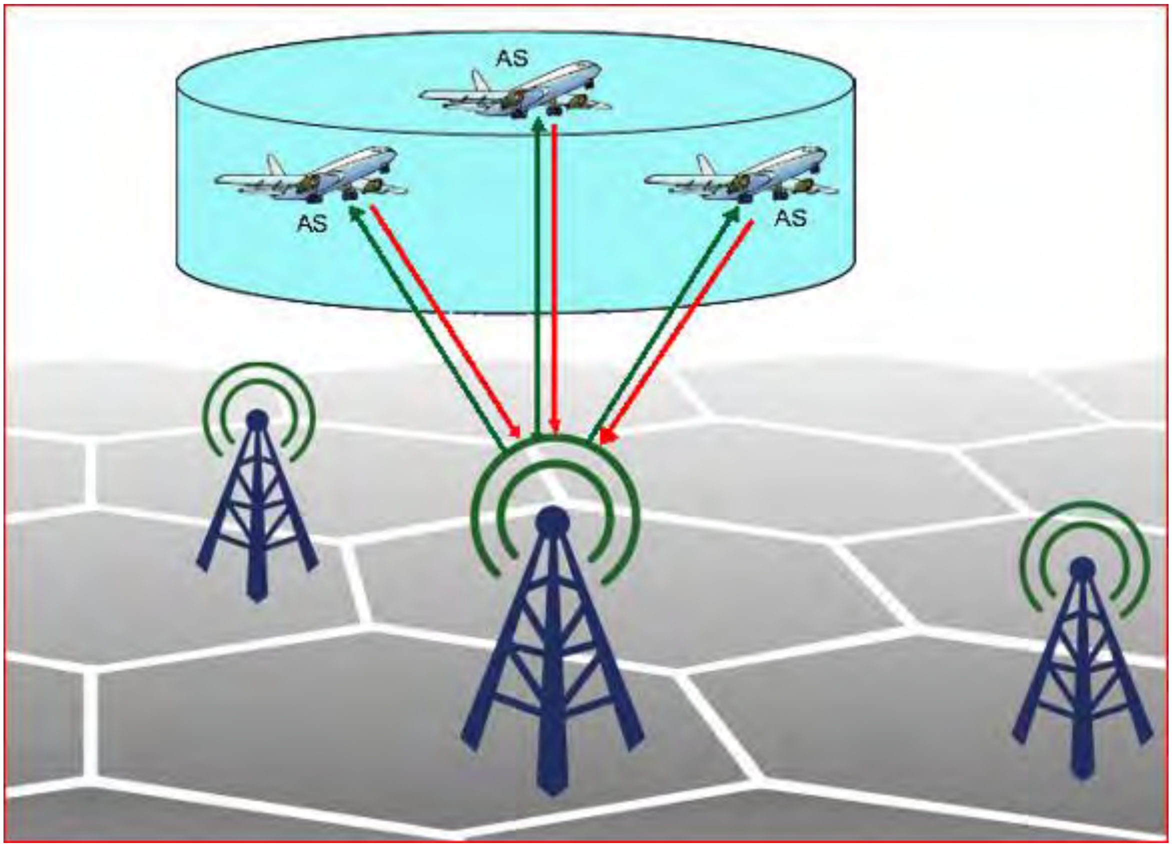


Figure 2.5 LDACS-1 Network Topology [38]

The GS transmit signal is organized in the following structure: The largest entity is a super frame (SF) of length 240ms. A SF consists of one broadcast (BC) and 4 multi frames (MF). While the MF employs the transmission of user specific data, the BC frame transmits signaling information relevant for all active AS in the cell. However, the data transmitted on the BC is neither safety nor time critical. Thus it is fully sufficient to decode the BC of the current GS only every few seconds. Therefore, the BC window is a perfect opportunity to tune the frequency to a different GS and perform ranging to that GS if only a single frequency receiver is used. However, if a multi frequency receiver is employed; all frame types within one SF may be used for ranging.

2.2.2.4. LDACS-1 Layer

In this section, the LDACS-1 layers are discussed. The LDACS-1 air-ground communication architecture is a cellular point-to-multipoint system with a star-topology where aircraft-stations are connected to a ground-station via a full duplex radio link. The ground-station is the centralized instance controlling the air ground communications within a certain volume of space called an LDACS-1 cell. The LDACS-1 protocol stack defines two layers, physical layer and data link layer. The general LDACS-1 layers are illustrated in Figure2.4.

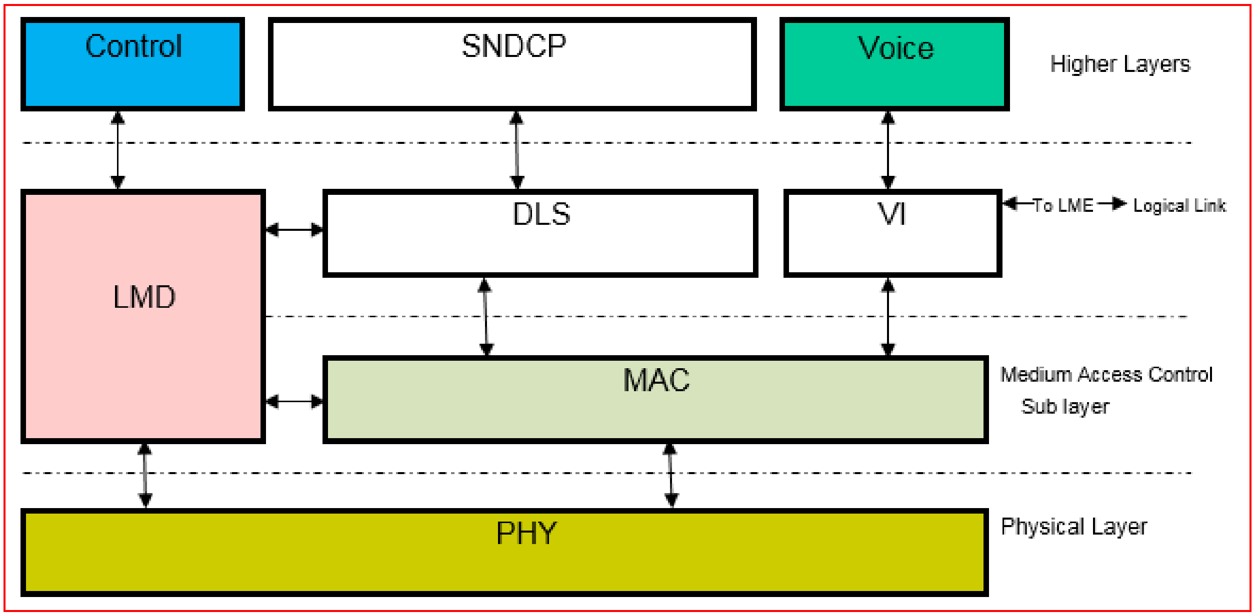


Figure 2.6. LDACS-1 protocol stacks [18]

The physical layer provides the means to transfer data over the radio channel. The LDACS-1 ground-station simultaneously supports bi-directional links to multiple aircraft-stations under its control.

The ground-station transmits a continuously stream of OFDM symbols on the forward link. Aircraft-stations transmit discontinuous on the RL with radio bursts sent in precisely defined transmission opportunities using resources allocated by the ground-station. An aircraft-station accesses the RL channel autonomously only during cell-entry. All other reverse link transmissions, including control and user data, are scheduled and controlled by the ground-station.

The data-link layer provides the necessary protocols to facilitate concurrent and reliable data transfer for multiple users. The functional blocks of the LDACS-1 data link layer architecture are organized in two sub-layers: The medium access sub-layer and the logical link control sub-layer (LLC). The logical link control sub-layer manages the radio link and offers a bearer service with different classes of service to the higher layers. It comprises the Data Link Services (DLS), and the Voice Interface (VI). The medium access sub-layer contains only the Medium Access (MAC) entity. Cross-layer management is provided by the Link Management Entity (LME). The Sub-Network Dependent Convergence Protocol (SNDCP) provides the interface to the higher layers.

Prior to fully utilizing the system, an aircraft-station has to register at the controlling ground-station in order to get a statically assigned dedicated control channel for the exchange of control data with the ground-station. The ground-station dynamically allocates the resources for user data channels according to the current demand as signaled by the aircraft-stations.

Except for the initial cell-entry procedure all communication between the aircraft-stations and the controlling ground-station (including procedures for requesting and allocating resources for user data transmission and retransmission timer management), is fully deterministic and managed by the ground-station. Under constant load, the system performance depends only on the number of aircraft-stations serviced by the particular ground-station and linearly decreases with increasing number of aircraft.

2.2.2.5. Frame Structure

The frame structure is shown in Figure 4. Time is divided into superframes with a duration of 240 ms. At the beginning of each superframe, aircraft have the opportunity to log onto the network using a Random Access Channel (RACH), whereas the Base Station (BS) transmits general cell information in the Broadcast Channel (BCCH). The rest of the superframe consists of four multiframes, each with a duration of 58.32 ms and consisting of both data and control frames. In the FL, the BS transmits control information, such as resource allocations, i.e., FL mapping and RL mapping, and acknowledgments on the Common Control Channel (CCCH). In the RL, each aircraft is assigned one slot per multiframe within the Dedicated Control Channel (DCCH) for the transmission of control data. At most, 52 aircraft can be accommodated within the DCCH. If more than 52 aircraft are registered with a single BS, not all aircraft will receive a DCCH slot in every multiframe. Both the CCCH and DCCH are of variable length to allow efficient use of the wireless resources.

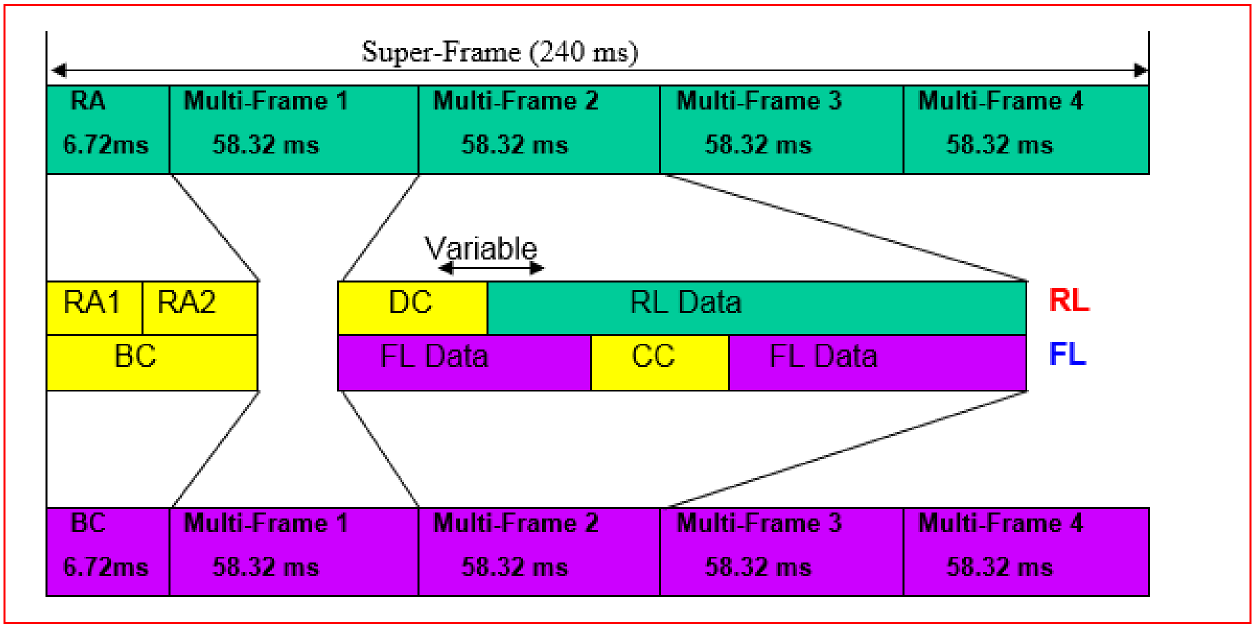


Figure 2.7. LDACS1 frame structure [18]

2.2.2.6. Resource Allocation

Before any transmission can take place, either in the RL or the FL, resources must be requested from the BS. At the beginning of a CCCH slot, the BS considers all received resource requests (sent via an RSRC_RQST message) since the last CCCH slot and distributes the FL and RL resources. For the FL transmissions, Data Link Service (DLS) module inside the BS sends the resource requests to Link Management Entity (LME) module and for the RL transmissions; each aircraft sends its resource request via RSRC_RQST message in a DCCH slot. After the BS allocates resources for the FL and RL, i.e., TDMA slots and OFDMA sub channels, for the aircraft, it informs each aircraft about the FL and RL allocations via FL_ALLOC and RL_ALLOC messages in the CCCH slot. With FL_ALLOC message, each aircraft knows which part of the multiframe that will be received in the next FL data slot belong to itself and with RL_ALLOC message, each aircraft knows when it is allowed to transmit and on which sub channels in the next RL data slot. The scope of this resource allocation is shown in Figure 4. The exact scheduling algorithm to be used by the BS is left open by the LDACS-1 specification.

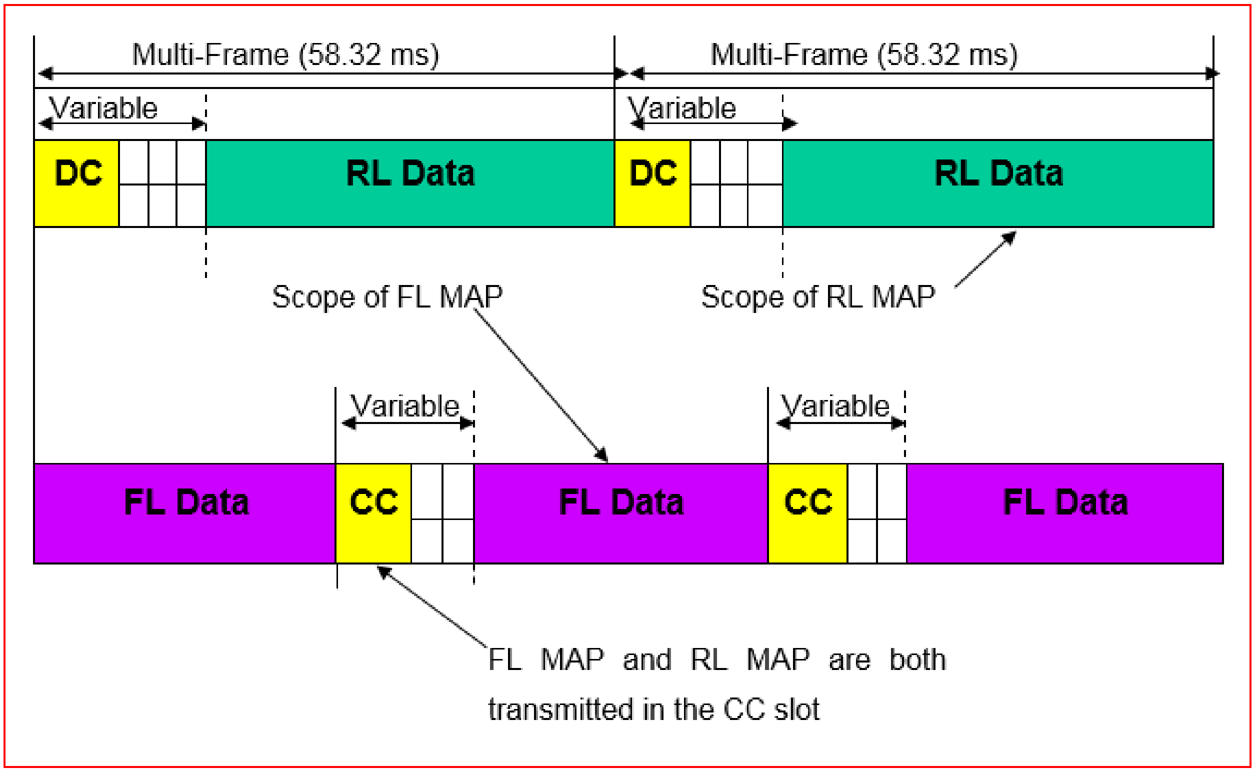


Figure 2.8 LDACS-1 resource allocation structure [18].

2.2.2.7. Handover Types

Two different types of handover are foreseen by the LDACS-1 specification. In both handover types, the BS polls the aircraft to provide power reports of their received signal strength. Polling of neighboring cells' received signal strength is requested by transmitting the Adjacent Cell Broadcast (ACB) and Scanning Table upcoming BCCH channel. In the upcoming BCCH channel, the aircraft switches to the next BS frequency and measures the received power by listening the System Identification Broadcast (SIB) message from neighboring BS. It then sends a POW_REP power report message to the current BS. If the adjacent cell's received power level is higher than that of the current cell, the current BS triggers a HO_COM handover message to the new cell.

In the case of a type 1 handover, the aircraft simply confirms the handover, sends a CELL_EXIT message to the current BS, and switches to the channel of the next BS, where it registers via the new base station's RACH by sending a CELL_RQST message. If no collision has occurred on the RACH, the BS will respond with a CELL_RESP on the CCCH and assign a subscriber access code and a DCCH slot to the aircraft. In the case of a collision on the RACH, the aircraft does not receive this response and will perform an exponential back off, attempting to access the RACH again later. The details of type 2 handover can be found in LDACS-1 specification [18].

2.2.2.8. LDACS-1 Deployment

There are three deployment options for LDACS-1 each option has its own advantage and drawbacks. Namely inlay, non-inlay and mixed concepts. In order to reduce the airborne co-site interference towards the LDACS-1 and feasibility limitations of an airborne duplexer, the currently proposed sub-range for the LDACS-1 Forward Link (FL) transmissions is 985.5 – 1008.5 MHz. Whereas for LDACS-1 Reverse Link (RL) transmissions band is 1048.5 – 1071.5MHz. Hence the effective bandwidth of the LDACS-1 signal is B_{eff} = 498.05 KHz. The proposed spacing between FL and RL is 63 MHz. This allocation would provide a total of 24 channels.

Figure 2.9 depict a possible LDACS deployment based on cellular network configuration. From the design perspective the LDAS is designed to be deployed as a cellular network. L-DACS has to cover very long distances (nearly 400km) and to support very high mobility (up to 1080km/hr), such a large coverage area results in a high number of aircraft within a cell. But depending on the interference situation, real operational coverage may be chosen to be smaller than 200nm [39]. In this case, the available channels will be reused in cell that are spaced sufficiently far apart as to keep the co-channel interference from other LDACS-1 cells within tolerable levels. The proposed frequency reuse factor for LDACS-1 system is 7. The cellular re-use pattern with the cell radius R and the re-use distance is shown Figure 2.9.

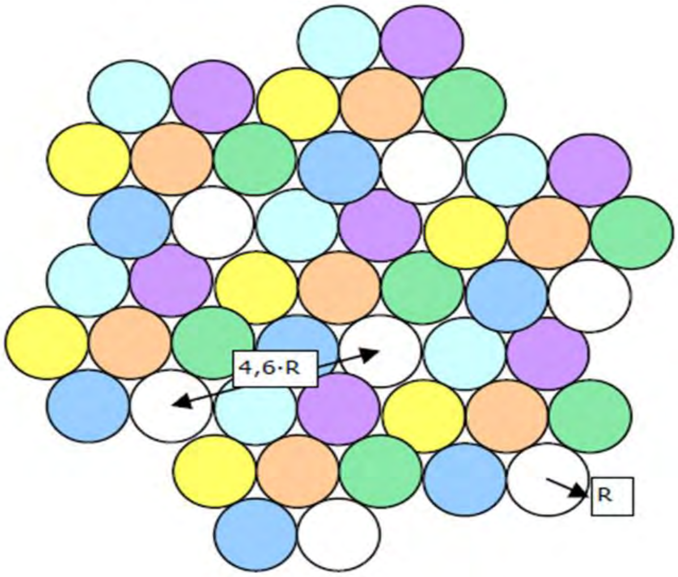


Figure 2.9 Co-channel interference in a 7 channels re-use pattern [40]

3

Connectivity route and network planning for domestic flight in Ethiopia

This chapter briefly discusses the domestic flight connectivity and network planning of LDACS-1 system in Ethiopia. For successful network deployments, the LDACS-1 network planning activities require in depth analysis of system parameters. To do so background information about Ethiopian Airline, current domestic destination, domestic flight traffic load and aircraft movement in Ethiopia has been presented. It also provides input parameters to LDACS-1 system. These includes: range and data capacity, radio link budget, EIRP, and bandwidth analysis.

Finally ground station setup, cell sizing and frequency spectrum allocation based on the GS layout will be presented.

3.1. Background Information

Ethiopia Airline (ET) is the only state-owned airline in the country. It is the oldest and the largest airlines in Ethiopia. Apart from the Boeing aircraft, ET also operates some Airbus aircraft [41].

ET primarily operates both international and domestic flight. However, we focused and performed an analysis of the domestic sector. Currently ET serves 20 domestic destinations and monopolize the entire domestic flight market. These flights mostly operate between 6AM and 7PM and link Addis Ababa with major cities, such as Arba Minch, Assosa, Axum, Bahar Dar, Bale Robe, Dire Dawa, Gambella, Gonder, Gode, Humera, Jijiga, Jimma, Kabri Dar, Kombolcha Lalibela, Mekele, Semera, Shire, and Shilavo. Addis Ababa International airport is well known as being highly congested and busiest route in the country [42].

Year 2014 data shows that; the airline gave service to 1,464,632 passengers on its domestic flight using 9 aircrafts. To protect its market and competition ET has set a strategic plan called Vision

2025. The 15- year strategic plan is expanding ET route to 26 domestic destinations with an annual traffic of 114,036 aircraft movements and 4,915,630 passengers [43].

3.2. Airline Route Type

The air transport network is one of the most important for airline development. Since the type of flight network an airline uses has a dominant impact on many of the planning problems, we will start by describing the common network types. Flight network is an informal name for the geographical network created by the flights operated by an airline timetable. There are three types of airline networks – *linear networks*, *point-to-point networks* and *hub-and- spoke networks* [44].

Linear networks are networks in which all airports are connected by a single tour. Point-to-point networks connect all airport pairs, to form a *complete graph*. In a point-to-point network it is thus possible to fly from any airport to any other airport with a single flight. Finally, in hub-and-spoke networks all flights connect to and from a central hub. The non-hub airports are called *outlying* airports, or *spoke* airports. To fly between two outlying airports, one must thus first fly to the hub, change flights, and continue to the destination airport [45].

3.3. Description of domestic network flight and traffic load in Ethiopia

This section provides some brief overview about list of airport, domestic flight networks and explains domestic flight traffic load related to vision 2025. According to Ethiopia civil aviation authority, there exist 53 airports in Ethiopia which are also known by IATA. Currently only 20 airports are used for public air transportation. Appendix C depicted the list of airports available based on IATA code and geographical location [46].

3.3.1. Ethiopian airlines current domestic flight network topology

Figure 3-1 shows the domestic route network. Addis Ababa airport has the largest number of routes in the country. There are three other international airports in the country which are Mekele in the north, Dire Dawa in the East and Bahir Dar airports in the northeast. But most of the domestic traffic originated or arrived in the capital. The operational domestic route network in Ethiopia exhibited the hub and spoke pattern in which the aircraft begin flights from a central point and return to the same point.

Figure 3.1 Major domestic air routes in Ethiopia [47]

Figure 3.1 depict the domestic network topology of Ethiopia. Majority of the domestic flight are spread out in the northern part of Ethiopia along the southern. In addition, Western and Eastern part of Ethiopia Airports are located far to each other, compared to the situation in the northern part of the country. But the Northern part comparatively airports are closer to each other.

As it has been mentioned in the previous section hub-and-spoke networks have been more common in Ethiopia. It is observed from below table 3.2 the longest domestic route that is operated in Ethiopia is the route between Addis Ababa and Shilavo, which is a 737.07Km flight and the average distance for domestic route is 453.01 Km. Table 3.2 shows the distances for some of the most common flights in the Ethiopian domestic network.

Route Addis Ababa to	Distance KM
Arba Minch	353.11 km
Asosa	481.59 km
Axum	574.83 km
Bahir Dar	334.18 km
Bale Robe	253 km
Dembi Dolo	438 km
Dire Dawa	342.91 km
Gambella	475.33 km
Gode	626.39 km
Gondar	421.17 km
Humera	634.04 km
Jijiga	439.96 km
Jimma	262.49 km
Kabri Dar	649.22 km
Kombolcha	254.4 km
Lalibela	333.83 km
Mekelle	505.63 km
Semera	375.65 km
Shire	567.4 km.
Shilavo	737.07 km

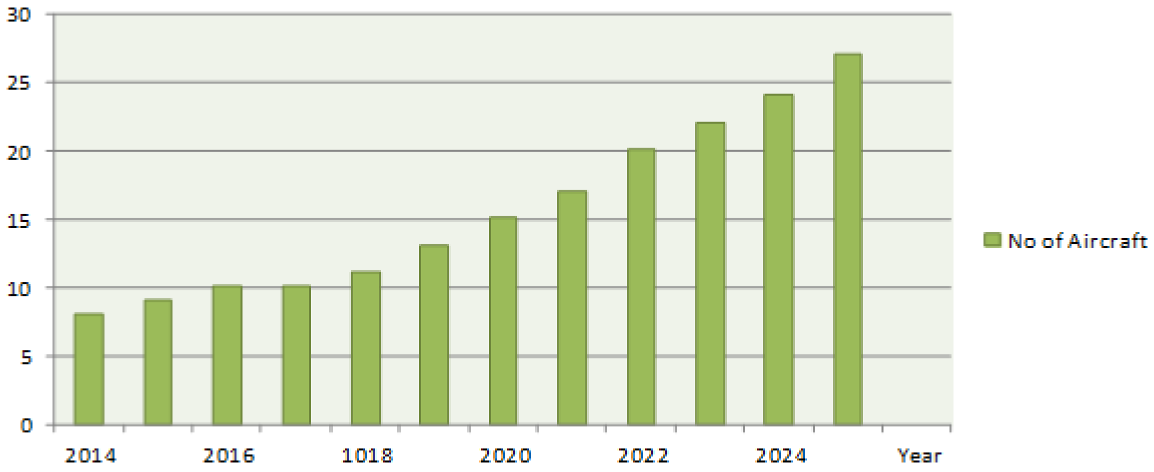
Table 3.1 Distances between Addis Ababa Airport to common domestic airport [47]

3.3.2. Domestic flight traffic load

Ethiopian Airlines has plan to expand the existing domestic flight with new several routes and further new fleet. Moreover, the aircraft movement and traffic load will be increased. This section discusses the domestic air traffic load which is vital parameters to predict the cell planning and frequency planning. Consequently, the LDACS-1 data traffic determines the distribution of aircraft in the cell and the amount of data traffic generated by each aircraft.

This study use data from domestic flights obtained from Ethiopia Airlines Vision 2025 and the application model in Communications Operating Concept and Requirements (COCR) document [48].

Figure 3.2 despite the operational Aircrafts and passengers in the year 2025. The COCR document also stated minimum data size (in kb) when information's are exchanged between the aircraft and the ground station [Appendix A].



(a)

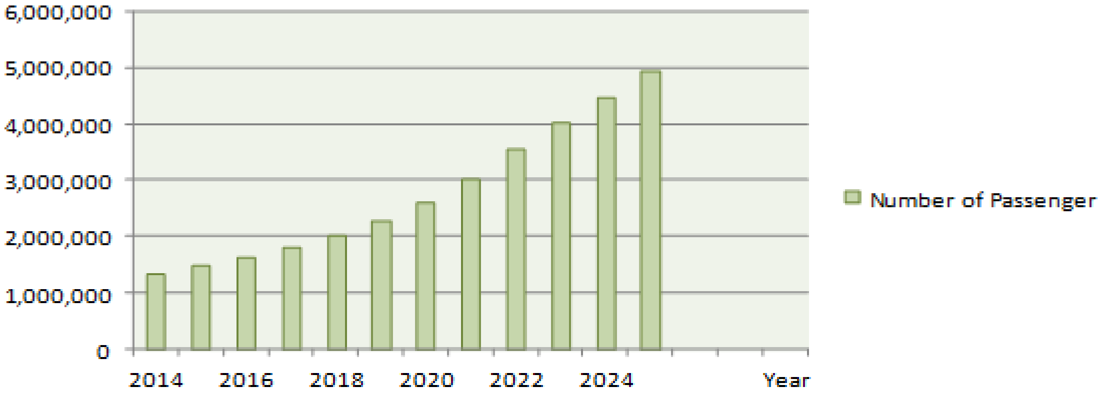


Figure 3.2 (a)Domestic Aircraft and (b) Passengers Growth [43].

Figure 3.2 also illustrates the domestic flight growth per year. The volume of air passengers has increased from 570,000 in 2010 to 4,900,000 in 2025 or an increase of 859.6% during the period. The total number of aircraft also experienced steady growth of 450% during the period from 6 aircrafts to 27 aircrafts. Air traffic movements show an increase of 470.6%. For the present study, source data on domestic flight plane there are an average of 313 domestic aircraft movement per day in Ethiopia.

Based on aircraft movement, distribution and the total traffic load, we can determine the number of cell and ground stations. However, as input for the radius of cell, we use the minimum and maximum distance between two airports that was described in the preceding chapter.

3.3.3. Aircraft movement

Another just as important data for domestic network planning is aircraft movement. Hence, on the national level, Addis Ababa airport is the busiest hub in the country and has by far the largest air traffic movements. For aircraft movement pattern we considered a typical days scheduled flights. We have analyzed scheduled flights on Mar 25, 2016 [Appendix B]. During the busiest hours in the day an aircraft arriving every 5 minutes in Addis Ababa airport.

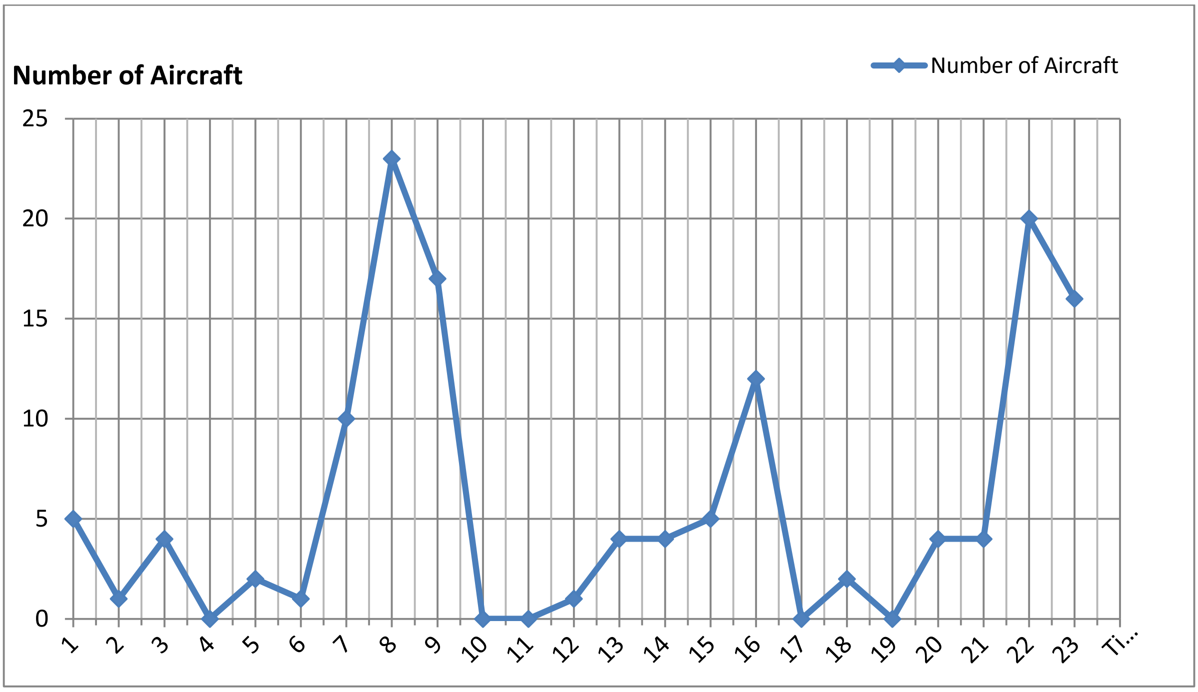


Figure 3.3 Hourly Airtrafic in Addis Ababa Airport [Appendix B]

3.4. System parameter analysis

This section discusses the mathematical analysis of system capacity. The first step the link budget analyses, EIRP and the bandwidth has been to determine.

3.4.1. Link budget analysis

A link budget is the accounting of all of the gains and losses from the transmitter, through the medium, to the receiver in a communication system. It accounts for all the gains including antenna gains, diversity gain, sub-channelization gains and the like. All loss parameters including attenuation of the transmitted signal due to propagation as well as the feed line and other losses are also considered.

The propagation model is very important for link budget. EUROCONTROL recommends that a free-space path loss model is a suitable propagation model for LDACS-1 [18]. This model does not take into account the losses due to interference and other environmental factors such as shadowing, diffraction, scattering and the like. In our simulation experiments, we consider a free-space path loss model for the wireless channel. Since the line-of-sight component is strong and all the base stations are visible from the aircraft, without any obstacle [49].

The transmitted power $\mathbf{P_{tx}}$ is defined in Eqn. 3.1. It is depending on the transmitter and receiver antenna gains $\mathbf{G_{tx}}$ and $\mathbf{G_{rx}}$**,** Cable and diplexer losses in the transmitter $\mathbf{L_{tx}}$ and the receiver $\mathbf{L_{rx}}$, the transmitter frequency $\mathbf{f_{tx}}$, and the distance between transmitter and receiver **d**. Then the transmitted power is obtained by

$$P_{tx} = P_{rx} - G_{rx} - G_{tx} + L_{tx} + L_{rx} + 20\log\left(\frac{\boldsymbol{c}}{\mathbf{4}*\boldsymbol{\pi}*\boldsymbol{ftx}*\boldsymbol{d}}\right) \qquad 3.1$$

For both FL and RL transmission the particular values are summarized in table 5.1 and 5.2 adapted from [18].

3.4.2. Equivalent Isotropic Radiated Power (EIRP)

EIRP is the amount of power that a theoretical isotropic antenna (that evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain. EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna.

$$TX\ EIRP\ =\ TX\_P_{out}\ +\ TX\_AntennaGain\ - TX\_CableLoss\ - Duplexer\ Loss \qquad 3.2$$

3.4.3. Calculation of the required Bandwidth

The calculation of the required bandwidth ***B*** that is needed to allow transmission for a given aircraft with a data rate is done for different services (Voice, Data, and video). According to the main LDACS-1 OFDM parameters the channel bandwidth is calculated using the following equations.

$$B_0 = N_{FFT} * \Delta f = 625.0kHz \qquad 3.3$$

Due to the guard bands, an effective RF bandwidth will obtained

$$B_{eff} = (N_u + 1) * \Delta f = 498.05\ kHz \qquad 3.4$$

B_0 the total FFT bandwidth

B_{eff} represents the occupied RF channel bandwidth on both the FL and the RL.

Parameter	**Value**
N_{FFT} FFT size	64
Δf Sub-carrier spacing	9.765625 kHz
N_u Number of used sub-carriers	50
OFDM symbol duration	102.4 µs

Table 3.2 LDACS-1 OFFDM parameters [18].

3.5. Ground station setup

A very fundamental planning task in cellular networks is the location of base station. In order to determine proper placement of GS and an appropriate cell size for the LDACS-1 system, it is necessary to consider the following facts:

- The aircraft location distribution and density will impose a certain traffic demand on the network for a given cell size.
- If cells are too large, too many aircraft will have to be handled by the same GS. Having too many aircraft in the same cell reducing performance since the GS has limited available throughput in the same cell. If cell ranges are too small, many GS's will be required and this can make deployment cost high.

- In addition to this Link budget limits the distance between the BS and the aircraft. The link budget calculations estimate the maximum allowed signal attenuation, called path loss, between the aircraft and the GS antenna. The maximum path loss allows the maximum cell range to be estimated. The cell range gives the number of base station sites required to cover the target geographical area.

Therefore, it is important to look at a compromise between these criteria. In the theoretical frequency reuse configuration, the distance between ground stations and site coverage area are determined by the following equation:

I. Distance between ground stations

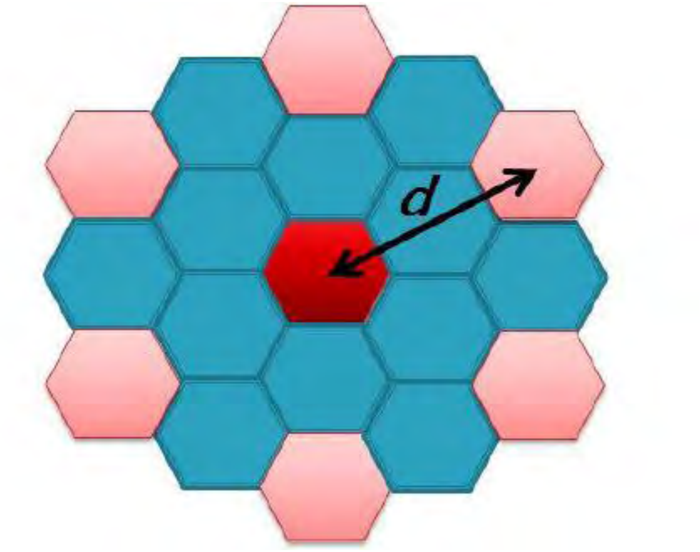


Figure 3.4 Distance between ground stations (center-to-center of service volume) [50]

$$d = r\sqrt{3 \ast \mathrm{R}} \tag{3.5}$$

d = distance between ground stations

r = Service volume radius

R = Reuse factor

The above equation shows that the service volume radius and the reuse factor determine how far apart the ground stations can be placed.

II. Site coverage Area for Omni Site

$$A = \frac{3\sqrt{3}R^2}{2} \qquad 3.6$$

III. Site coverage Area for three Sector Site

$$A = \frac{9\times\sqrt{3}\times R^2}{8} \qquad 3.7$$

IV. Required Sites number

The number of sites needed to meet coverage requirements can be calculated by dividing the site are to be covered, i.e.

$$Site\ Number = \frac{Area\ to\ be\ covered}{Site\ coverd\ area} \qquad 3.8$$

Given the cell radius, the cell coverage area depends on the site configuration. The following figure shows the different types of site configurations, and this thesis will continue using three-sector site configuration.

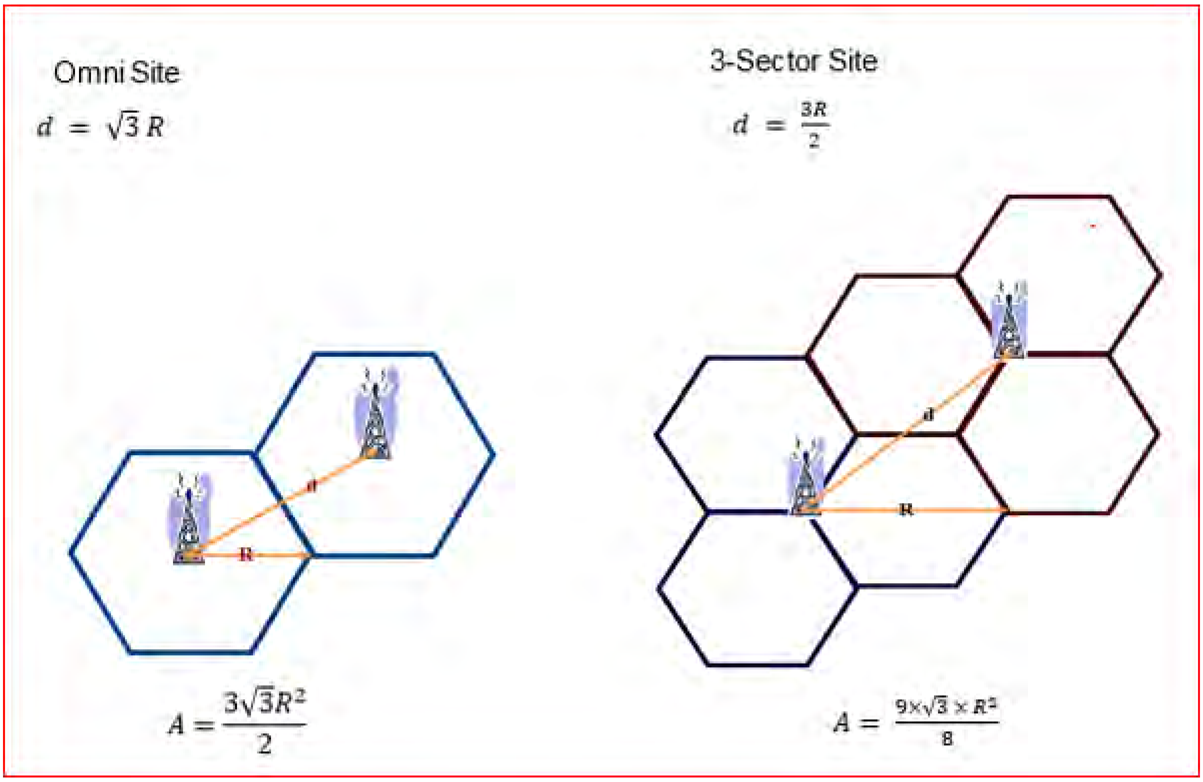


Figure 3.5 Site configuration and coverage area calculation [51]

The above equation shows that the service volume radius and the reuse factor determine how far apart the ground stations can be placed. According to the specification maximum LDACS cell radius of 200NM (370 km) is considered for altitudes higher than 3000m. For lower altitudes, a typical cell radius of 40NM (75 km) is used. The proposed frequency reuse factor is 7 [52]. And also for aeronautical communication three-dimensional cellular system proposed in [53].

3.5.1. Aeronautical geometry

Another important feature to determine the ground stations is the relationship between GS, AS, and flight attitude h. The altitude is referred with respect to see level.

The air planes have high speeds, and move in almost linear routes for most of their journeys. Some regions, such as oceanic and remote airspace aircraft typically flying along parallel routs. The average cruise altitude of most commercial and general aircraft flying at altitude of 11 km [54]. In our study, we assume that all domestic aircraft maintain a constant altitude of 9km. This assumption does not hold up when aircraft are taking off and landing. This is the decision altitude for navigation using Vertical Navigation VNAV [55].

The radio horizon is defined from direct rays of an antenna which are tangential to the surface of the Earth. As shown in Figure 3.6, AH is the LOS distance of aircraft and GS which could be theoretically calculated as follows.

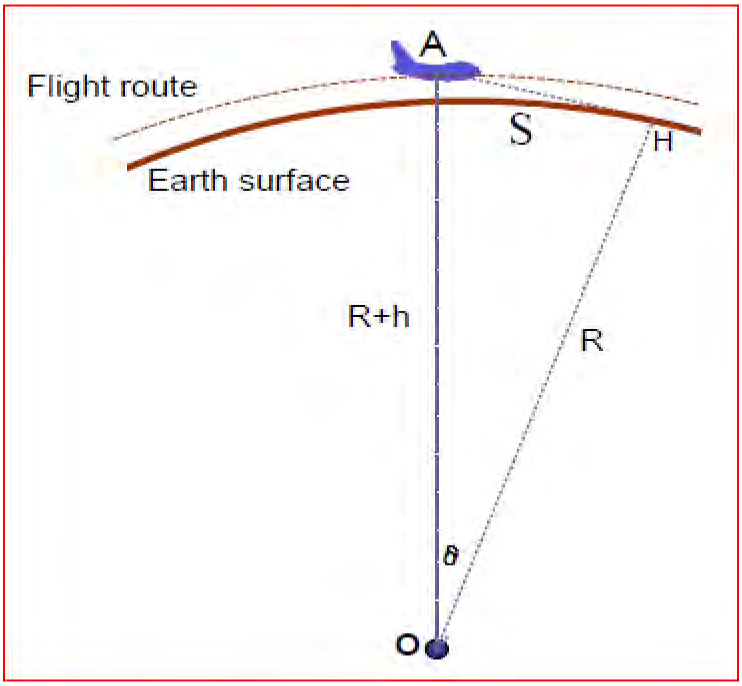


Figure 3.6 Radio line of sight LOS distance [56]

Thus, in Figure 3.5, R is the radius of the Earth which differentiates between 6336 km to 6399km but generally assumed 6378km, and h is flight altitude of the aircraft.

Suppose that an aircraft is flying at the height ***h*** from the surface of the earth. The distance AH (LOS communication distance without considering Fresnel and other parameters) to the horizon of the earth can be estimated using the Pythagoras theorem as follows:

The distance **S** along the curved surface of the Earth to the horizon with **θ** in radians, therefor the following can be derived.

$$S = R\theta \quad \leftrightarrow \quad \theta = \frac{S}{R} \qquad 3.9$$

Then

$$\cos\theta = \cos\left(\frac{\mathrm{S}}{\mathrm{R}}\right) = \frac{R}{R+h} \qquad 3.10$$

Solving for ***S*** gives

$$S = R\cos^{-1}\frac{R}{R+h} \qquad 3.11$$

The distances $\overline{AH}$ and S are nearly the same when the height of the object is negligible compared to the radius, $h \ll R$

Then the maximum radius of a cell is gives as

$$R_{cell} = R\cos^{-1}\frac{R}{R+h} \qquad 3.12$$

$$r_{max} = R_E\cos^{-1}\left(\frac{R_E}{R_E+h}\right) \qquad 3.13$$

Because for analysis of communications paths it is more convenient to deal with straight-line ray paths, it is desirable to change the geometrical coordinate system so that the refracted rays appear to be straight lines. For this purpose, ITU has taken global data and a statistical developed factor 'k' is introduced to provide an accurate distance measurement. In this case a fictitious Earth, having radius $\breve{R}_E = kR_E > R_E$ [57] [58].

$$\breve{R}_E = kR_E = \frac{4}{3}R_E \qquad 3.14$$

R_E=6,371 km

This shows that aircraft that are flying an altitude h=12km have 375KM cell radius as foreseen by the LDACS-1 specification. This is smaller than the maximum radio horizon. Therefore, the resulting aircraft traffic load is covered by cells with ranges at most 375KM inherently [18].

3.6. Assumptions of ground station and data capacity

As explained in the previous section, the area to be analyzed and deployed has been chosen to be the entire parts of Ethiopia. This study considers two scenarios for the location of GS depending on cell size and data capacity therefore the following assumptions are made:

- A total of 1,127,000 km sq. is assumed to be covered.
- The air distance between the two airports calculated using Airport Distance Calculator. Thus the minimum distance between two airports is approximately 31.46 kilometers. And the maximum distance is 207.54 Km [59].
- Cell radius of 75KM for scenario I and cell radius 150KM for scenario II is considered.

- In both FL and RL channel QPSK signal with convolutional code rate of 0.45 is used. [60].
- The total per aircraft DC overhead is approximately 4 OFDM symbol times or 0.48ms.
- The aircrafts are distributed uniformly in the cell and each aircraft generate a uniform traffic.
- All aircrafts travelling with equal speed [61].
- All aircraft are assumed to be moving in random directions.
- The altitude distribution of aircraft is assumed to be uniform which mean the maximum flight height around 9Km.
- For each aircraft, the average traffic in kilobits per second is 18.2 kbps on the FL and 5.2 kbps on the RL [18], [Appendix A].

3.7. Frequency planning approach

In addition to BS location and placement, frequency assignment plays a vital role in network planning and optimization processes. To avoid co channel interference, the frequency planning has to done carefully. Figure 3.7 for an illustrate the GSM cell lay out for 7 cell structure.

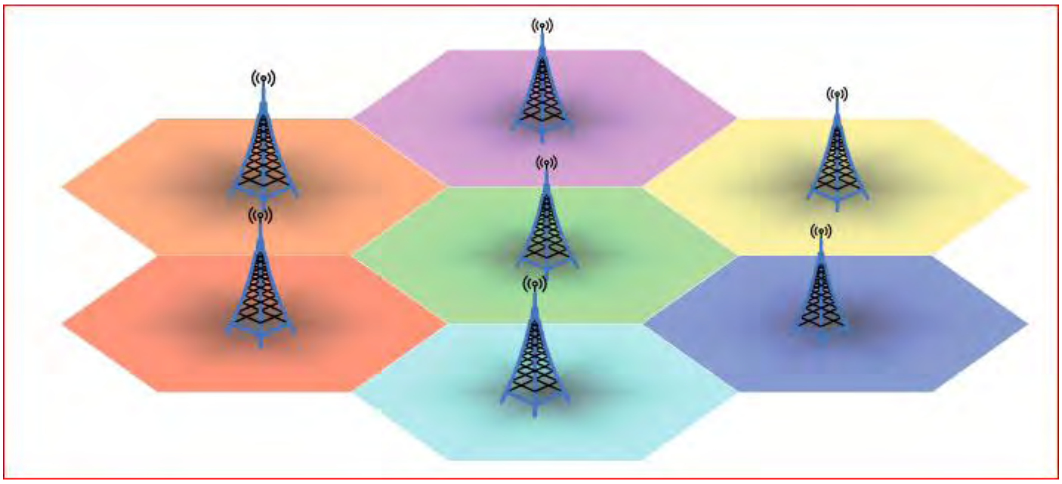


Figure 3.7 An illustration of frequency assignment [62]

The frequency assignment in LDAC system use the list of frequency available in L band. This band frequency can be used for national purpose. Especially the government may use it for secured communication purpose. Likewise, the Ethiopian Government considers frequency spectrum as a high-value. However, frequencies are leased by Governmental agencies, diplomatic communities, national security and military, aviation institutions and amateur radio. Due to security reasons details of L-band in Ethiopia is not available. Thus for effective frequency assignment of LDACS-1, it is necessary to consider the following point:

- Since LDACS-1 system is not deployed in Ethiopia, the lower band (963.5 – 970.5 MHz) is chosen to be the operating band for this thesis.

Figure 3.9 provides a detail layout of spectrum assignment in FL and RL channel. Channels in LDACS-1 are organized into four L-band frequency channel plan:

Band 1	963.5 – 970.5 MHz
Band 2	985.5 – 1008.5 MHz
Band 3	1048.5 – 1071.5 MHz
Band 4	1149.5 – 1156.5 MHz

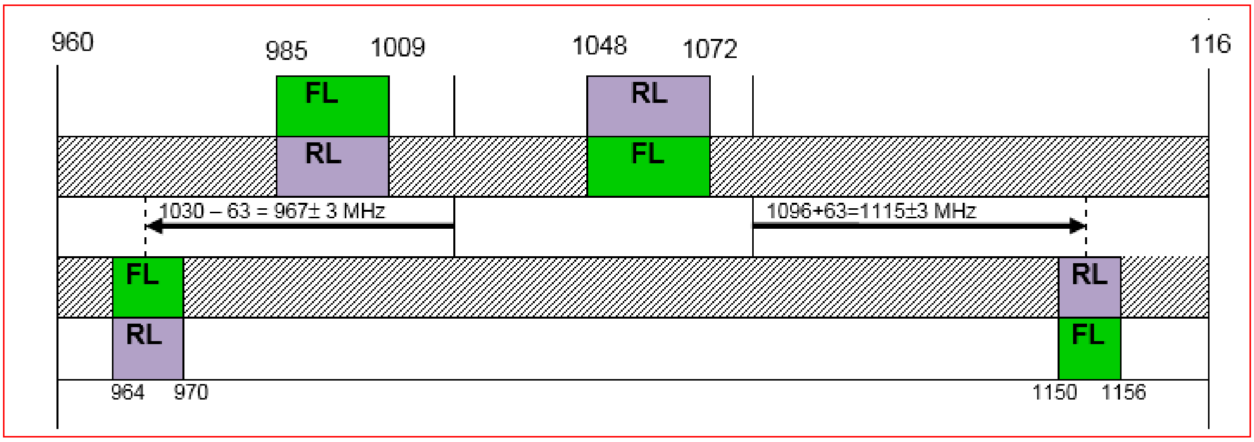


Figure 3.8 LDACS-1 frequency band [18]

3.7.1. Channel assignment of LDACS-1

LDACS-1 is designed as a cellular communication system with a maximum cell radius of around 200nm. it provides a continuous coverage in the area of interest [63]. As it has been described in chapter two there are two different deployments scenarios are possible for LDACS-1.the inlay and the non-inlay. The inlay scenario uses the spectrum region in (between) the existing DME channel. The inlay deployment of LDACS-1 is the preferred approach. However, the FL channels are affected by interference from DME. In [64], it was concluded that DME signals represent the most severe interference towards LDACS-1. For relieving this issue different interference mitigation approached have been proposed. In the case of non-inlay scenario, the LDACS-1 channels use in regions of spectrum where the L-band that are currently not used by DME's. In both scenario, there will be a total of 35 channels available. But these channels are subject to interference because the L-band is also used by other systems. Therefore, in this investigation we focus on the DME frequency planning approach, since it is easy to implement [65].

Frequency planning and simulation is performed using ATOLL software. When allocating frequencies, the toll can take into account interference matrices, reuse distance, and any constraints imposed by neighbors.

ATOLL tool has identified the frequency bands and channel numbers then automatically allocate frequency for each cell. The software assigned channels to the network automatically. Once automatic frequency planning is completed, we analyzed and view the frequency allocation on the map. (Refer to Figure 4.5 and the corresponding Table 4.4 below)

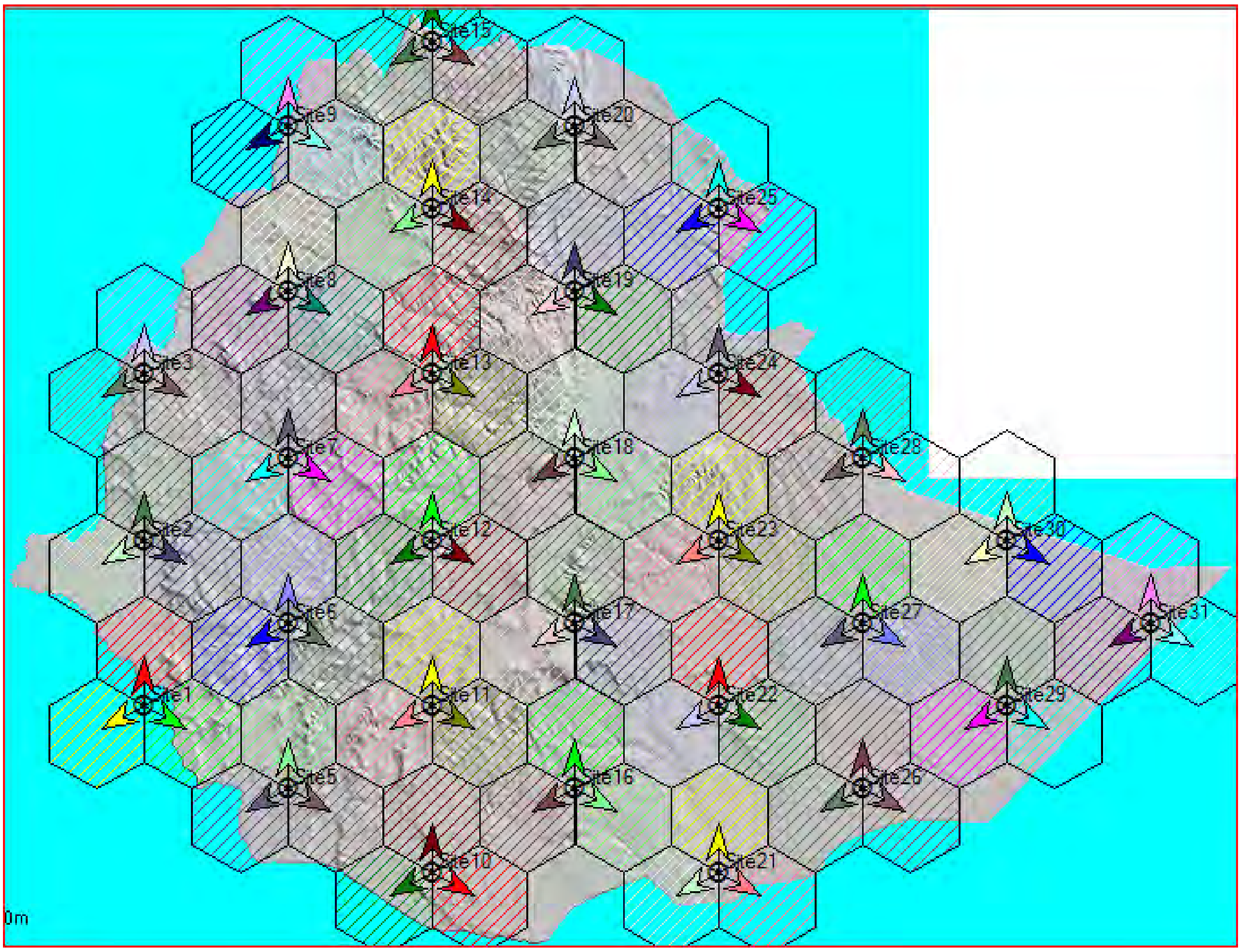


Figure 3.9 Investigated LDACS-1 Cell layout throughout Ethiopia (75 Km cell radius)

After completion of LDACS-1 Frequency planning described above for a total of 31 cells over Ethiopia and the initial results have been obtained.

Cell ID	**Frequency**	**Cell ID**	**Frequency**	**Cell ID**	**Frequency**
Site1_1	961.75	Site2_1	960.75	Site3_1	973.75
Site1_2	964.75	Site2_2	968.25	Site3_2	962.75
Site1_3	973.75	Site2_3	961.75	Site3_3	965.75
Site10_1	961.75	Site20_1	963.75	Site30_1	
Site10_2	964.75	Site20_2	968.25	Site30_2	966.25
Site10_3	973.75	Site20_3	962.75	Site30_3	973.75

Cell ID	Frequency	Cell ID	Frequency	Cell ID	Frequency
Site11_1	967.75	Site21_1	965.75	Site31_1	964.75
Site11_2	968.25	Site21_2	973.75	Site31_2	968.25
Site11_3	963.75	Site21_3	964.75	Site31_3	960.75
Site12_1	961.75	Site22_1	964.75	Site4_1	
Site12_2	964.75	Site22_2	960.75	Site4_2	
Site12_3	973.75	Site22_3	973.75	Site4_3	
Site13_1	967.75	Site23_1	967.75	Site5_1	973.75
Site13_2	968.25	Site23_2	963.75	Site5_2	960.75
Site13_3	963.75	Site23_3	968.25	Site5_3	
Site14_1	966.25	Site24_1	973.75	Site6_1	973.75
Site14_2	961.75	Site24_2	962.75	Site6_2	964.75
Site14_3	964.75	Site24_3	965.75	Site6_3	965.75
Site15_1	961.75	Site25_1	964.75	Site7_1	961.75
Site15_2	967.75	Site25_2	964.75	Site7_2	960.75
Site15_3	964.75	Site25_3	964.75	Site7_3	968.25
Site16_1	964.75	Site26_1	973.75	Site8_1	973.75
Site16_2	961.75	Site26_2		Site8_2	965.75
Site16_3	962.75	Site26_3	961.75	Site8_3	960.75
Site17_1	965.75	Site27_1	966.25	Site9_1	
Site17_2	973.75	Site27_2	961.75	Site9_2	973.75
Site17_3	964.75	Site27_3	968.25	Site9_3	968.25
Site18_1	966.25	Site28_1			
Site18_2	961.75	Site28_2	961.75		

Cell ID	Frequency	Cell ID	Frequency	Cell ID	Frequency
Site18_3	964.75	Site28_3	964.5		
Site19_1	964.75	Site29_1	963.75		
Site19_2	973.75	Site29_2	960.75		
Site19_3	960.75	Site29_3	973.75		

Table 3.3 Automatic Frequency Prediction result

4

Simulation Results

This chapter discusses and describes the network planning of LDACS-1 into a computerized simulation results. Figure 4.1 shows a block diagram of how the simulation is anchored into the research. This model consists of simulation input, simulation engine, and simulation output. This study is a large size network design process therefore; the network design is usually dome by a planning tool. The simulation engine is ATOLL environment. It is an open, scalable, and flexible multi-technology network design and optimization platform that supports. The planning tool requires a digital map of the coverage site along with coordinates of location of BS. The network design inputs are given to ATOLL and the tool produces different predictions simulation in the output.

The chapter contains four parts. First, the data input for the simulation is discussed. Then, the specification of the coverage and capacity dimensioning model into a simulation is discussed. In the third section, we thoroughly analyzed the performance of capacity and coverage of network planning using two different scenarios in terms of cell size and data rate. The chapter finishes with the ATOLL simulation result concerns.

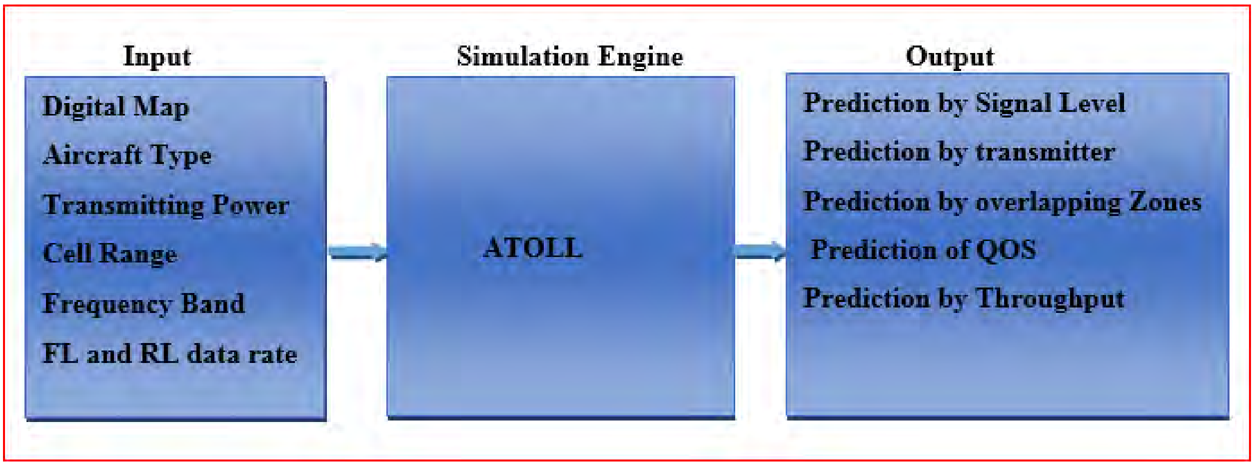


Figure 4.1 Simulation engine

4.1. Simulation Data input

Considering the fact that LDACS is a new technology and there is no existing infrastructure in Ethiopia. Therefore, collecting design inputs could be a time consuming task and unavailable inputs should be predicted.

Hence LDACS radio network planning simulation is intended to carry out the link budget calculation, propagation model, coverage and capacity. The first data is retrieved and an in depth discussion on the extraction of the data from the sources is found in [18], [42]. The second data is the historical domestic flight destination. This data set contains flight route, longitude and latitudes of the airport, distance between the nearest airport,

4.1.1. Planning parameters

ATOLL simulation software required input parameters to simulate the desired aeronautical network structure. First we need to have the link budget value to obtain the maximum range of each GS and the maximum available throughput for each connection. For this paper, the aircraft position and LDACS-1 link budget are the basic requirements, a sample of this data is shown in Table 4.1 and Table 4.2. All listed parameter in below tables were chosen carefully according to the type of terrain and airport types.

	Unit	ENR	ENR	ENR	TMA	APT	Equation
TX Parameters							
TX out Power	dBm	46	41	36	41	38	a
TX Antenna Gain	dB	8	8	8	8	8	b
TX Cable loss	dB	2	2	2	2	2	c
Duplexer loss	dB	0	0	0	0	0	C1
Tx EiRP	dBm	52	47	42	47	44	d = a+b-c-c1
Propagation Parameters							
Transmit mid-band Frequency	MHz	993	993	993	993	993	E
Tx –Rx Distance	Nm	200	120	60	40	10	f
Path Loss	dB	143.76	139.32	133.30	129.78	117.74	g=37.8 +20log(f’e)

	Unit	ENR	ENR	ENR	TMA	APT	Equation
Miscellaneous Margins							
Interference Margin	dB	0	0	0	0	0	h
Implementation Margin	dB	4	4	4	4	4	i
Safety Margin	dB	6	6	6	6	6	j
Banking Loss Allowance	dB	0	0	0	7	7	k
RX Parameters							
Maximum RX Antenna Gain	dBi	0	0	0	0	0	l
Duplexer loss	dB	0.5	0.5	0.5	0.5	0.5	m
Rx Cable loss	dB	3	3	3	3	3	m1
RX received signal Power	dB	-95.26	-95.82	-94.80	-93.26	-84.24	n= d-g+l-m-k-m1
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	o
Bandwidth	Hz	498050	498050	498050	498050	498050	p
Thermal Noise Power	dBm	-117.03	-117.03	-117.03	-117.03	-117.03	q= o + r + i
Receiver Noise Figure	dB	6	6	6	6	6	r
Total Rx Noise Power	dBm	-107.03	-107.03	-107.03	-107.03	-107.03	s= q + r + i
Eb/No @ No Interference	dB	4.36	4.36	4.36	5.16	15.76	t= v-10log(u/p)
L-DACS1 bit rate	bps	480000	480000	480000	480000	480000	u
Required C/N @ BER=10-6	dB	4.2	4.2	4.2	5	15.6	v
Rx Sensitivity (So)	dBm	-102.83	-102.83	-102.83	-102.03	-91.43	w =v + s
Rx operating point (S1)	dBm	-96.83	-96.83	-96.83	-96.83	-85.43	x = w + j
System operating margin (OM)	dB	1.57	1.00	2.03	2.75	1.19	z = n - x

Table 4-1 L-DACS1 Link Budget and cell radius result for FL [18]

	Unit	ENR	ENR	ENR	TMA	APT	Equation
TX Parameters							
TX out Power	dBm	46	41	36	41	39	a
TX Antenna Gain	dB	0	0	0	0	0	b
TX Cable loss	dB	3	3	3	3	3	c
Duplexer loss	dB	0.5	0.5	0.5	0.5	0.5	C1
Tx EiRP	dBm	42.5	37.5	32.5	37.5	35.5	d = a+b-c-c1
Propagation Parameters							
Transmit mid-band Frequency	MHz	1087	1087	1087	1087	1087	e
Tx –Rx Distance	Nm	200	120	60	40	10	f
Path Loss	dB	144.55	140.11	134.09	130.57	118.52	g=37.8 +20log(f’e)
Miscellaneous Margins							
Interference Margin	dB	0	0	0	0	0	h
Implementation Margin	dB	4	4	4	4	4	i
Safety Margin	dB	6	6	6	6	6	j
Banking Loss Allowance	dB	0	0	0	7	7	k
RX Parameters							
Maximum RX Antenna Gain	dBi	8	8	8	8	8	l
Duplexer loss	dB	0	0	0	0	0	m
Rx Cable loss	dB	2	2	2	2	2	m1
RX received signal Power	dB	-96.05	-96.61	-95.59	-94.07	-84.02	n= d-g+l-m-k-m1
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	o
Bandwidth	Hz	498050	498050	498050	498050	498050	p
Thermal Noise Power	dBm	-117.03	-117.03	-117.03	-117.03	-117.03	q= o + r + i
Receiver Noise Figure	dB	5	5	5	5	5	r

	Unit	ENR	ENR	ENR	TMA	APT	Equation
Total Rx Noise Power	dBm	-108.03	-108.03	-108.03	-108.03	-108.03	s= q + r + i
Eb/No @ No Interference	dB	6.35	6.35	6.35	7.15	17.75	t= v-10log(u/p)
L-DACS1 bit rate	bps	303300	303300	303300	303300	303300	u
Required C/N @ BER=10-6	dB	4.2	4.2	4.2	5	15.6	v
Rx Sensitivity (So)	dBm	-102.83	-102.83	-102.83	-102.03	-91.43	w =v + s
Rx operating point (S1)	dBm	-97.83	-97.83	-97.83	-97.03	-86.43	x = w + j
System operating margin(OM)	dB	1.78	1.22	2.24	2.96	2.40	z = n - x

Table 4.2 Link budget and cell radius results for RL [18]

4.1.2. Site coverage and number of site

For the second requirement of the coverage planning is to find optimal locations for the base stations to build a continuous coverage of Ethiopia air space with area of 1,127,000 Km^2. In this case different basic parameters (Allowable path loss, the radius of the cell, coding schemes,) have been calculated. By LDACS technology characterization, the minimum SINR has been determined by setting different data rate for the uplink and downlink with different modulation and coding schemes. The overall coverage prediction is then determined based upon the combination of the digital map information and the selected basic parameters. Other parameters that we have used in the simulations are shown in Table 4.3 and Table 4.4.

Modulation	FL		RL	
	Coding Rate	Data Rate [kbit/s]	Coding Rate	Data Rate [kbit/s]
QPSK	0.45	303.3	0.44	220.3
QPSK	0.60	400.0	0.60	299.0
QPSK	0.67	450.0	0.69	346.1
16QAM	0.45	606.7	0.44	440.5
64QAM	0.60	1220.0	0.61	944.0
64QAM	0.68	1373.3	0.67	1038.4

Table 4.3 Average data rate for FL and RL [18]

For a hexagonal cell model, we have used the general cell coverage estimation approach, and radio link budget analysis methodology. To determine the number of BS we have used equation 3.5 – 3.8. Based on this information, the following table summarizes the planning regions with their site area and the corresponding site number based on coverage planning.

Measures		Scenario I	Scenario II
Cell radius (km)		75	150
Site Coverage Area (Km^2)		10,960.634	58,456.7147
Deployment Area(Km^2)		1,127,000	1,127,000
Number of cells per site		3	3
Number of site		30	12
Total traffic load in the coverage area	FL (kbps)	546	218.4
	RL (kbps)	156	62.4
Total number of Aircraft		780	312

Table 4.4 Result of site coverage area and required site for each Scenario

Table 4.4 shows that the total number of site required to cover the entire air space are 30 for the first scenario and 12 sites for the second scenario. We make the assumption that the ground stations will be placed near the airports. Whose positions have been chosen to fairly share the total traffic load in the region.

The average capacity in kilobits per second is a measure of the cell throughput that can be achieved in one sector. It is a minimum link budget that the cell/ sector can offer to the system. We can clearly see that a 150KM range is enough to connect more than 100% of aircraft traffic load for the year 2025.

4.2. Simulation parameter based on different scenarios

In this section we are studding two scenarios for the coverage and capacity of an LDACS-1 system for Ethiopia air space.

4.2.1. Scenario I

As mentioned in the previous chapter, this scenario involves multiple ground stations that are placed in different geographical locations and the size of the cells will be R=75km. In Ethiopia 75km is the approximate distance from Addis Ababa airport terminal to Mojo. Hence, the study assumed the total deployment area, Ethiopia, is 1,127,000 square kilometers.

To deploy LDACS-1 system from the coverage point of view, it requires deploying a total of 30 base stations all over the selected area. But this is not exact number of BS, because there is a gap while calculating the number of sites which is since the clutter type (urban, suburban and rural area) is located in different areas. So, this will be corrected in the optimization of the network planning process.

Moreover, the coverage and capacity planning is highly dependent on the layout of the GS sites. The most considerable parameters are number of aircraft per sector, inter-site distance, link budget and cell overlapping zone. In this study, we have assumed that the cell overlapping factor is 15% for both scenarios and one site is to be served 26 aircrafts [18].

For the more realistic case of the antenna systems we assumed that three sectors antenna for all sites. Every BS three sectors will be used and the direction of the antenna will be 120^0 per sectors. So, it will be assumed for simplicity the antenna pointing directions 120^0 in all airports. These listed in table 4.2.

In Figure 4.7 we can see the map of Ethiopia with 30 GS of for the first scenario along with the directions of the antenna sectors and their base stations. Moreover, because radius R is 75 km, this scenario is more realistic and can be utilized easily, because there will be a lower path loss.

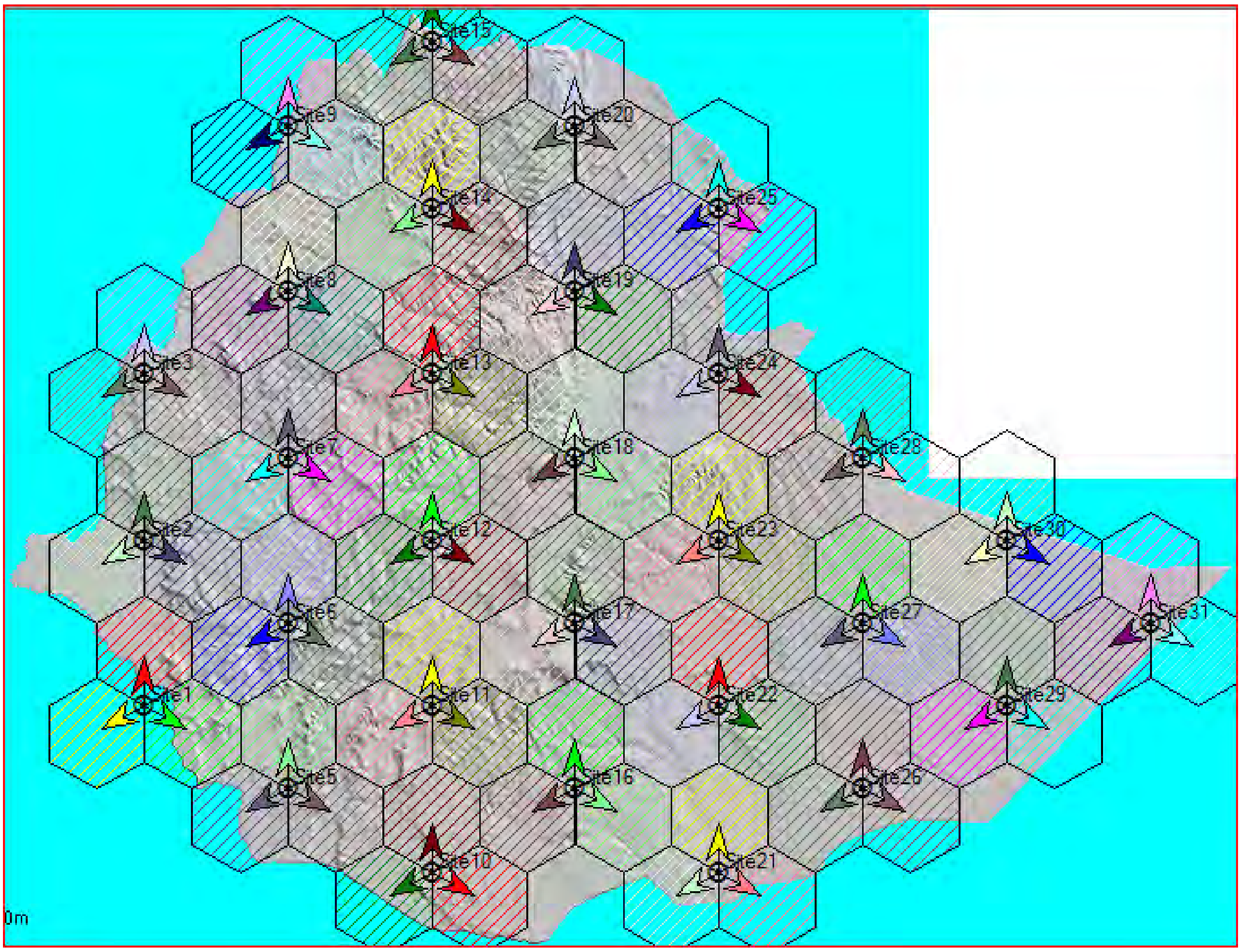


Figure 4.2 Map of Scenario I, R=75km, h=9 km.

Cell ID	**Base Station Location**		**Antenna Directions in Degree**	**Cell Size (km)**
	Longitude	**Latitude**		
Site1	40°39'36.28"E	6°21'41.97"N	120^0,120^0,120^0	75
Site10	44°10'56.75"E	4°20'37.79"N	120^0,120^0,120^0	75
Site11	44°10'46.99"E	6°22'45.38"N	120^0,120^0,120^0	75
Site12	44°10'33.43"E	8°24'52.37"N	120^0,120^0,120^0	75
Site13	44°10'15.99"E	10°26'58.59"N	120^0,120^0,120^0	75

Cell ID	**Base Station Location**		**Antenna Directions in Degree**	**Cell Size (km)**
	Longitude	**Latitude**		
Site14	44°9'54.55"E	12°29'3.85"N	$120^0,120^0,120^0$	75
Site15	44°9'28.98"E	14°31'7.98"N	$120^0,120^0,120^0$	75
Site16	45°56'23.53"E	5°21'41.02"N	$120^0,120^0,120^0$	75
Site17	45°56'36.91"E	7°23'48.1"N	$120^0,120^0,120^0$	75
Site18	45°56'54.69"E	9°25'54.48"N	$120^0,120^0,120^0$	75
Site19	45°57'16.98"E	11°28'0"N	$120^0,120^0,120^0$	75
Site2	40°38'24.8"E	8°23'28.49"N	$120^0,120^0,120^0$	75
Site20	45°57'43.94"E	13°30'4.47"N	$120^0,120^0,120^0$	75
Site21	47°41'36.97"E	4°20'22.06"N	$120^0,120^0,120^0$	75
Site22	47°42'9.1"E	6°22'22.22"N	$120^0,120^0,120^0$	75
Site23	47°42'53.71"E	8°24'21.74"N	$120^0,120^0,120^0$	75
Site24	47°43'51.1"E	10°26'20.4"N	$120^0,120^0,120^0$	75
Site25	47°45'1.63"E	12°28'18.02"N	$120^0,120^0,120^0$	75
Site26	49°27'10.14"E	5°20'45.3"N	$120^0,120^0,120^0$	75
Site27	49°28'13.26"E	7°22'31.03"N	$120^0,120^0,120^0$	75
Site28	49°29'37.16"E	9°24'15.88"N	$120^0,120^0,120^0$	75
Site29	51°12'53.79"E	6°20'32.94"N	$120^0,120^0,120^0$	75
Site3	40°36'52.86"E	10°25'14.02"N	$120^0,120^0,120^0$	75

Cell ID	Base Station Location		Antenna Directions in Degree	Cell Size (km)
	Longitude	**Latitude**		
Site30	51°14'35.74"E	8°21'57.16"N	$120^0,120^0,120^0$	75
Site31	52°58'47.47"E	7°19'34.9"N	$120^0,120^0,120^0$	75
Site5	42°25'24"E	5°21'24.09"N	$120^0,120^0,120^0$	75
Site6	42°24'47.37"E	7°23'24.67"N	$120^0,120^0,120^0$	75
Site7	42°23'58.69"E	9°25'24.51"N	$120^0,120^0,120^0$	75
Site8	42°22'57.64"E	11°27'23.41"N	$120^0,120^0,120^0$	75
Site9	42°21'43.83"E	13°29'21.17"N	$120^0,120^0,120^0$	75

Table 4.5 Summarizes the scenario I

4.2.2. Scenario II

Based on sections 4.1, we can deduce the following assumptions for this scenario.

- We retain the same maximum fling height h=9km, which is the height of the cellular cell.
- But we increase the range of the cell to R= 150km.
- Aircraft movement per year 114,036.
- All ground stations within the aircraft's radio horizon are visible. Hence an elevation model of the Earth's surface was not considered.

As a result, we expect a decrease in the number of cells; we use 12 BS to cover all of Ethiopian airspace. In Figure 4.3 the cell of the scenario II are depicted with the directions of the sectors and the outlines of their ranges. From Figure 4.4 we can see the map of Ethiopia with the 12 BS and Table 4.6 summarizes the details of scenario two.

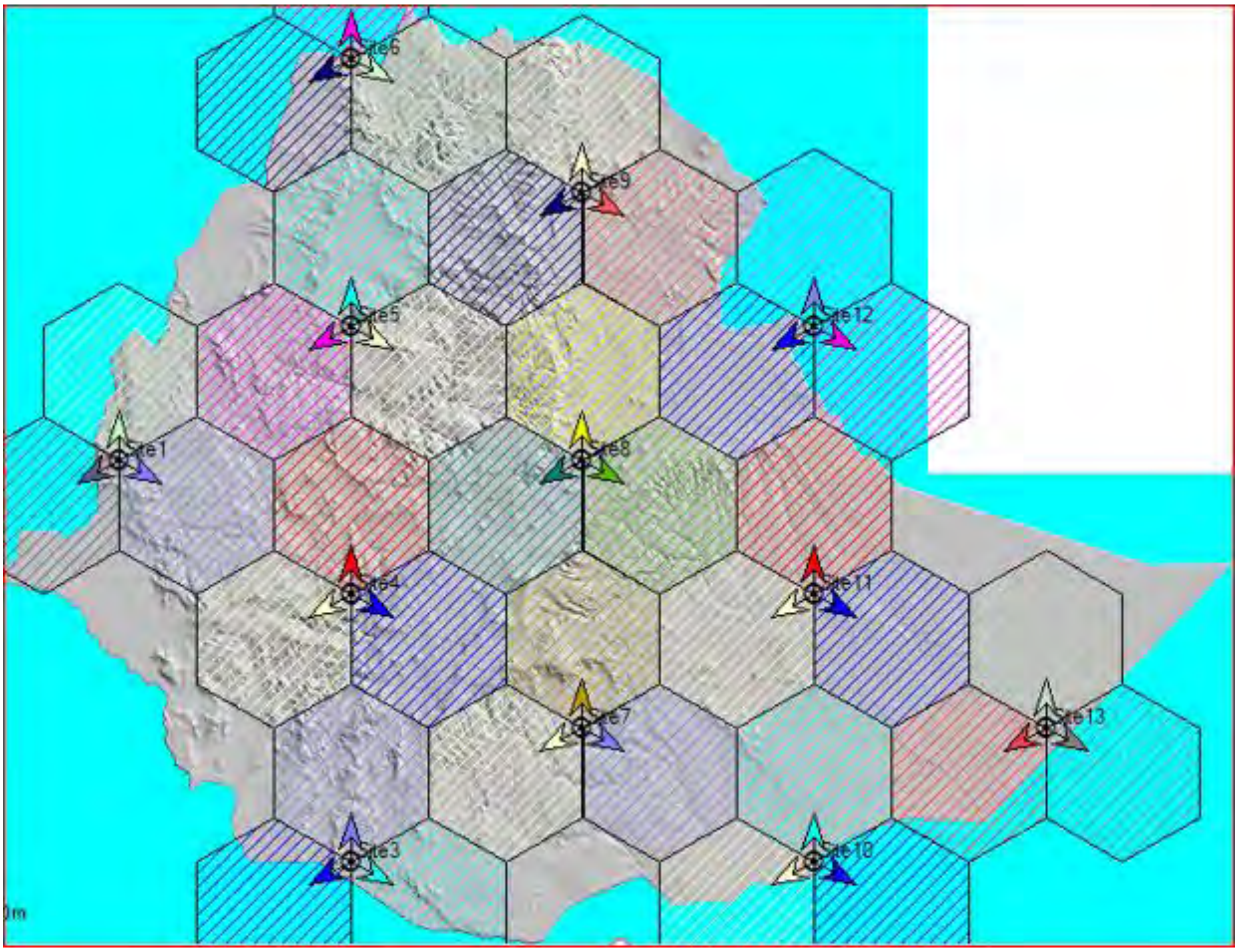


Figure 4.3 Map of Scenario II, R=150km, h=9 km.

Cell ID	Longitude	Latitude	Antenna Directions in Degree	Cell Size (km)
Site1	40°25'1.08"E	9°19'7.6"N	120^0 , 120^0 , 120^0	150 km
Site10	48°53'10.87"E	4°27'10.07"N	120^0 , 120^0 , 120^0	150 km
Site11	48°54'35.19"E	7°42'7.8"N	120^0 , 120^0 , 120^0	150 km
Site12	48°56'46.24"E	10°57'3.33"N	120^0 , 120^0 , 120^0	150 km
Site13	51°42'5.27"E	6°3'0.08"N	120^0 , 120^0 , 120^0	150 km
Site3	43°16'9.24"E	4°27'39.77"N	120^0 , 120^0 , 120^0	150 km
Site4	43°15'31.59"E	7°42'59.38"N	120^0 , 120^0 , 120^0	150 km

Cell ID	**Longitude**	**Latitude**	**Antenna Directions in Degree**	**Cell Size (km)**
Site5	43°14'33.08"E	10°58'17.1"N	120^0 , 120^0 , 120^0	150 km
Site6	43°13'12.73"E	14°13'32.16"N	120^0 , 120^0 , 120^0	150 km
Site7	46°4'54.92"E	6°5'25.9"N	120^0 , 120^0 , 120^0	150 km
Site8	46°5'24.85"E	9°20'47.99"N	120^0 , 120^0 , 120^0	150 km
Site9	46°6'8.06"E	12°36'7.87"N	120^0 , 120^0 , 120^0	150 km

Table 4.6 Summarize Scenario II

4.3. Simulation results

Digital map of Ethiopia (shown in Figure 4.4) has been used for LDACS-1 network planning in this stage. These maps consisted only airports, mountain and water but not included building heights, main street and etc. But the average values for these parameters have already been incorporated into simulation tool. Therefore, efficient network planning is obviously a big challenge here with limited resources. At first to cover the whole country BS were placed (shown in Figure 4.5). A BS consists of the site, one or more transmitters, various pieces of equipment, and radio settings such as, cells. After placing the BS coverage prediction was done that helped to justify the placement of the BS. Coverage estimation calculates the area where BS can be received by the aircrafts. It gives the maximum area that can be covered by the BS. But, it is not necessary that an acceptable connection between the transmitter and receiver can be established in coverage area. However, BS can be detected by the aircraft in coverage area.

Automatic frequency planning and cell planning were performed before running each of these simulations. In detail simulation results were obtained and the corresponding legends show each of them with different color.

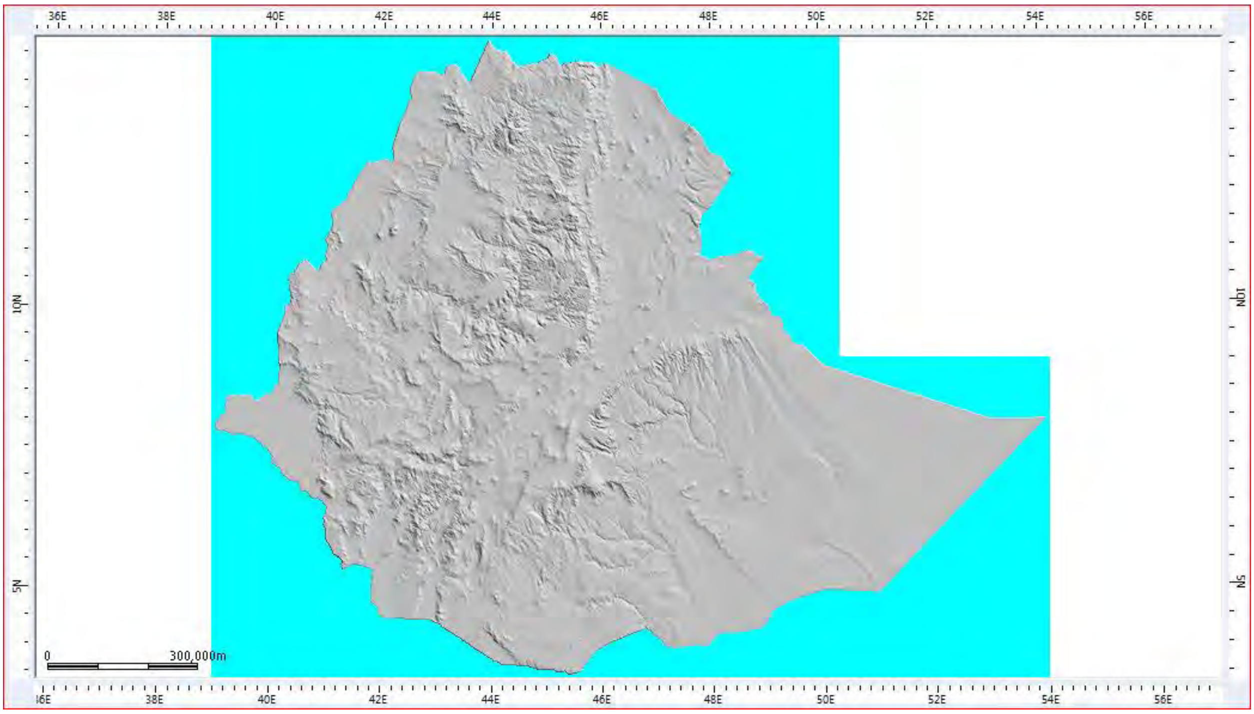
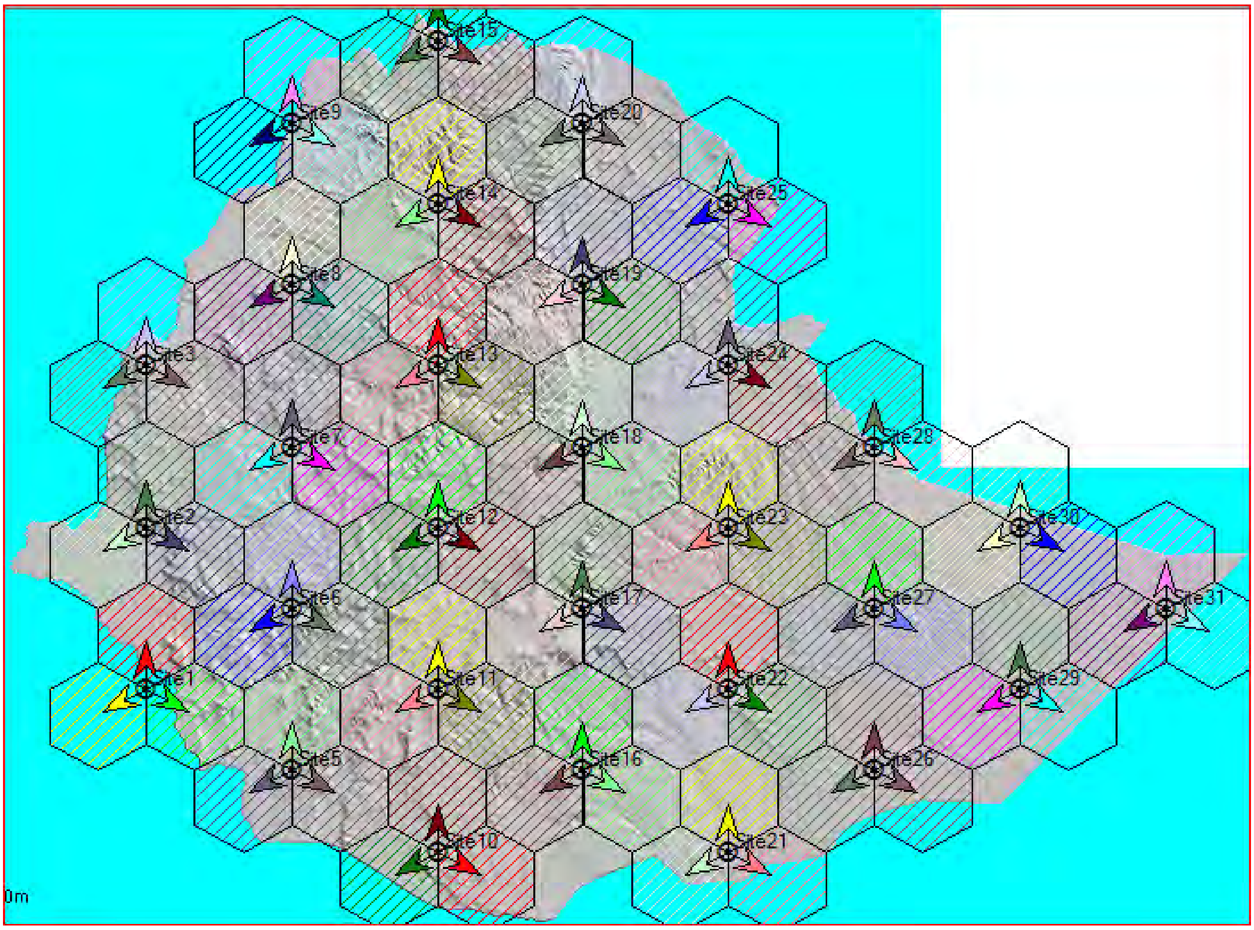
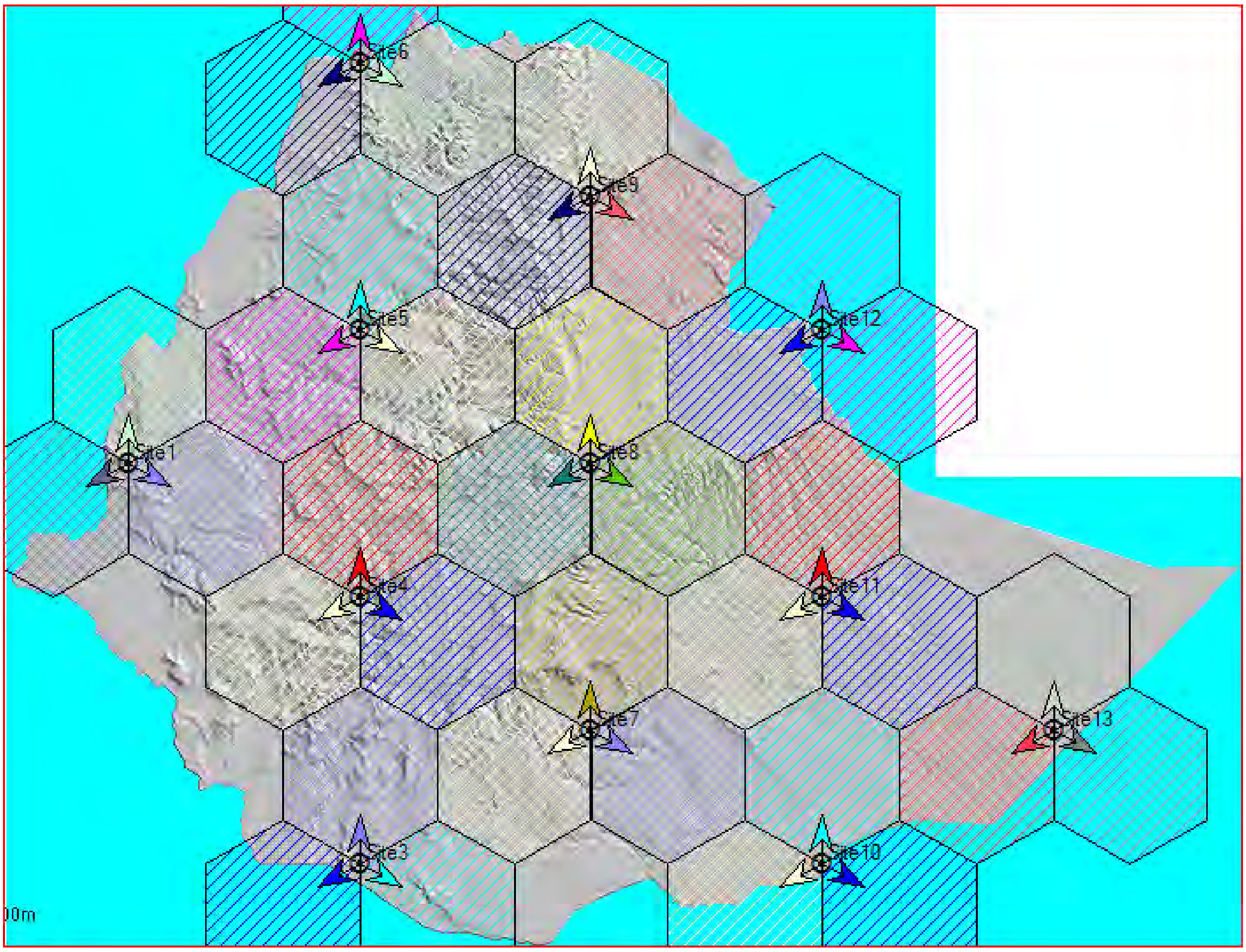


Figure 4.4 Ethiopian Digital Map



(a)

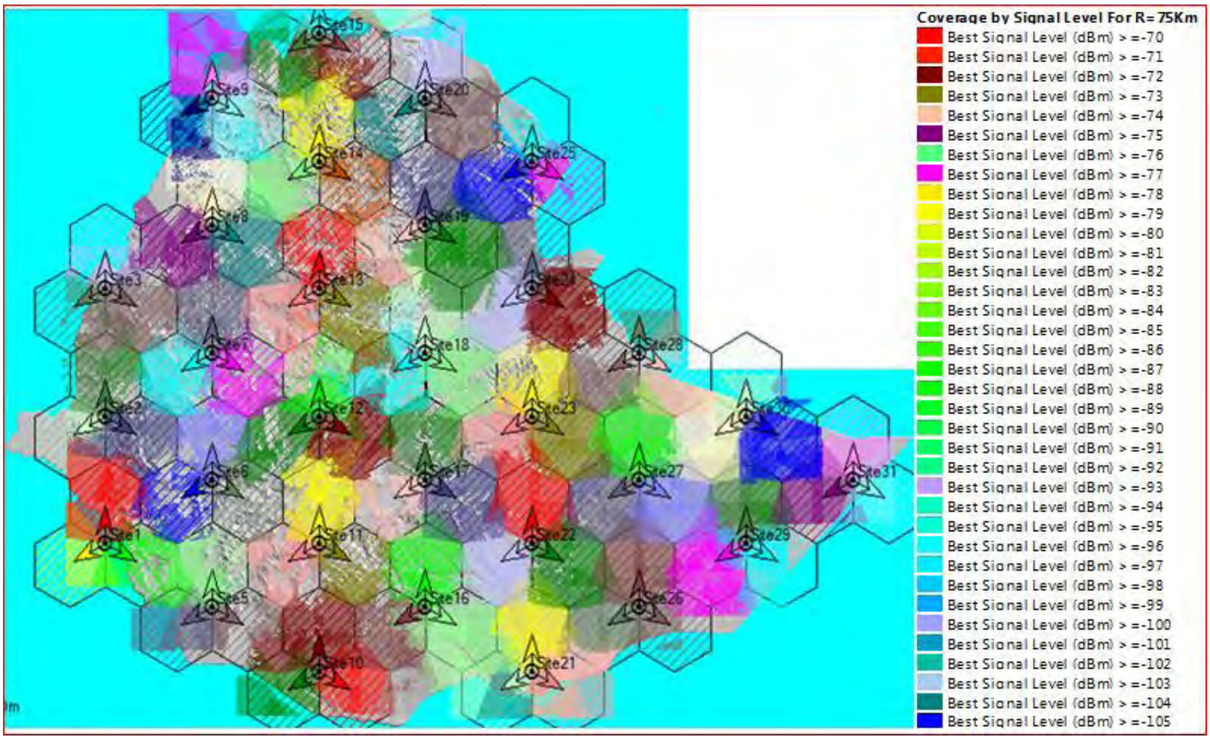


(b)

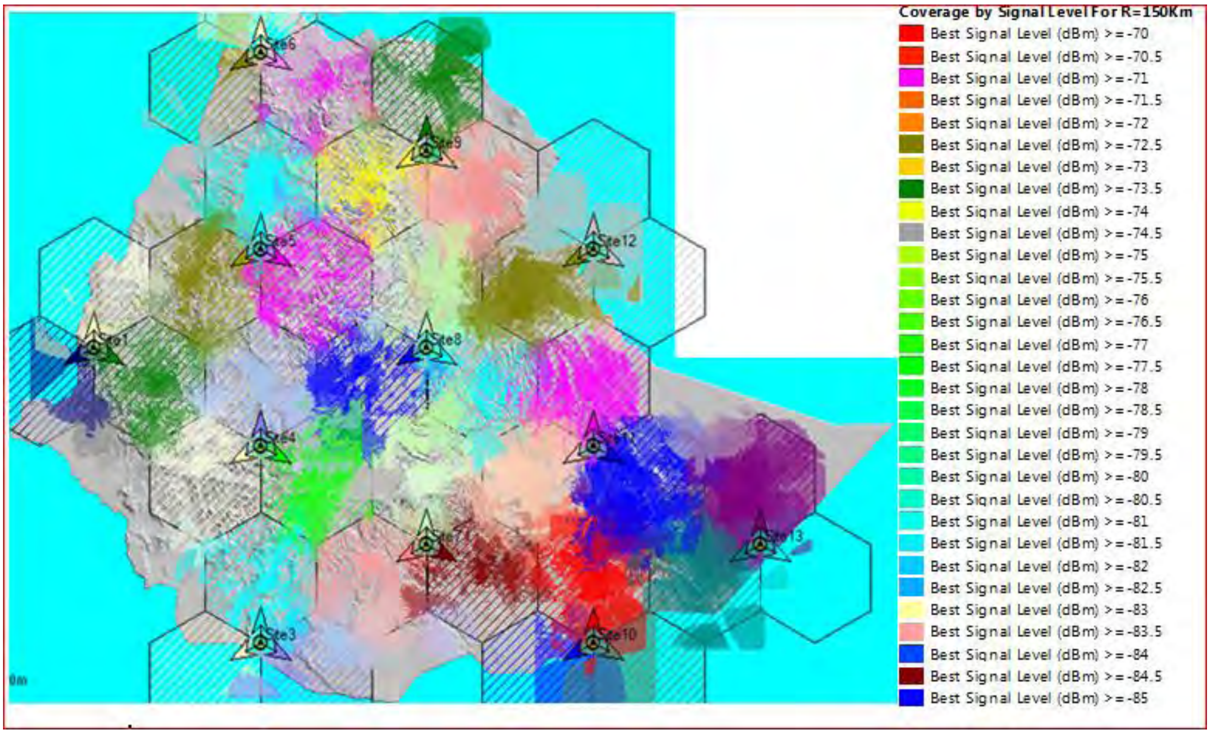
Figure 4.5 Transmitters placed on Ethiopia Map (a) for first scenario (b) for second scenario

4.3.1. Coverage by Signal Level

A coverage prediction by signal level allows us to predict coverage zones by the transmitter signal strength at each pixel. The prediction analysis is done based on the transmitted signal level (in dBm), FL and RL throughput, channel to Interference plus Noise Ratio. Signal level in a cell addresses the highest signal strength of the best server for each pixel of the studied area. Accordingly, the coverage prediction results are shown in Figure 4.6a and Figure 4.6b. Additionally the respective figures results can be plotted in the histogram style's as Figure 4.7a and Figure 4.7b. Figure 4.7 illustrate the relation between best signal level (in dBm) Vs coverage area in (%). For the strong signal i.e-65 dBm, more than 80.7% of the target area is covered under scenario I, whereas 67.6 % of the target area is covered when scenario II is considered. The histogram in Figure 4.7 also shows the signal strength level on both scenarios.

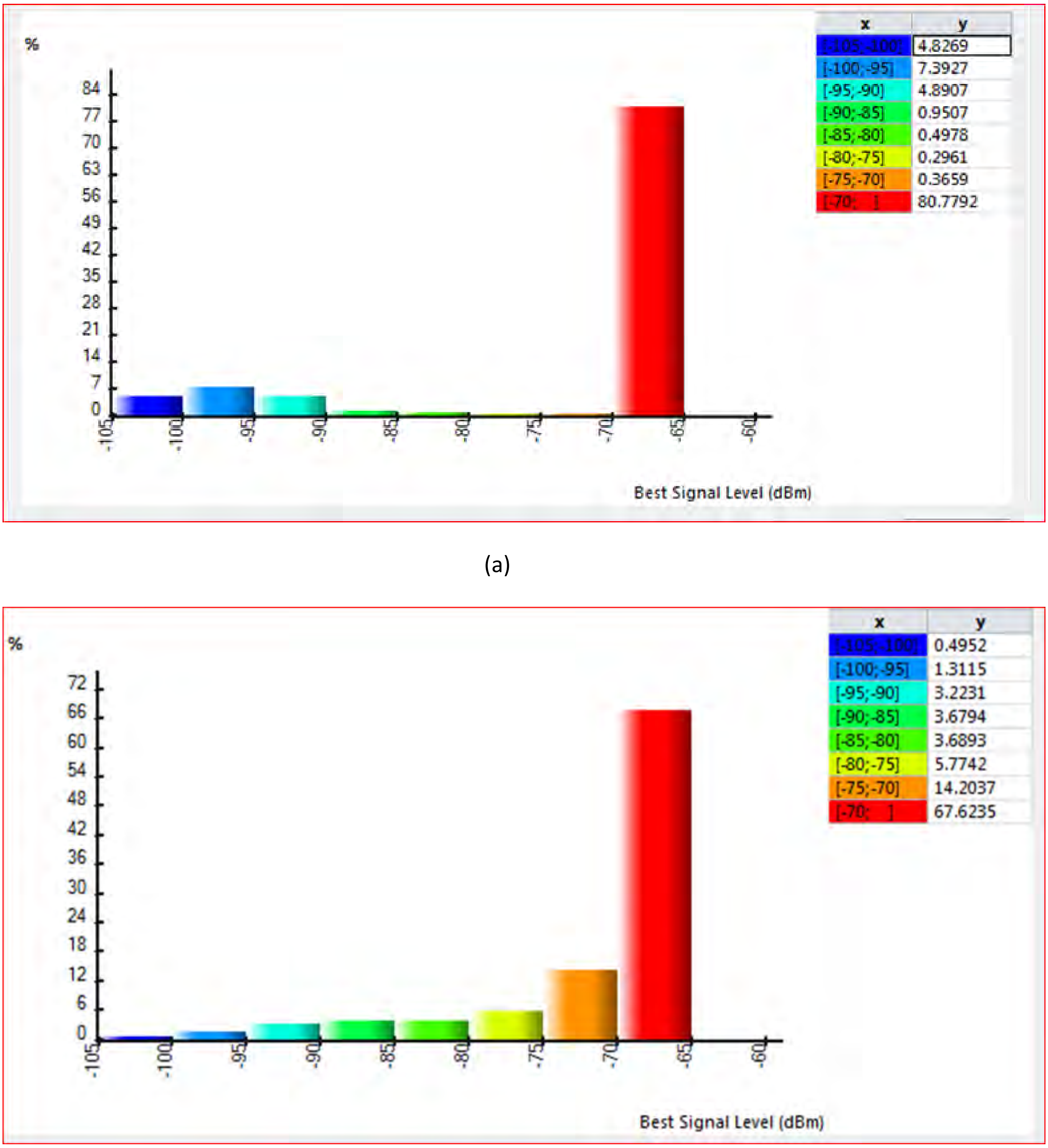


(a)



(b)

Figure 4.6 Coverage by Signal Level (a) for first scenario and (b) for Second scenario



x	y
[-105;-100]	4.8269
[-100;-95]	7.3927
[-95;-90]	4.8907
[-90;-85]	0.9507
[-85;-80]	0.4978
[-80;-75]	0.2961
[-75;-70]	0.3659
[-70;]	80.7792

(a)

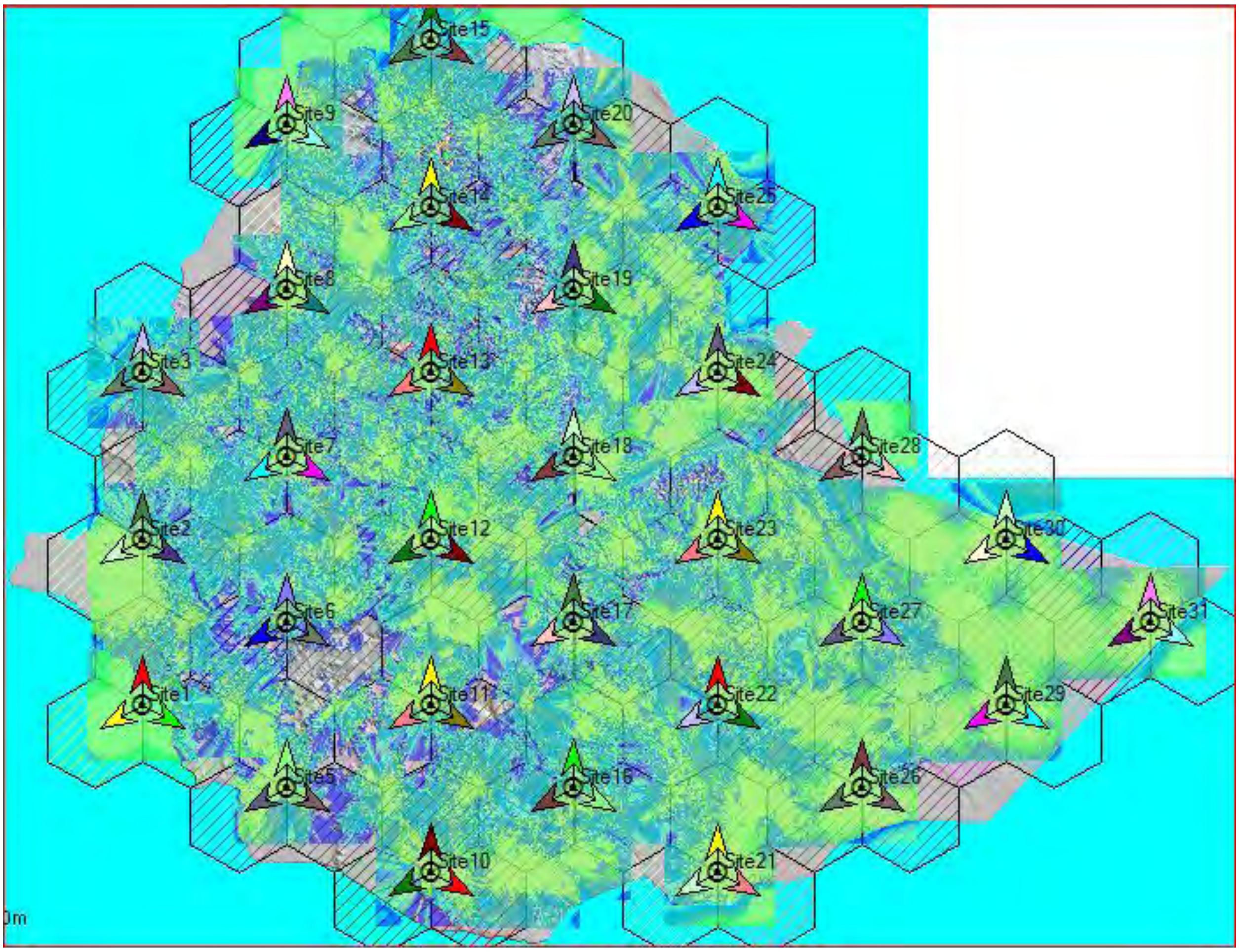
x	y
[-105;-100]	0.4952
[-100;-95]	1.3115
[-95;-90]	3.2231
[-90;-85]	3.6794
[-85;-80]	3.6893
[-80;-75]	5.7742
[-75;-70]	14.2037
[-70;]	67.6235

(b)

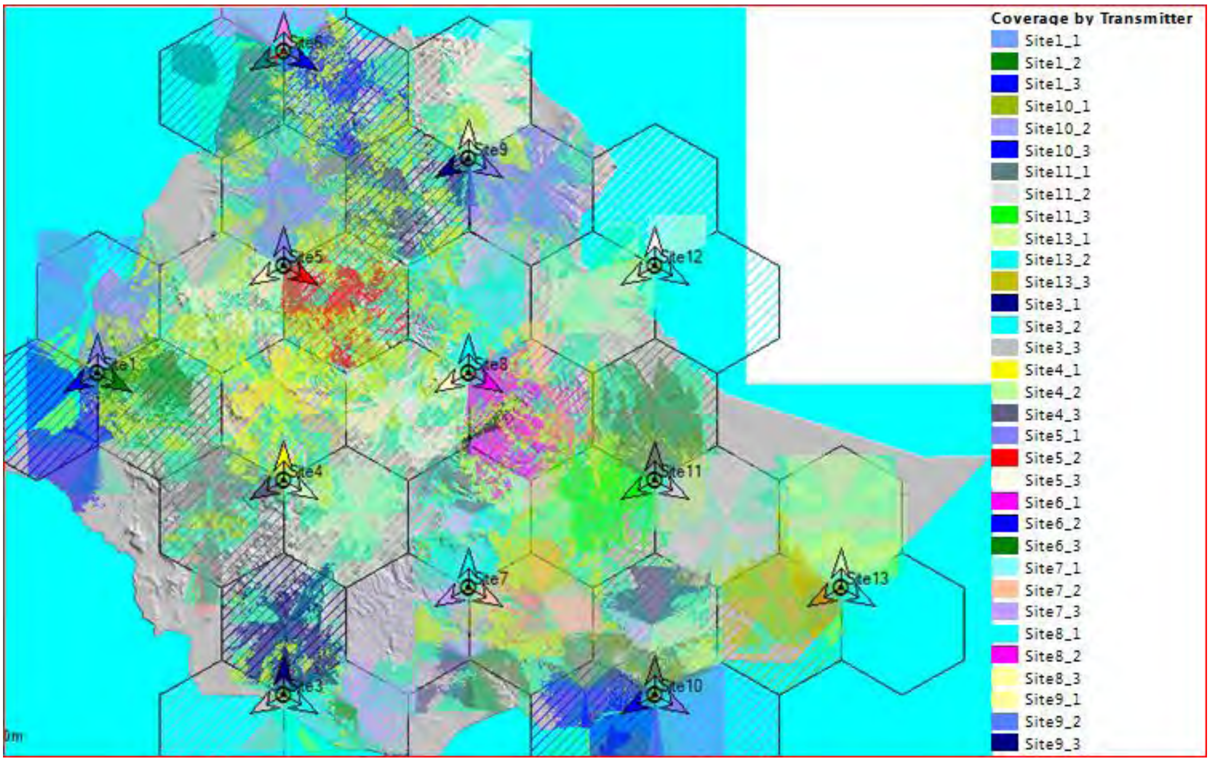
Figure 4.7 Signal Level versus Coverage Area in Percent (a) for scenario I (b) for scenario II

4.3.2. Coverage Prediction by Transmitter

A coverage prediction by transmitter allows predicting coverage zones by transmitter at each pixel. How far the placed transmitters have covered is shown in coverage by transmitter map in Figure 4.8. When we create a transmitter, ATOLL automatically creates a cell for the transmitter using the properties of the currently selected station template. Then ATOLL computes the power received by the aircraft given a specific transmitted power for BS. And then comprises of all the gains and losses in the path of signal from BS to the aircraft. This includes transmitter and receiver gains as well as losses and the effect of the wireless medium between them We can base the coverage on the signal level, path loss, or total losses within a defined range. For a transmitter with more than one cell, the coverage is calculated for the cell with the highest power.



(a)



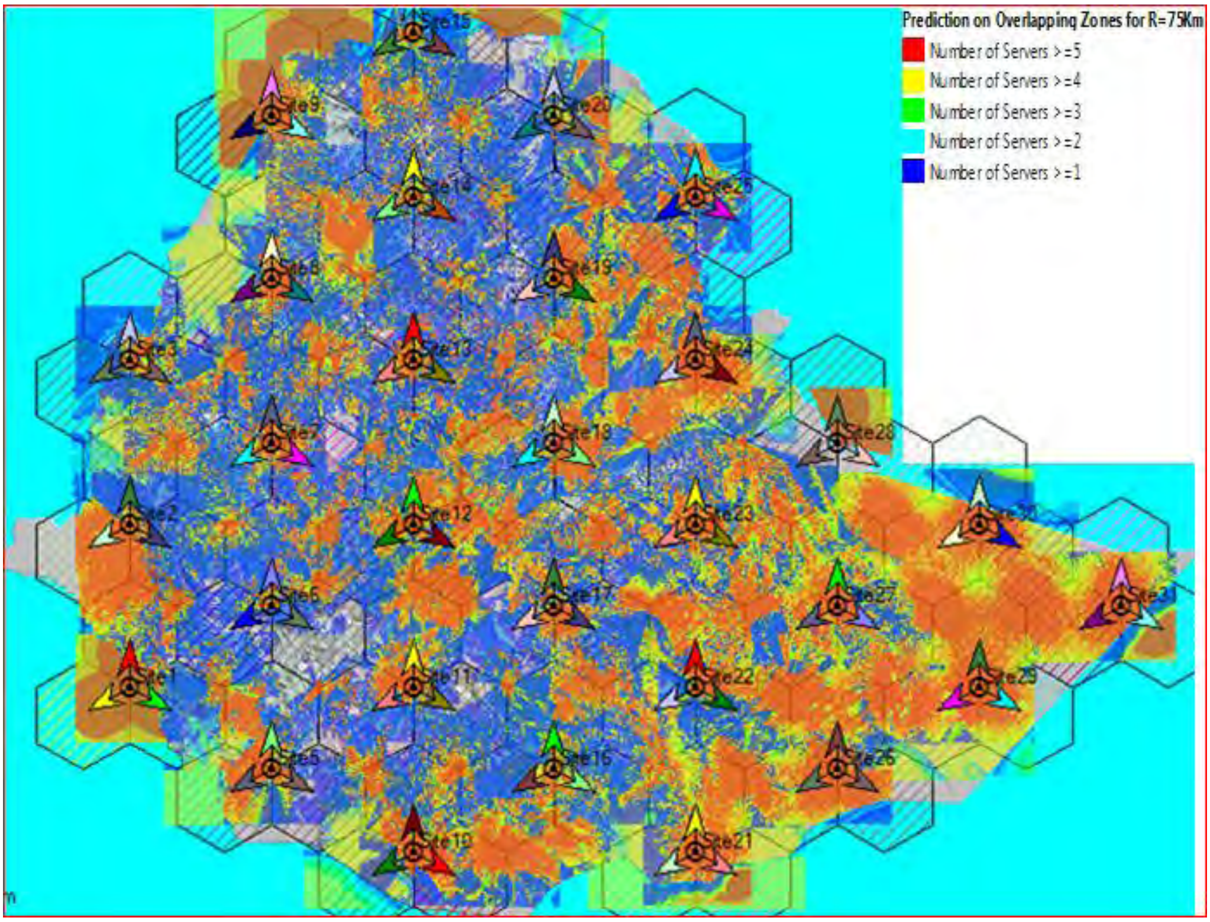
(b)

Figure 4.8 Coverage Prediction by Transmitter(a) for scenario I (b) for scenario II

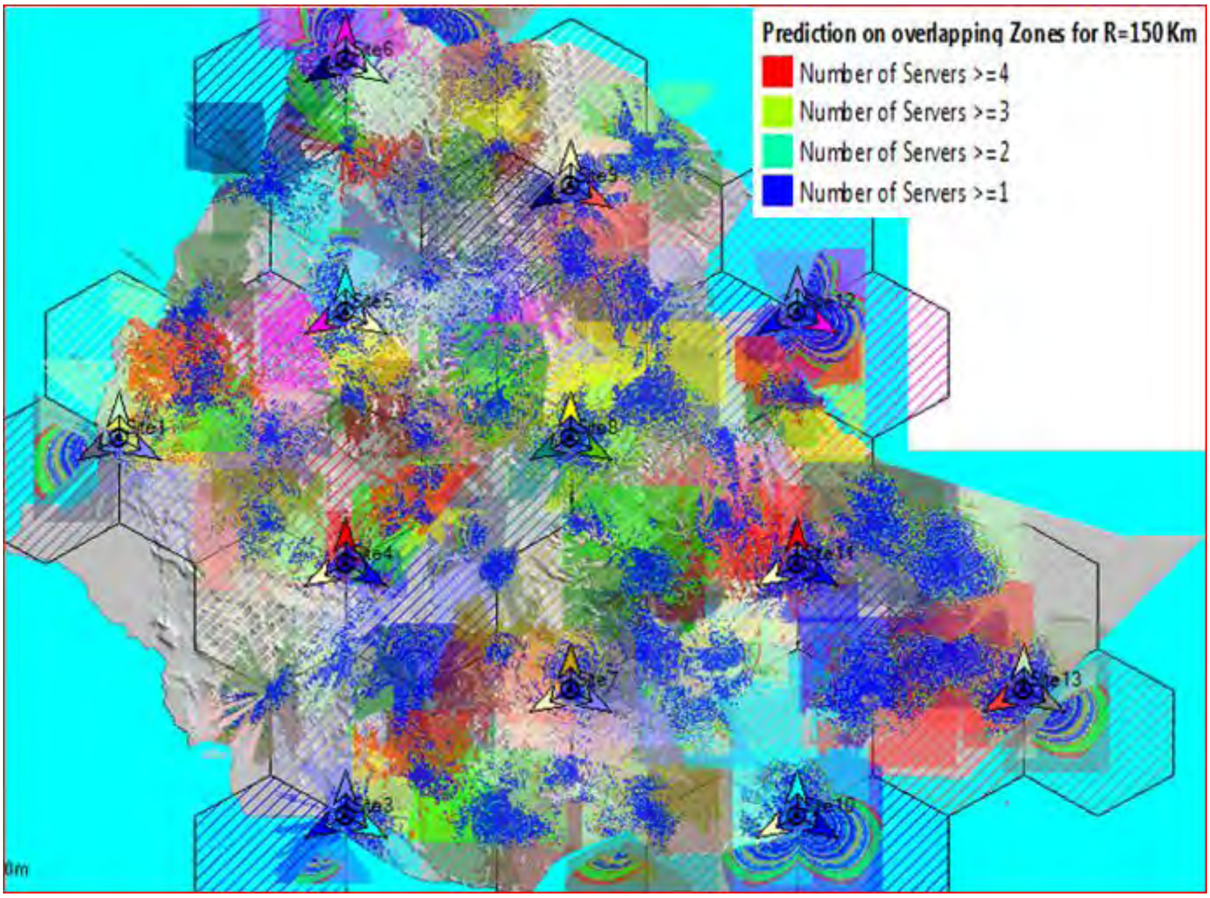
4.3.3. Coverage Prediction on Overlapping Zones

The other coverage prediction that has been done on the selected area is by the overlapping zones meanwhile cells are considered to overlap. Hence large areas over overlapping reduce the performance. Overlapping zones as shown on Figure 4.9 are composed of pixels that are, for a defined condition, covered by the signal of at least two transmitters. To determine the coverage prediction on overlapping zones path loss, or total losses within a defined range should be considered. Therefore, for a transmitter with more than one cell, the coverage is calculated for the cell with the reference signal power (the one with the highest power is selected as the reference).

Figure4.10. a. and 4.10b provide the overlap results for scenario I and II respectively. When the system uses two transmitters the overlapping percentage for scenario-1 is 88.1856% whereas for scenario 2 the overlapping percentage decrease to 39.4231%.

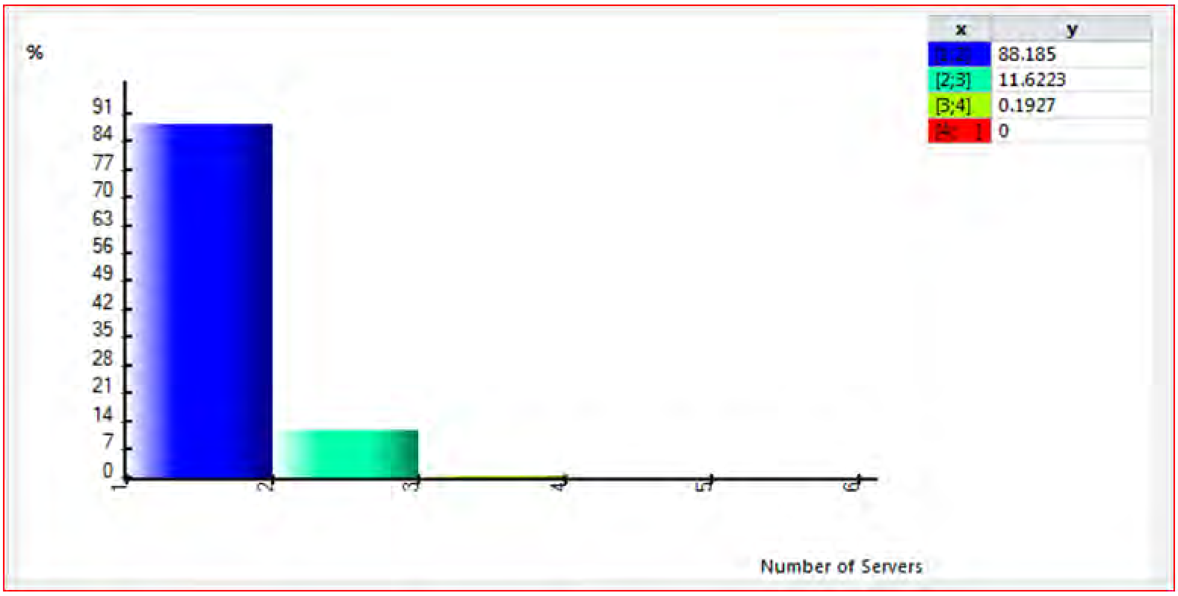

Prediction on Overlapping Zones for R=75Km
Number of Servers >=5
Number of Servers >=4
Number of Servers >=3
Number of Servers >=2
Number of Servers >=1

(a)



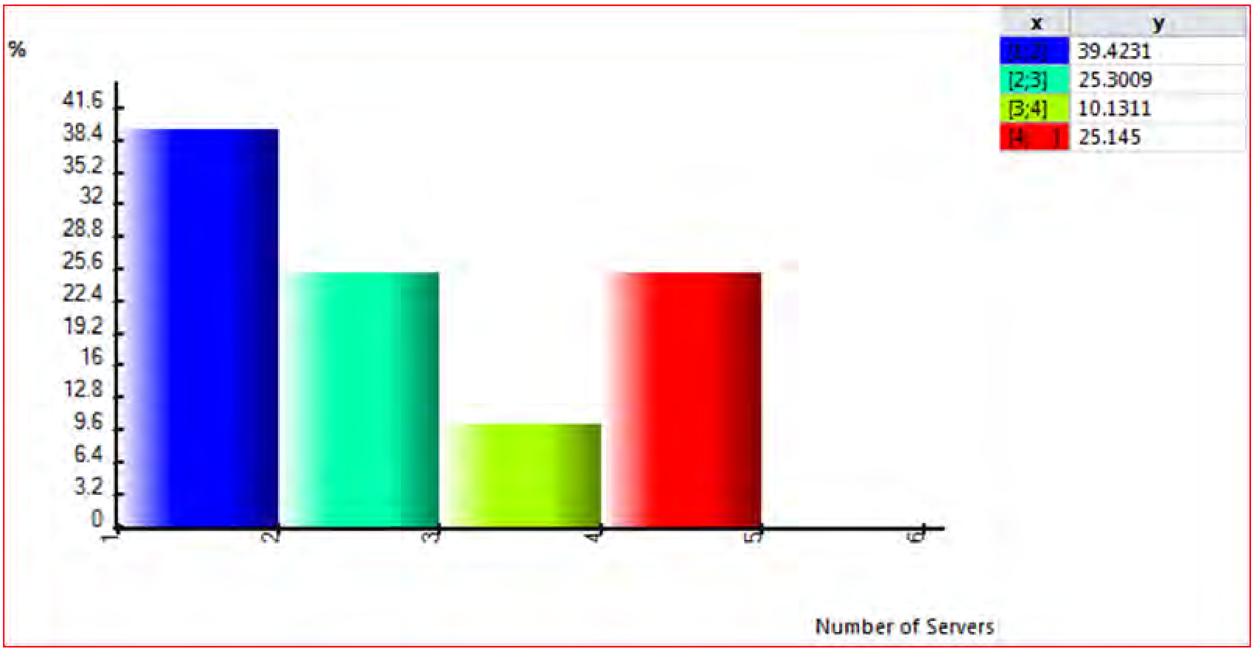
(b)

Figure 4.9 Coverage Prediction on overlapping zone for scenario I and (b) for scenario II



x	y
[1;2]	88.185
[2;3]	11.6223
[3;4]	0.1927
[4;]	0

(a)



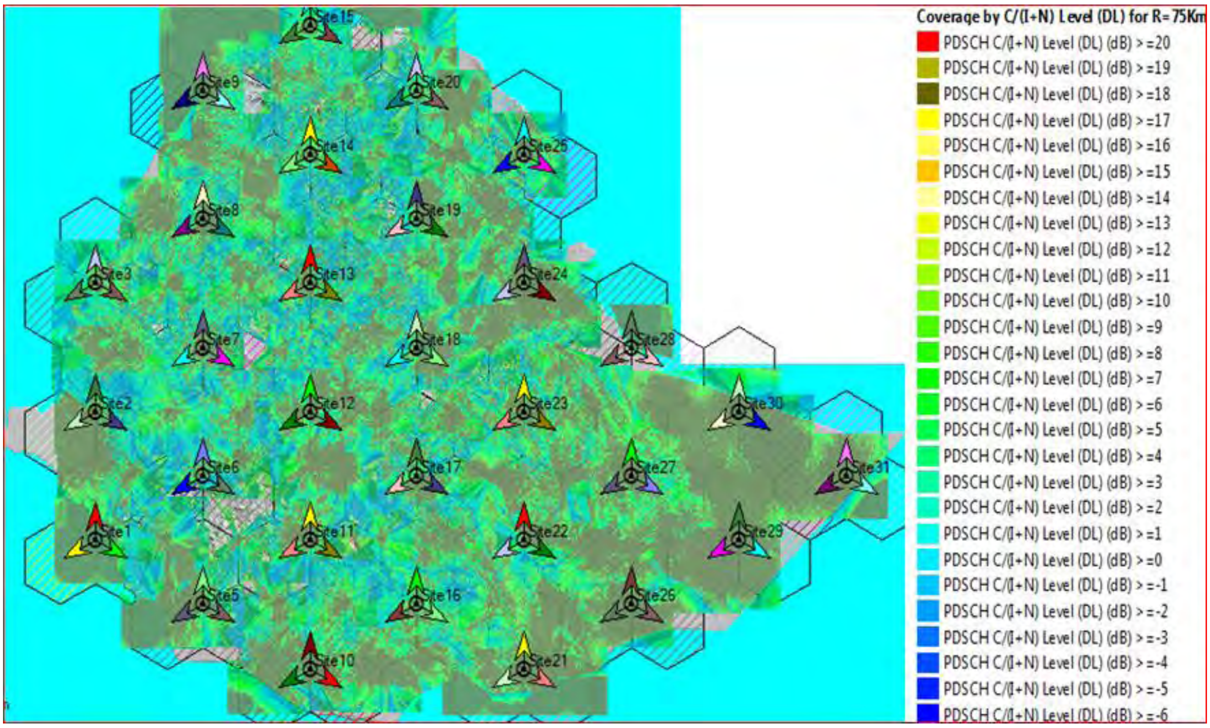
(b)

Figure 4.10 Histogram based coverage on overlapping zone (a) scenario I and (b) scenario II

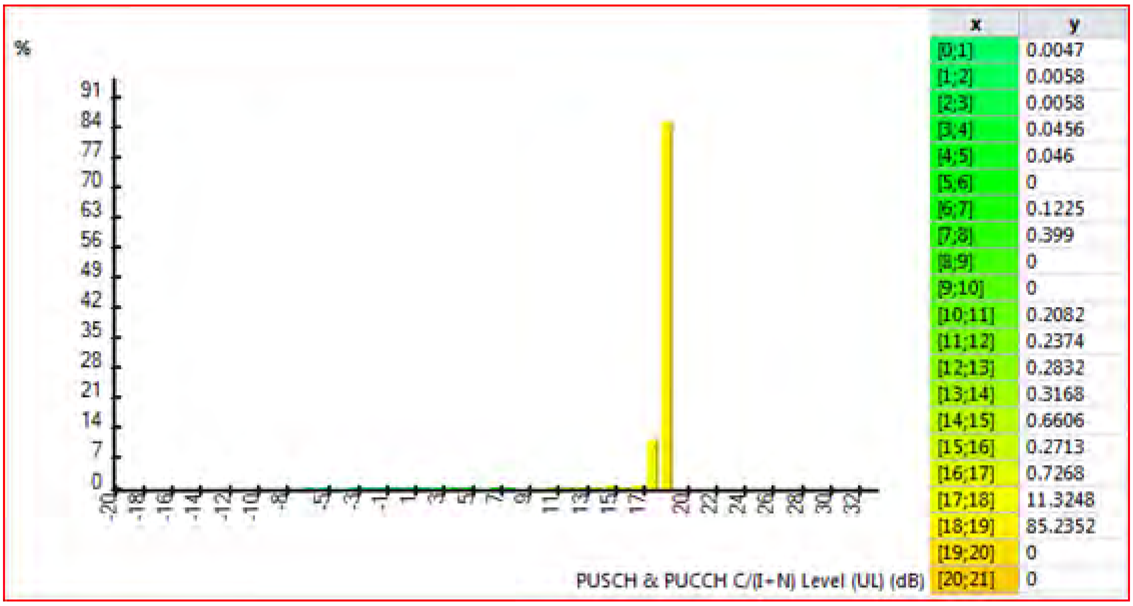
4.3.4. Prediction of QoS

This section, analysis the performance of ATOLL software based on QoS and it uses carrier-to-interference-and-noise ratio C/ (I + N) as tool to determine its performance. Before making a prediction all parameters such as uplink noise values, Required C/N, traffic loads and FL noise are defined. Then, depending on the prediction values, ATOLL calculates the serving transmitter for each pixel depending on the downlink reference signal level. The serving transmitter is determined according to the received reference signal level from the cell with the highest power. If more than one cell covers the pixel, the one with the lowest order is selected as the serving (reference) cell. Then, depending on the prediction definition, it calculates the interference from other cells, and finally calculates the C/(I+N).

Figure 4.11 depicts the simulation result obtained by ATOLL when the transmitter power is 43dB. It also shows the values of co-channel interference (in percentage) against C/(I + N) (in dB). Result comparison is made between LDACS-1's system specification (standard) and ATOLL simulation output results. In LDACS, we can make a circuit quality indicator coverage prediction based on the bit error rate (BER). From the LDACS-1 specification the minimum acceptable carrier to noise ratio is equal 5.2 dB, hence using the default coding and modulation a bit error rate of 10^{-5} achieved using FEC. Nevertheless the value carrier to noise ratio obtained from the ATOLL is 85.2% (the C/(I + N) is higher than C/(I + N) threshold), Therefore, simulation result value is higher than the standard value. Thus system provide an optimum QOS.

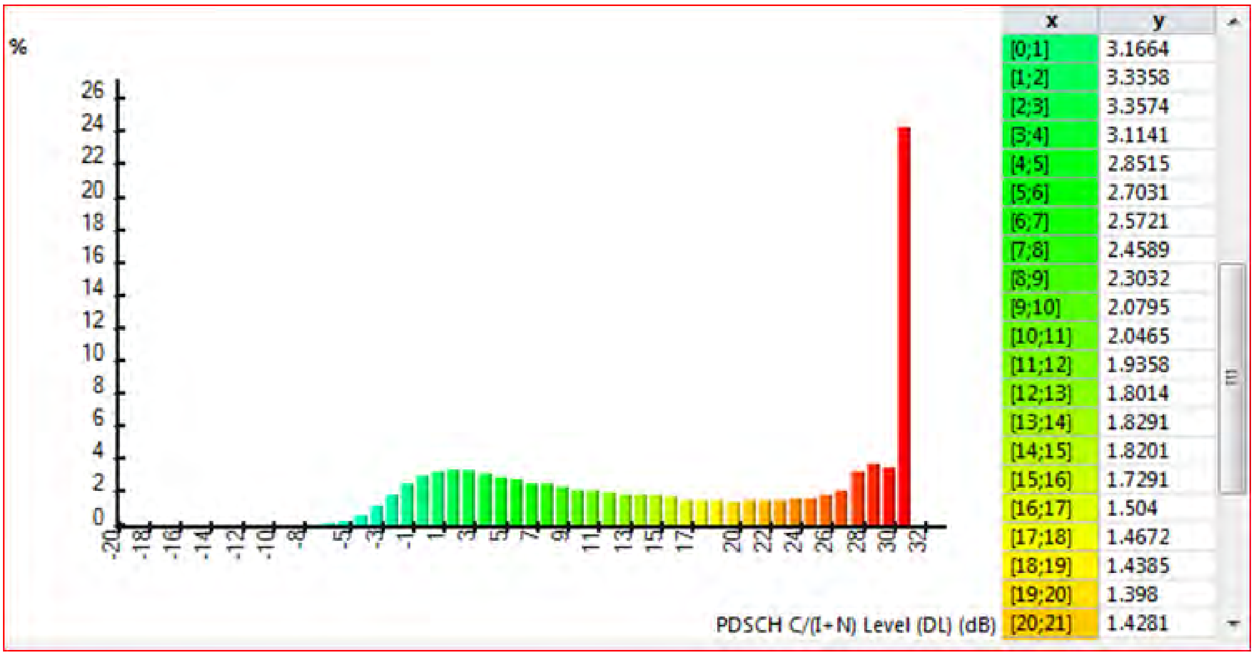


(a)



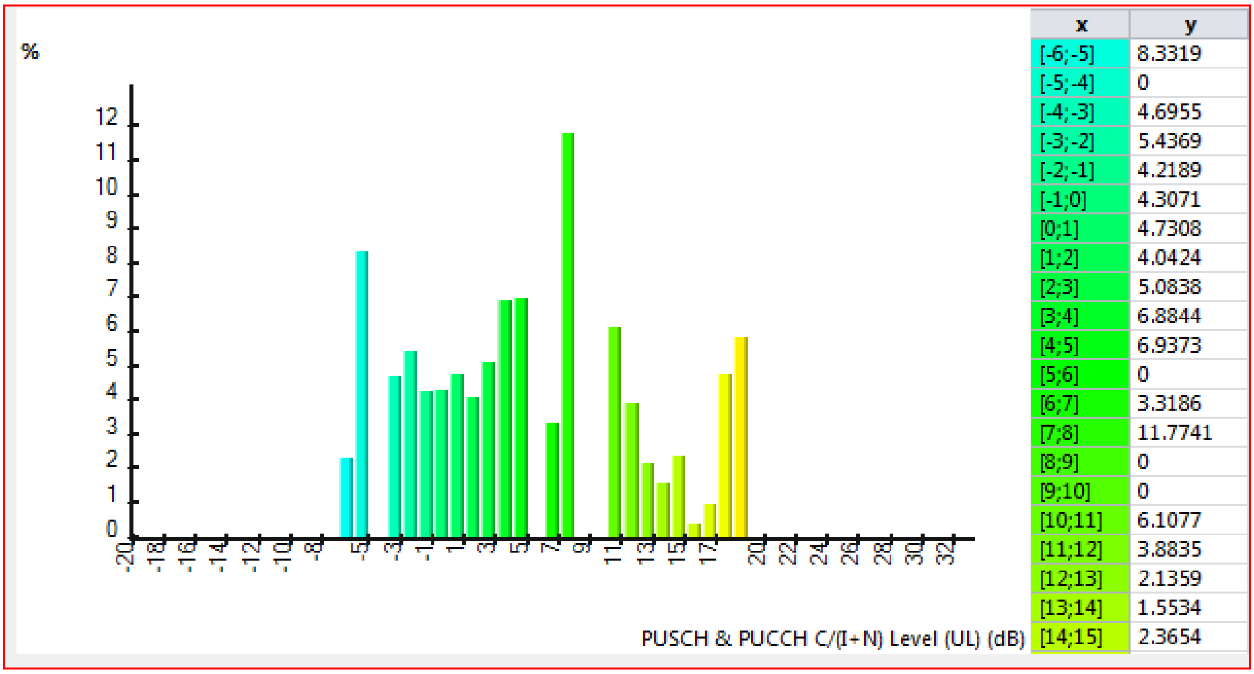
x	y
[0;1]	0.0047
[1;2]	0.0058
[2;3]	0.0058
[3;4]	0.0456
[4;5]	0.046
[5;6]	0
[6;7]	0.1225
[7;8]	0.399
[8;9]	0
[9;10]	0
[10;11]	0.2082
[11;12]	0.2374
[12;13]	0.2832
[13;14]	0.3168
[14;15]	0.6606
[15;16]	0.2713
[16;17]	0.7268
[17;18]	11.3248
[18;19]	85.2352
[19;20]	0
[20;21]	0

Figure 4.11(a) Coverage by C/(I + N) Level (UL) (b) Histogram for Scenario I



x	y
[0;1]	3.1664
[1;2]	3.3358
[2;3]	3.3574
[3;4]	3.1141
[4;5]	2.8515
[5;6]	2.7031
[6;7]	2.5721
[7;8]	2.4589
[8;9]	2.3032
[9;10]	2.0795
[10;11]	2.0465
[11;12]	1.9358
[12;13]	1.8014
[13;14]	1.8291
[14;15]	1.8201
[15;16]	1.7291
[16;17]	1.504
[17;18]	1.4672
[18;19]	1.4385
[19;20]	1.398
[20;21]	1.4281

Figure 4.12 Coverage by C/(I + N) Level (DL) for Scenario I



x	y
[-6;-5]	8.3319
[-5;-4]	0
[-4;-3]	4.6955
[-3;-2]	5.4369
[-2;-1]	4.2189
[-1;0]	4.3071
[0;1]	4.7308
[1;2]	4.0424
[2;3]	5.0838
[3;4]	6.8844
[4;5]	6.9373
[5;6]	0
[6;7]	3.3186
[7;8]	11.7741
[8;9]	0
[9;10]	0
[10;11]	6.1077
[11;12]	3.8835
[12;13]	2.1359
[13;14]	1.5534
[14;15]	2.3654

Figure 4:13 Coverage by C/(I + N) Level (UL) for Scenario II

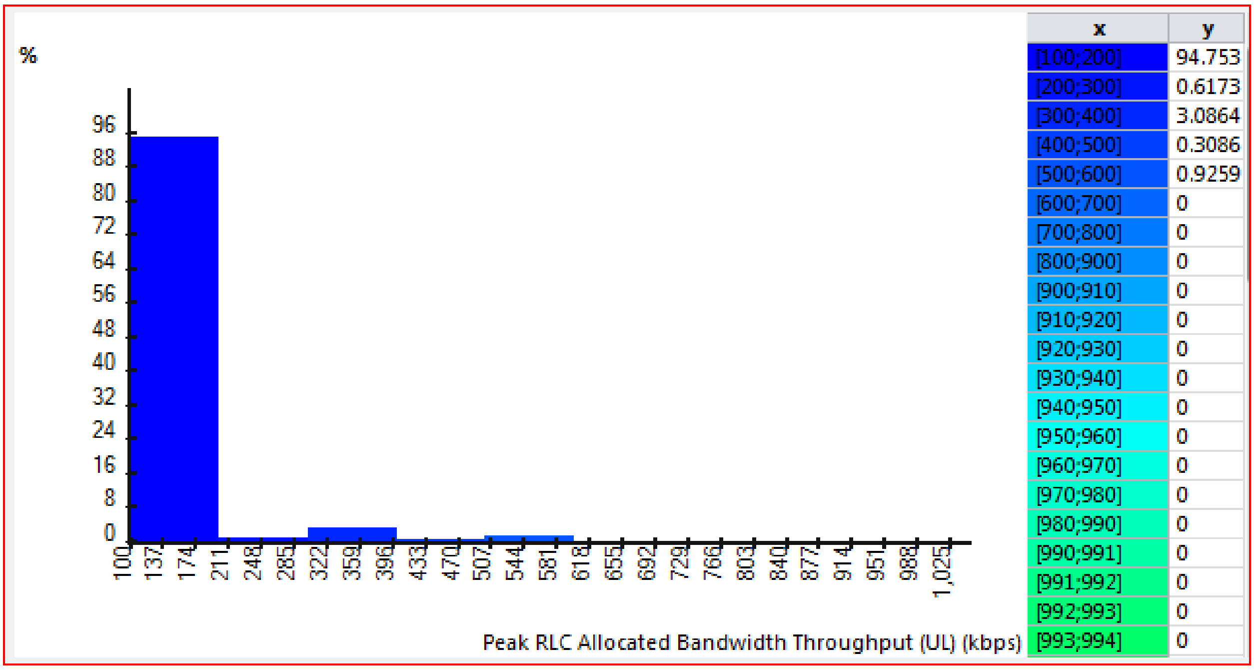
4.3.5. Prediction by Throughput

Downlink and uplink throughput coverage predictions analyze and plot the channel throughputs and cell capacities based on C/ (I+N) and bearer calculations for each pixel.

ATOLL simulate the total number of symbols in the downlink and the uplink frames, which was obtained from the parameters obtained in GS layout and the assigned frequency in each cells. To determine the peak RLC and FLC channel throughputs, ATOLL uses the bearer at each pixel and multiplies the bearer efficiency by the number of symbols in the frame.

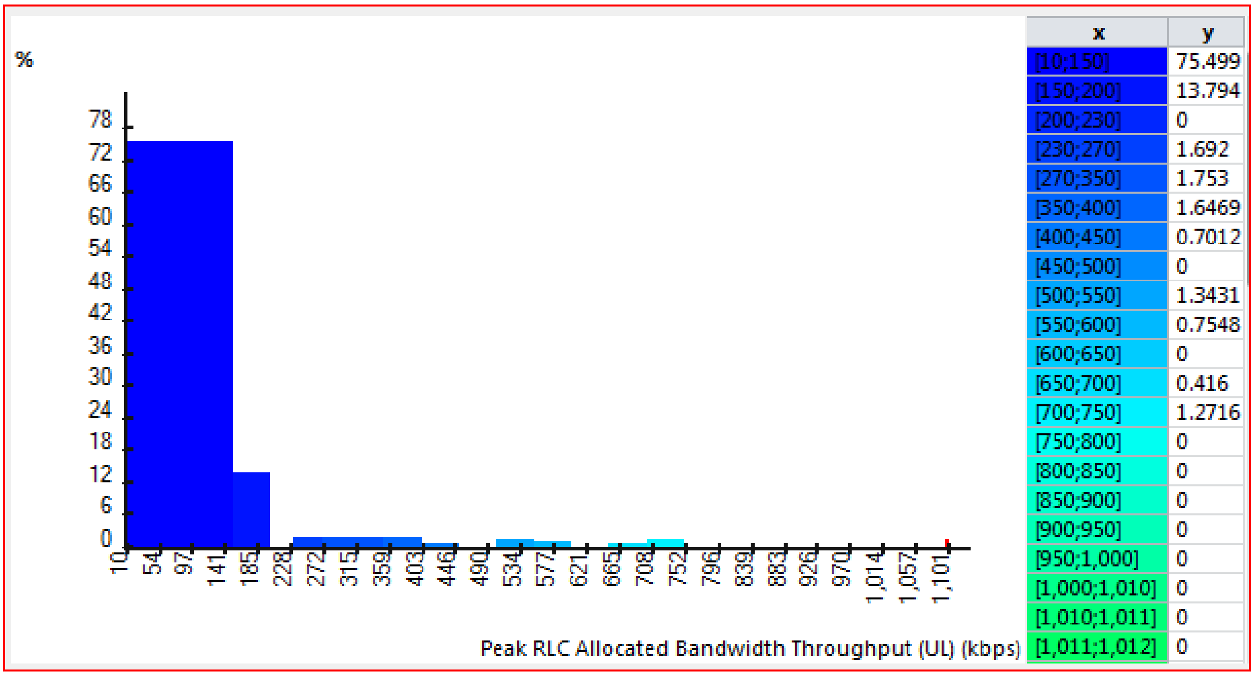
To do capacity and coverage analysis in the FL and RL, it is assumed that the aircrafts are uniformly distributed in the cell and generate equal data traffic. The simulation results are depicted in Figure 4.13 and 4.14. However, Figure 4.13 it is observed that:

- 94.753 % of the coverage prediction by throughput for air traffic data communication can be applicable for scenario I, while 75.499 % data traffic handle for the second scenario.
- For assigned frequency band the proposed network planning can accommodate both the current and future domestic traffic.



x	y
[100;200]	94.753
[200;300]	0.6173
[300;400]	3.0864
[400;500]	0.3086
[500;600]	0.9259
[600;700]	0
[700;800]	0
[800;900]	0
[900;910]	0
[910;920]	0
[920;930]	0
[930;940]	0
[940;950]	0
[950;960]	0
[960;970]	0
[970;980]	0
[980;990]	0
[990;991]	0
[991;992]	0
[992;993]	0
[993;994]	0

(a)



x	y
[10;150]	75.499
[150;200]	13.794
[200;230]	0
[230;270]	1.692
[270;350]	1.753
[350;400]	1.6469
[400;450]	0.7012
[450;500]	0
[500;550]	1.3431
[550;600]	0.7548
[600;650]	0
[650;700]	0.416
[700;750]	1.2716
[750;800]	0
[800;850]	0
[850;900]	0
[900;950]	0
[950;1,000]	0
[1,000;1,010]	0
[1,010;1,011]	0
[1,011;1,012]	0

(b)

Figure 4.14 Coverage by throughput (a) for scenario I and (b) for scenario II

5

Conclusion and Recommendation

This chapter finalizes the present study by summarizing the main conclusions obtained throughout this work and presenting an overall analysis about the main results achieved. In doing so we focus on the analysis of LDACS-1 specifications and Ethiopian airlines vision 2025 and evaluated the feasibility of LDACS-1 network in Ethiopia. Moreover, it is important to note that our proposed network is not optimum. The conclusions and recommendation are as follows.

5.1. Conclusion

The basic objective of this dissertation focuses on the possibility of LDACS-1 network for domestic flight in Ethiopia. The study has emphasized the LDACS-1 specification and Ethiopian airlines vision 2025 documents have been chosen to perform domestic flight network. The research is divided into five parts. In chapter two, we mention the current Aeronautical communication system and Emerging Solution. This chapter has focused on the main design aspects of LDACS-1 that support a variety of functions like spectral deployment, system architecture, network topology, the basic modes of operation OFDMA and TDMA, coding schemes and data rates. We also describe about LDACS-1 deployment with introduction to FL and RL.

Chapter three presents in details about domestic air connectivity route in Ethiopia, network coverage and capacity dimensioning. Based on domestic flight traffic load in the year 2025 and LDACS-1 specification, the study analyzed different scenarios to handle the data traffic. It is applied two scenarios, in the first scenario which has the cell radius 75 km and the network performance evaluated. In the second scenario of this work, large 150KM cells have been considered and the traffic load was evaluated.

Chapter four presents about the simulation result. Various graphs are used to provide the bounds for simulation results, in terms of coverage by signal level, coverage prediction by transmitter, coverage prediction by overlapping zones and prediction by QoS. Several important conclusions are drawn regarding the characterization of air traffic for various parameters.

In the dimensioning stage coverage prediction was performed. As it is shown in the coverage planning simulation, we get that sites number are 30 and 12 for scenario I and scenario II respectively. It was analyzed that more than 80.7% of the target area is covered by strong signal for scenario I but in the case of scenario II more than 67.6% of the target area is covered.

Again, using the desired parameter capacity analysis was performed. For initial LDACS-1 network planning deployment in Ethiopia, at the very beginning only small number of aircraft in a cell is considered for capacity calculation.

Regarding throughput measurements, the expected performances are obtained for scenario I and scenario II. The maximum cell load in the first scenario is 200 kbps while 141 kbps in the second scenarios. In addition, the total number of aircraft in the first scenario is approximately 780 whereas 312 for the second scenario.

The study has focused to analyzing the possibility of LDACS-1 deployed in Ethiopia. Taking into account LDACS-1 deployed in the small regions of the L-band that are currently not used by DME's. Since the interference scenario in the case of inlay case not considered. It can be observed from the simulation result the frequency assignment results presented in Table 3.5 above is shown graphically in Figure 3.8. The assigned frequency appears in each cell and marked in different colures. Therefore, in order to achieve an optimum frequency assignment, the detail frequency planning should require in all possible cases inlay as well as non-inlay. So, there remains the challenge for future studied. But all outputs are expected to be used in nominal network planning stage.

Finally, it can be concluded from the overall results of the study, LDACS-1 system can be implemented for the domestic network planning and an acceptable level of domestic connectivity.

5.2. Recommendation future work

Based on the studies we have concluded above, there are some discussions which can further enhancements should be done.

- One major assumption made in this work is uniform aircraft distribution in the study region. In a practical network planning and design, it is difficult to obtain uniform aircraft distributions in different cells. Therefore, more research is needed to analyzing the performance of different aircraft distribution in the cell.
- The interference of LDACS-1 system in legacy system can also be another research topic. For example, a possible case would be when interference to L-band channels with a certain frequency offset from nearly LDACS systems.
- The analysis of data generated assumes equal for all aircraft in the overall area. This is a decent assumption, especially when future operational concepts all aircraft would not like to transfer equal information to ATC. One possible research topic is to study the effect of LDACS-1 network into different data traffic that generate from each aircraft.

Reference

[1] G´en´erale de l', "Aviation Civile, *Radiot´el´ephonie*, 2nd ed", DGAC, Avril 2006, ISBN 2-11-091276-6.

[2] R. Jafari, A. Encarnacao, A. Zahoory, F. Dabiri, H. Noshadi, and M. Sarrafzadeh, "Wireless Sensor Networks for Health Monitoring," Proc. Mobile and Ubiquitous Systems: Networking and Services, pp. 479-481, Jul. 2005.

[3] M. Sajatovic and M. Schnell, "Future Aeronautical Communications Concepts and Their Impact on ATM Procedures," in *Air Traffic Control Association (ATCA) conference Proceedings*, 2005.

[4] Chandra, V. Gummallam, and J. Limb, "Wireless Medium Access Protocols," IEEE Commun. Surveys, 2002.

[5] EUROCONTROL/FAA, Future Communications Study Operational Concepts and Requirements Team, "*Communications Operating Concept and Requirements for the Future Radio System*", April 225, 2007.

[6] European Conference of Postal and Telecommunications, '*Compatibility between UMTS and existing and planned aeronautical systems above 960 MHz'*, Electronic Communications Committee (ECC), 12 November 2010.

[7] Cheng-Hong Chen, James W. Howland, Robert I. Millar, Brian E. White, Warren J. Wilson, *VHF Air/Ground Communications for Air Traffic Control,* New York, The MITRE Corporation 202 Burlington Road Bedford, MA 01730-1420, July 1993.

[8] Simon Plass, *Future Aeronautical Communications*, InTech Janeza Trdine 9, 51000 Rijeka, Croatia, September, 2011, ISBN 978-953-307-625-6.

[9] European Organization for the Safety of Air Navigation, "Medium-Term Forecast: IFR Flight Movements 2010-2016," EUROCONTROL, Tech. Rep. Doc378, 2010.

[10] Baris Baspinar, N. Kemal Ure, Emre Koyuncu, Gokhan Inalhan, "*Analysis of Delay Characteristics of European Air Traffic through a Data-Driven Airport-Centric Queuing Network Model"*, International Federation of Automatic Control, Istanbul, Turkey, May 2016.

[11] J. Prinz et al., “VHF channel occupancy measurements over core Europe,” in Proc. 5th NASA ICNS Conf. Workshop, Fairfax, VA, May 2–5, 2005.

[12] https://planefinder.net/

[13] Najett Neji, Raul de Lacerda, Alain Azoulay, Thierry Letertre, Olivier Outtier, *Interference Analysis for the Future Aeronautical Communication System*. IEEE, 2009.

[14] E. Haas, “Aeronautical channel modeling,” Vehicular Technology, IEEE Transactions on, vol. 51, no. 2, pp. 254 –264, March 2002.]. Also Free space loss is recommended ITU-RP.525.

[15] Najett Neji, Raul De Lacerda, Alain Azoulay, Thierry Letertre, and Olivier Outtier, “Survey on the Future Aeronautical Communication System and its development for continental communications”, 21 Jan 2013.

[16] B.Belabbas, M.Felux, M.Meurer, N. Schneckenburger, M.Schnell, “LDACS-1 for an Alternate Positioning Navigation and Time Service”, German Aerospace Center (DLR), Germany.

[17] Ulrich Epple, Felix Hoffmann, and Michael Schnell, “Modeling DME Interference Impact on LDACS1”, German Aerospace Center (DLR), Wessling, Germany.

[18] M. Sajatovic, B. Haindl, M. Ehammer, Th. Gräupl, M. Schnell, U. Epple, S. Brandes, February 2009, “LDACS1 System Definition Proposal: Deliverable D2”, Eurocontrol Study Report, Edition 1.0.

[19] B.Belavvas, B.Elwischger and U.Epple, LDACS1 L-band Compatibility and Extension Towards Navigation. DGLR, March 2013.

[20] Alcatel-Lucent. *Strategic White Paper: Using Air-to-Ground LTE for In-Flight Ultra-Broadband_Opening the Skies to Unlimited Possibili-ties*, accessed on Jan. 12, 2016. [Online]. Available: https://www.alcatellucent. com/solutions/4g-lte-airports-and-air-ground.

[21] D. Medina and F. Hoffmann, The Airborne Internet, German Aerospace Center (DLR) Oberpfaffenhofen, Germany, October 2009.

[22] Schnell, M. and Scalise, S., “Newsky - A Concept for Networking the Sky for Civil Aeronautical Communications,” *25th Digital Avionics Systems Conference, 2006 IEEE/AIAA*, 15-19 2006, pp. 1 –6.

[23] Unisbg, “Broadband Aeronautical Multi-Carrier Communications System”, Deutsches Zentrum Fur Luft Und Raumfahrt E.V., Paris, 27/3/2008.

[24] D. Stacey, “Aeronautical radio communication systems and networks, isbn n 978-0-470-01859,” Johl Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, p. 10, 2008.

[25] M. H. Tooley and D. Wyatt, Aircraft communications and navigation systems: principles, operation and maintenance. Routledge, 2007.

[26] D. Stay, “Aeronautical radio communication systems and networks, isbn n 978-0-470-01859,” Johl Wiley & Sons Ltd, The Artrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, p.10,2008.

[27] ARINC Report 634, HF Data Link System Design Guidance Material, ARINC Report 634, Maryland, U.S.A., Aug. 1996.

[28] http://www.airliners.net/

[29] EUROCONTROL, “Implications of End-to-End communication for Air Traffic Control”, EEC Technical/Scientific Report No. 2009-012.

[30] ARINC 750-2, “VHF Data Radio”, ARINC, Maryland, U.S.A., Dec.1997.

[31] P. Delhaise, D. Desperier and B. Roturier, VDL Model 2 Physical layer validation re-port. EATMP Reference Number COM5-11-0501, EUROCONTROL, April 2001.

[32] Future Aeronautical Communications: The Data Link Component, Nikos Fistas Published by InTech Janeza Trdine 9, 51000 Rijeka, 2011.

[33] An Introduction to LTE,3GPP LTE Encyclopaedia, December 2010.

[34] IEEE Approves IEEE 802.16m – Advanced Mobile Broadband Wireless Standard, News release (IEEE Standards Association), 31 March 2011.

[35] Dr. Muthalagu Raja, *DME Interference Mitigation for (LDACS1) Based on Decision-Directed Noise Estimation*, Virginia, USA April 21-23, 2015.

[36] N. Schneckenburger, N. Franzen, S. Gligorevic, M. Schnell, “L-band Compatibility of LDACS1”, German Aerospace Center (DLR), Oberpfaffenhofen, Germany, August, 2011.

[37] Prasad, R; “OFDM for Wireless Communications”; Artech House, 2004.

[38] B. Belabbas, M. Felux, M. Meurer, N. Schneckenburger, M. Schnell, “LDACS1 for an Alternate Positioning Navigation and Time Service”, German Aerospace Center (DLR), Germany.

[39] CEPT, “Compatibility between UMTS and existing and planned aeronautical system above 960 MHZ”, Report from CEPT to the European Commission. Task 3.

[40] European Conference of Postal and Telecommunications, ‘*Compatibility between UMTS and existing and planned aeronautical systems above 960 MHz’*, Electronic Communications Committee (ECC), 12 November 2010.

[41] Ethiopian Airlines Fleet Details and History, https://www.planespotters.net/airline/Ethiopian-Airlines

[42] https://www.ethiopianairlines.com/AA/EN/book/route-network/domestic-network.

[43] Ethiopian Airline: “Vision 2025” for a period from 2010 to 2025.

[44] M. Lohatepanont and C. Barnhart. Airline Schedule Planning: Integrated Models and Algorithms for Schedule Design and Fleet Assignment. Transportation Science, 38(1):19–32, February 2004.

[45] Mattias Gr¨onkvist, “The Tail Assignment Problem”, Mattias Gro¨nkvist, 2005.

[46] http://www.prokerala.com/travel/airports/ethiopia/

[47] https://www.ethiopianairlines.com/AA/EN/book/route-network/domesticnetwork.

[48] EUROCONTROL, FAA, “Communications Operating Concept and Requirements for the Future Radio System, (COCR),” Tech. Rep. Version 2.0, 2007.

[49] EUROCONTROL, “Framework for Spectrum Compatibility Analysis in L-Band for FCI technology Candidates”, Draft 1.0.

[50] T. S. Rappaport, Wireless Communications: Principles and Practice, 2nd ed. Singapore: Pearson Education, Inc., 2002.

[51] Minya Gavrilovic, “Impact of Base Station Antenna Azimuth Beamwidth on the Performance of 3-Sector Site LTE Deployments”, OCCI, November 6th, 2014.

[52] CEPT, “Compatibility between UMTS and existing and planned aeronautical system above 960 MHZ”, Report from CEPT to the European Commission. Task 3

[53] J.D.Parsons, “The mobile Radio Propagation Channel”, Second Edition. Copyright 200 Johnn Wiley & Sons Ltd Print ISBN 0-471-98857-X.

[54] L. E. Miller, "Propagation Model Sensitivity Study," J. S. Lee Associates, Inc. contract report, July 1992.

[55] AC 91-010, “Vertical Navigation”, SRVSOP, 12/10/2009.

[56] EUROCONTROL, "VDL Mode 2 Capacity Analysis Through Simulations," 2006.

[57] J.D.Parsons, “The mobile Radio Propagation Channel, Second Edition”, Copyright 200 Johnn Wiley & Sons Ltd Print ISBN 0-471-98857-X.

[58] L. E. Miller, "Propagation Model Sensitivity Study," J. S. Lee Associates, Inc. contract report, July 1992.

[59] www.mapsofworld.com/international-airports

[60] R. Jain, F. Templin and K -S. Y in, “Analysis of L-Band Digital Aeronautical Communication Systems: L-DACS1 and L-DACS2,” in IEEE Aerospace Conference, 2011.

[61] http://traveltips.usatoday.com/altitude-plane-flight-100359.html.

[62] J. W. Mark and W. Zhuang, Wireless Communications and Networking. New Delhi: PHI, 2005.

[63] Miodrag Sajatovic, German Aerospace Center (DLR), “Updated LDACS1 Prototype Specification”, SESAR, Joint Undertaking, 19/11/2010.

[64] U. Epple and M. Schnell, “Overview of Interference Situation and Mitigation Techniques for LDACS1,” in Proc. Digital Avionics System Conference, Oct. 2011.

[65] M. Schnell *et al.*, "B-AMC — broadband aeronautical multi-carrier communications," 2008 Integrated Communications, Navigation and Surveillance Conference, Bethesda, MD, 2008, ICNSURV.2008.4559173.

Appendix A

LDACS-1 system is to be used for communications between the aircraft and air traffic controllers and will also be used to allow supplemental data services, like transmission of weather information or general airline data. The FCS identifies the communication requirements to support emerging global future ATM concepts taking into account and defines resulting COCR. However, we have implemented the COCR application for our research. There are different applications listed in the COCR document. The COCR divides airspace into five representative airspace domains and ATS services are expected to be utilized in the respective domains. ATS data communications services vary by the domain in which the aircraft is or will be operating. The ATS data services have been grouped into eight categories as indicated in Table A.1.

Data Communications Management Services (DCM)	**Clearance/ Instruction Services (CIS)**	**Flight Information Services (FIS)**	**Advisory Services (AVS)**	**Flight Position/ Intent/ Preferences Services (FPS)**	**Emergency Information Services (EIS)**	**Delegated-Separation Services (DSS)**	**Miscellaneous Services (MIS)**
Data Link Logon (DLL) ATC Communication Management (ACM)	ATC Clearance (ACL) Departure Clearance (DCL) Downstream Clearance (DSC) ATC Microphone Check (AMC) Data Link Taxi (DTAXI) Common Trajectory Coordination (COTRAC	Data Link Automatic Terminal Information Service (D-ATIS) Data Link Operational Terminal Information Service (D-OTIS) Data Link Operational En Route Information Service (D-ORIS) Data Link Significant Meteorological Information (D-SIGMET) Data Link Runway Visual Range (D-RVR) Data Link Surface Information and Guidance (D-SIG)	Arrival Manager Information Delivery (ARMAND) Dynamic Route Availability (DYNAV) Data Link Flight Update (DFLUP)	Surveillance (SURV) Flight Plan Consistency (FLIPCY) Flight Path Intent (FLIPINT) System Access Parameters (SAP) Wake Broadcast (WAKE) Pilot Preferences Downlink (PPD) Traffic Information Service-Broadcast (TIS-B)	Data Link Alert (DALERT) Urgent Contact (URCO)	In-Trail Procedures (ITP) Merging and Spacing (M&S) Crossing and Passing (C&P) Paired Approach (PAIRAPP)	Air-to-Air Self Separation (AIRSEP) Auto Execute (A-EXEC)

Table A.1 COCR ATS data service Groups

However, not all applications listed in the COCR are relevant for the LDACS-1 system. For example, the Data Link Taxi Clearance services are used on the runway.

1. Message Quantities and Sizes

Table A.2 provide the average number of message quantities and sizes per service instance for ATS, AOC and NET services, respectively. For addressed services, message sizes are provided for the uplink and downlink directions. For broadcasted services, the message size is the transmitted message size.

Services	**Uplink Qty x Size (bytes)**	**Downlink Qty x Size (bytes)**
ACL	2 x 93	2 x 93
ACM	1 x 126	1 x 88
A-EXEC	1 x 600	1 x 100
AIRSEP	6 x 497	
AMC	1 x 89	0 x 0
ARMAND	1 x 260	1 x 88
C & P ACL	2 x 93	2 x 93
ITP SURV	1 x 34	
COTRAC (Interactive)	3 x 1969	4 x 1380
COTRAC (Wilco)	2 x 1613	2 x 1380
D-ALERT	1 x 88	1 x 1000
D-ATIS (Arrival)	5 x 100	3 x 93
D-ATIS (Departure)	3 x 101	2 x 96
DCL	1 x 117	2 x 88
D-FLUP	5 x 190	3 x 129
DLL	1 x 491	1 x 222
D-ORIS	9 x 478	3 x 93
D-OTIS	11 x 193	3 x 107
D-RVR	4 x 116	3 x 121
DSC	3 x 96	4 x 87
D-SIG	4 x 1340	3 x 129
D-SIGMET	4 x 130	3 x 129
D-TAXI	2 x 132	1 x 98

DYNAV	1 x 515	1 x82
FLIPCY	1 x 105	1 x 173
FLIPINT	1 x 143	1 x 2763
ITP ACL	2 x 93	2 x 93
ITP SURV	1 x 34	
M&S ACL	2 x 93	2 x 93
M&S SURV	1 x 34	
PAIRAPP ACL	2 x 93	2 x 93
PAIRAPP SURV	1 x 34	
PPD	1 x 105	1 x 277
SAP (Contract Setup)	2 x 95	2 x 100
SAP (Report)	0 x 0	1 x 107
SURV (ATC)	1 x 34	
TIS-B	1 x 34	
URCO	1 x 98	1 x 82
WAKE	1 x 34	

Table A.2 ATS Message Quantities and Sizes per Instance

Appendix B

Scheduled Flights in Addis Ababa airport on Mar 25, 2016.

Departing	**Destination**	**Flight Number**	**Airline**
12:40	Arba Mintch AMH	ET0135	Ethiopian Airlines
13:00	Asosa ASO	ET0150	Ethiopian Airlines
13:00	Gambela GMB	ET0150	Ethiopian Airlines
13:00	Goma GOM	ET0811	Ethiopian Airlines
13:20	Dire Dawa DIR	ET0204	Ethiopian Airlines
14:30	Axum AXU	ET0116	Ethiopian Airlines
14:40	Gondar GDQ	ET0114	Ethiopian Airlines
14:50	Hargeisa South HGA	ET0374	Ethiopian Airlines
14:55	Juba JUB	ET0354	Ethiopian Airlines
15:10	Jimma JIM	9Y0400	Ethiopian Airlines
15:10	Makale MQX	ET0104	Ethiopian Airlines
15:15	Bahar Dar BJR	ET0142	Ethiopian Airlines
16:00	Dire Dawa DIR	ET0364	Ethiopian Airlines
16:00	Dire Dawa DIR	ET0212	Ethiopian Airlines
16:00	Jijiga JIJ	ET0212	Ethiopian Airlines
16:00	Jimma JIM	ET0133	Ethiopian Airlines
16:30	Bahar Dar BJR	ET0140	Ethiopian Airlines

18:00	Makale MQX	ET0108	Ethiopian Airlines
18:45	Bahar Dar BJR	ET0146	Ethiopian Airlines
20:00	Makale MQX	ET0148	Ethiopian Airlines
20:56	Harare HRE	ET0893	Ethiopian Airlines
07:00	Makale MQX	ET0100	Ethiopian Airlines
07:30	Bahar Dar BJR	9Y0300	
07:30	Dire Dawa DIR	ET0200	Ethiopian Airlines
07:30	Gode GDE	ET0200	Ethiopian Airlines
07:30	Jijiga JIJ	ET0200	Ethiopian Airlines
07:40	Axum AXU	ET0122	Ethiopian Airlines
07:40	Gondar GDQ	ET0122	Ethiopian Airlines
07:40	Lalibela LLI	ET0122	Ethiopian Airlines
07:50	Bahar Dar BJR	ET0126	Ethiopian Airlines
08:00	Makale MQX	ET0112	Ethiopian Airlines
08:05	Gondar GDQ	ET0124	Ethiopian Airlines
08:05	Lalibela LLI	ET0124	Ethiopian Airlines
08:10	Bahar Dar BJR	ET0120	Ethiopian Airlines
08:10	Lalibela LLI	ET0120	Ethiopian Airlines
08:30	Dire Dawa DIR	9Y0508	Ethiopian Airlines
08:30	Jijiga JIJ	9Y0504	Ethiopian Airlines

09:00	Arba Mintch AMH	ET0135	Ethiopian Airlines
09:00	Axum AXU	ET0128	Ethiopian Airlines
09:00	Jimma JIM	ET0135	Ethiopian Airlines
09:23	Harare HRE	ET0863 LH9684	Ethiopian Airlines Deutsche Lufthansa
11:00	Makale MQX	9Y0302	
11:30	Bahar Dar BJR	ET0144	Ethiopian Airlines
11:30	Jijiga JIJ	ET0202	Ethiopian Airlines
12:20	Axum AXU	ET0102	Ethiopian Airlines
12:20	Makale MQX	ET0102	Ethiopian Airlines

Table B.1 Scheduled Flights in Addis Ababa airport

Appendix C. List of Airport in Ethiopia

Airport Name	**Latitude**	**Longitude**	**Closest Airport**	**Distance (Km) to closest Airport**	**Airport Type**	**IATA**
Aba Tenna D Yilma Airport	9.6247	41.8542	Jigiga Airport	106.55	Medium	DIR
Arba Minch	6.03923	37.5905	Soddu Airport	90.07	Medium	AMH
Asela Airport	7.96667	39.1167	Bole International	117.88	Small	ALK
Asosa Airport	10.067	34.55	Mendi Airport	64.71	Medium	ASO
Awarech Airport	8.26667	44.1833	Degahbur	66.14	Small	AWH
Awassa Airport	7.067	38.5	Soddu Airport	86.79	Small	AWA
Axum Airport	14.1468	38.7728	Indaselassie	54.51	Medium	AXU
Bahar Dar	11.6081	37.3216	Debra Tabor	83.96	Medium	BJR
Beica Airport	9.38333	34.5333	Asosa Airport	76.03	Small	BEI
Beles Airport	11.3333	36.4167	Chagni Airport	33.81	Small	PWI
Bole International	8.97895	38.7995	Tum Airport	64.79	Medium	ADD
Bulchi Airport	6.21667	36.667	Jinka Airport	49.59	Small	BCY
Buno Dedelle	8.45	36.33333	Nekemt Airport	72.89	Small	XBL
Chagni Airport	11.0333	36.4667	Beles Airport	33.81	Small	MKD
Combolcha	11.0825	39.7114	Lalinela	127.32	Small	DSE

Airport Name	**Latitude**	**Longitude**	**Closest Airport**	**Distance (Km) to closest Airport**	**Airport Type**	**IATA**
Debra Marcos	10.35	37.717	Mota Airport	81.77	Small	DBM
Debra Tabor	11.967	38	Mekane Selam	35.53	Small	DBT
Degahbur	8.23333	45.5833	Awareh Airport	66.14	Small	DGC
Dembidollo	8.554	34.858	Gambela	57.13	Small	DEM
Gambela	8.13083	34.5639	Dembidollw	57.13	Medium	GMB
Geladi Airport	6.966667	46.4167	Warder Airport	119.62	Small	GLC
Gedna Wuha	12.93333	36.1667	Gondar Airport	145	Small	ETE
Ghimbi Airport	9.667	35.833	Nekemt Airport	85.2	Small	GHD
Ghinnir Airport	7.1327	40.7092	Goba Airport	79.34	Small	GNN
Goba Airport	7.017	40	Ghinnir Airport	79.34	Small	GOB
Gode Airport	5.93513	43.5786	Kelafo Airport	90.8	Medium	GDE
Gondar Airport	12.52	37.4342	Debra Tabor	86.99	Medium	GDQ
Gore Airport	8.1667	35.55	Dembidollo	87.5	Small	GOR
Humera Airport	14.25	36.5833	Genda Wuha	153.23	Small	HUE
Indaselassie	14.078	38.2725	Axum	54.51	Small	SHC
Jijiga Airport	9.35972	42.7875	Aba Tenna D yilma	106.55	Small	JIJ

Airport Name	**Latitude**	**Longitude**	**Closest Airport**	**Distance (Km) to closest Airport**	**Airport Type**	**IATA**
Jima Airport	7.66513	36.8176	Waca Airport	67.58	Medium	JIM
Jinka Airport	5.78364	36.5623	Bulch Airport	49.54	Small	BCO
Kebri Dar	6.73254	44.2381	Gode Airport	114.81	Small	ABK
Kelafo Airport	5.657	44.35	Gode Airport	90.8	Small	LFO
Lalibela Airport	11.975	38.98	Mekane Selam	96.01	Small	LLI
Makale Airport	13.4674	39.5335	Axum Airport	111.64	Medium	MQX
Mekane Selam	11.6833	38.15	Debra Tabor	35.53	Small	MKS
Mena Airport	6.35	39.7167	Goba Airport	80.52	Small	MZX
Mendi Airport	9.81667	35.0833	Asosa Airport	64.71	Small	NDM
Mizan Teferi	6.95639	35.5556	Tippi Airport	31.46	Small	MTF
Mota Airport	11.0667	37.8833	Mekane Selam	74.5	Small	OTA
Moyale Airport	3.533333	39.05	Neghelli Airport	207.57	Small	MYS
Mui Airport	6	36	Jinka Airport	66.71	Small	MUF
Neghelli Airport	5.28333	39.7	Shakiso Airport	100.04	Small	EGL
Nekemt Airport	9.05	36.6	Buno Bedelle	72.89	Small	NEK
Semera Airport	11.5	41.0833	Combolcha Airport	156.69	Small	SZE
Shakiso Airport	5.733	38.9175	Neghelli Airport	100.04	Small	SKR

Airport Name	**Latitude**	**Longitude**	**Closest Airport**	**Distance (Km) to closest Airport**	**Airport Type**	**IATA**
Soddu Airport	6.83333	37.75	Waca Airport	74.3	Small	SXU
Tippi Airport	7.2025	35.415	Mizan Teferi	31.46	Small	TIE
Tum Airport	9.55	38.6833	Bole International	64.79	Small	TUJ
Waca Airport	7.167	37.167	Jimma Airport	67.58	Small	WAC
Warder Airport	6.966667	45.3333	Geladi Airport	119.62	Small	WRA

Table C.1 List of Airports in Ethiopia