A RELIABLE AND COST-EFFECTIVE MODEL TO ENHANCE THE ROBUSTNESS OF A GEOSTATIONARY SATELLITE CONTROL EARTH STATION SYSTEM

BY

NUR SHAZANA BINTI ABDUL RAHMAN

A thesis submitted in fulfilment of the requirement for the degree of Master of Science in Engineering

Kulliyyah of Engineering
International Islamic University of Malaysia

MAY 2023

ABSTRACT

A ground network of communications satellite system is typically made up of Earth Station(s), Mission Operations Center (MOC), Science Operations Center (SOC), and the supporting infrastructure that connects them all. A ground network grows as more Earth Stations are added, which requires additional considerations to ensure that the MOC can communicate with all the Earth Stations in the network. It also requires continuous upgrade to provide a better reliability for a better performance. The improvements of the reliability of a Geostationary satellite control Earth Station system can be accomplished via redundancies of the subsystems, multiple testing in the planning stage and selection of only the best components for its subsystems. Suitable maintenance activities from time to time also play an important role to prevent the cost blow out and any unwanted failures. Hence, the development of a new reliability model based on identified factors that caused calamity to the system was the main objective of this research. In addition, this research also aims to develop an operational cost model along with the suitable maintenance activities to enhance the robustness of the geostationary satellite control Earth Station system. The models were designed by applying Monte Carlo from MATLAB software. The reliability and cost data that were used for simulations was obtained from MEASAT. Based on the previous studies, configurations with more redundancies in the subsystem can affect the reliability performance, which can decrease the failure rate. At the end of this research, a new reliability model of an Earth Station system which was compared against 2-parallel, 3-parallel, and 4-parallel configurations within the range of affordability (operational cost model) along with the suitable maintenance activities were proposed to enhance the robustness of the geostationary satellite control Earth Station system. The three elements consisting of the reliability model, suitable maintenance activities as well as the operational cost model were integrated together creating a sustainable framework. The obtained results showed that an Earth Station that was configured with the 2-parallel configuration provided the cheapest and optimum reliability system performance even though the 3-parallel and the 4-parallel configurations provided higher reliability. Consequently, the sustainable framework encompassing reliability and cost elements were modelled based on the 2-parallel configuration together with the proposed maintenance activities. Furthermore, root mean square (RMS) values were also calculated for both the reliability and the operational cost models. The results demonstrated that the calculated RMS values for both new reliability and new operational cost models produced the smallest values of 20.84% and 22.82% respectively. Therefore, the calculated RMS values for both reliability and operational cost models showed that the 2-parallel configuration fit to be applied in the Earth Station system design which contributes to the system design with acceptable reliability and most affordable cost.

ملخص البحث

تتكون الشبكة الأرضية لنظام الاتصالات عبر الأقمار الصناعية عادةً من محطة أو محطات أرضية، ومركز ، والبنية التحتية الداعمة التي تربطهم (SOC) ، ومركز العمليات العلمية(MOC) عمليات المهام جميعاً. وتؤدي إضافة المزيد من المحطات الأرضية إلى توسع الشبكة الأرضية، ممّا يتطلب اعتبارات إضافية لضمان إمكانية اتصال مركز عمليات المهام بجميع المحطات الأرضية في الشبكة. كما يتطلب ذلك ترقية مستمرة لتوفير موثوقية أفضل للحصول على أداء أفضل. ويمكن تحسين موثوقية نظام المحطة الأرضية للتحكم في الأقمار الصناعية ثابتة الموقع من خلال إضافة أنظمة فرعية جديدة، وكذلك من خلال الاختبارات المتعددة في مرحلة التخطيط، واختيار أفضل المكونات فقط لأنظمتها الفرعية. كما أنّ أنشطة الصيانة المناسبة من وقت لآخر تلعب دوراً مهماً في منع المغالاة في التكلفة وأي إخفاقات غير مرغوب فيها. ومن ثم، فإن الهدف الرئيسي لهذا البحث هو تطوير نموذج موثوقية جديد يعتمد على العوامل المحددة التي قد تسبب كارثة للنظام. إضافة إلى ذلك، يهدف هذا البحث إلى تطوير نموذج تكلفة تشغيلية جنباً إلى جنب مع أنشطة الصيانة المناسبة لتعزيز متانة نظام المحطة الأرضية للتحكم بالأقمار الصناعية ثابتة الموقع. وقد صمّمت النماذج باستخدام نظام المحاكاة في برنامج (Monte Carlo) كما تم الحصول على بيانات الموثوقية والتكلفة المستخدمة في عمليات المحاكاة .(MATLAB) واستناداً إلى الدراسات السابقة، يمكن أن تؤثر التشكيلات .(MEASAT) من القمر الصناعي التي تحتوي على المزيد من الأنظمة الفرعية على أداء الموثوقية، مما قد يقلل من معدل الفشل. وفي نهاية هذا البحث، تم اقتراح نموذج موثوقية جديد لنظام محطة أرضية تمت مقارنته مع تشكيلات محطات أرضية متوازية ثنائية وثلاثية ورباعية، ضمن نطاق القدرة على تحمل التكاليف (نموذج التكلفة التشغيلية) جنباً إلى جنب مع أنشطة الصيانة المناسبة، بهدف تعزيز متانة نظام المحطة الأرضية للتحكم بالأقمار الصناعية ثابتة الموقع. وقد تم دمج العناصر الثلاثة المكونة من نموذج الموثوقية وأنشطة الصيانة المناسبة بالإضافة

إلى نموذج التكلفة التشغيلية، تم دمجها معاً لإنشاء إطار عمل مستدام. وقد أظهرت النتائج التي تم الحصول عليها أن المحطة الأرضية التي تم تكوينها بالتشكيل المتوازي الثنائي قدمت أداء نظام الموثوقية الأرخص والأمثل على الرغم من أن التشكيلات المتوازية الثلاثية والرباعية أظهرت موثوقية أعلى. وبالتالي، فقد تم تصميم إطار العمل المستدام الذي يشتمل على عناصر الموثوقية والتكلفة بناءً على التشكيل المتوازي الثنائي جنباً إلى جنب مع أنشطة الصيانة المقترحة. علاوة على ذلك، تم حساب قيم جذر متوسط التربيع (**RMS**) لكل من نماذج الموثوقية والتكلفة التشغيلية. وقد أظهرت النتائج أن قيم (**RMS**) المحسوبة لكل من الموثوقية الجديدة ونماذج التكلفة التشغيلية الجديدة أنتجت أصغر قيم **20.84**٪ و المحسوبة لكل من نماذج الموثوقية والتكلفة (**RMS**) **22.82**٪ على التوالي. لذلك، أظهرت قيم التشغيلية أن التشكيل المتوازي الثنائي مناسب ليتم تطبيقه في تصميم نظام المحطة الأرضية، ممّا يساهم في تصميم النظام بموثوقية مقبولة وبتكلفة معقولة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Communication Engineering)

……………………………….
Nadirah Abdul Rahim
Supervisor

……………………………….
Khairayu Badron
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Communication Engineering

……………………………….
Norun Farihah Abdul Malek
Internal Examiner

……………………………….
Ahmad Afif Bin Ahmarofi
External Examiner

This thesis was submitted to the Department of Electrical and Computer Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Communications Engineering)

…………………………………..
Md. Rafiqul Islam
Head, Department of Electrical and Computer Engineering

This thesis was submitted to the Kulliyyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Communications Engineering)

……………………………….
Sany Izan Ihsan
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted for any other degrees at IIUM or other institutions.

Nur Shazana Binti Abdul Rahman

Signature:……………………… Date: 9th May 2023………

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

A SUSTAINABLE FRAMEWORK TO ENHANCE THE ROBUSTNESS OF A GEOSTATIONARY SATELLITE CONTROL EARTH STATION SYSTEM

I declare that the copyright holder of this thesis/dissertation are jointly owned by the student and IIUM.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Nur Shazana Binti Abdul Rahman

……………………………… ……9th May 2023……

Signature Date

This thesis is dedicated to my dearest parents and friends for laying the foundation of what I turned out to be in life.

ACKNOWLEDGEMENTS

Alhamdulillah, all glory is due to Allah, the Almighty, whose Grace and Mercies have been with me throughout the duration of my programme. Although, it has been tasking, His Mercies and Blessings on me to ease the herculean task of completing this thesis.

I wish to express my deepest gratitude to my supervisor Dr. Nadirah Abdul Rahim whose enduring disposition, kindness, promptitude, thoroughness and friendship have facilitated the successful completion of my work. I put on record and appreciate her detailed comments, useful suggestions and inspiring queries which have considerably improved this thesis. Her brilliant grasp of the aim and content of this work led to her insightful comments, suggestions and queries which helped me a great deal. Despite her commitments, she took time to listen and attend to me whenever requested. The moral support she extended to me is in no doubt a boost that helped in building and writing the draft of this research work. I am also grateful to my co-supervisor, Dr. Khairayu Badron, whose support and cooperation contributed to the outcome of this work. I would also like to express my gratitude to Research Management Centre of IIUM for providing monthly stipend and other expenses to me to complete this research successfully.

Also, an utmost appreciation to my special friend, Adib, and both of my parents for their understanding and their prayer to Allah for my success in conducting this research and endless motivation for me to do this research with my best. I owed them for their kindness in helping me to succeed in this journey.

Finally, I want to thank me. I want to thank me for believing in me, doing all this hard work, having no days off and for never quitting. Alhamdulillah!

TABLE OF CONTENTS

Abstract……………………………………………………………………………..ii
Abstract in Arabic……………………………………………………………...iii
Approval Page…………………………………………………………...…..v
Declaration……………………………………………………………...……...vii
Copyright Page……..…………………………………………………..……...viii
Acknowledgements…………………………………………………...……..x
Table of Contents……………………………………….…………………..xi
List of Tables………………………………………………………………...xiii
List of Figures………………………………………………..……………....xiv
List of Abbreviations………………………………………………….…......xvi
List of Symbols……………………………………………………..……..xviii
List of Publications………………………………………………………………..xix

CHAPTER ONE: INTRODUCTION……………………………………………...1
1.1 Background 1
1.2 Problem Statement 2
1.3 Hypothesis..3
1.4 Research Objectives 3
1.5 Research Scopes And Research Data..4
1.6 Thesis Organization 4

CHAPTER TWO: LITERATURE REVIEW……………………………………..5
2.1 Introduction..5
2.2 Earth Station Failures..6
2.3 Basic Earth Station System Model 7
2.3.1 Parallel Networks..9
2.3.2 Redundancy In Design 10
2.3.3 Parallel Structures For Repairable Parts In The Earth Station..........11
2.3 Monte Carlo Simulation...13
2.4 Reliability of A Satellite Control Earth Station 14
2.4.1 Mean-Time-Between Failures (Mtbf)...16
2.5 Operational Cost 17
2.5.1 Affordability of A Satellite Control Earth Station 18
2.6 Maintainability of A Satellite Control Earth Station 22

2.6.1 Preventive Maintenance 22
2.6.2 Corrective Maintenance 23
2.7 Overview of Previous Research Works 23
2.8 Percentage Fractional Error And Root Mean Square (Rms) Error 31
2.9 Chapter Summary 31

CHAPTER THREE: RESEARCH METHODOLOGY 33
3.1 Introduction 33
3.2 Initial Assumptions of Redundancies In An Earth Station System 35
3.3 Initial Assumptions of Maintenance In Earth Station System 35
3.4 How Maintenance Associates With Cost 37
3.5 Maintenance Approaches 39
3.6 Proposed Maintenance Activities 41
3.7 Technical Modelling 42
3.8 Financial Modelling 47
3.9 Chapter Summary 47

CHAPTER FOUR: RESULTS, MODELLING AND DISCUSSION 48
4.1 Introduction 48
4.2 Simulation of Non-Fixed Failure Rate of Rf/Antenna System 48
4.3 Reliability Simulation of An Earth Station System 51
4.4 Affordability Profile Generation 54
4.5 Reliability Model 57
4.6 Operational Cost Model 58
4.7 Validation of Reliability And Operational Cost Models 60
4.8 Maintenance Framework 62
4.9 Chapter Summary 65

CHAPTER FIVE: CONCLUSION AND FUTURE WORK 66
5.1 Research Findings 66
5.2 Research Contribution 67
5.3 Challenges And Future Work 68

REFERENCES 69
APPENDIX B: MATLAB Coding Simulation 73

LIST OF TABLES

Table 2.1	Subsystems in RF/antenna system and its functions.	8
Table 2.2	Affordability Components.	19
Table 2.3	The Overview of Previous Works.	26
Table 3.1	Type of maintenance repair when a subsystem fails.	36
Table 3.2	Time taken for maintenance.	37
Table 3.3	The Required Maintenance Activities by Functional Subsystem	41
Table 3.4	State numbers and their description	42
Table 3.5	State transition details	43
Table 3.6	Subsystem representation in MATLAB matrix form	44
Table 3.7	Brief explanation on technical simulation	44
Table 4.1	The random average failure per year for 2-parallel, 3-parallel, and 4-parallel configurations.	50
Table 4.2	The system reliability of different MTBF for 2-parallel, 3-parallel, and 4-parallel configurations.	53
Table 4.3	The estimated cost consumed per year for 2-parallel, 3-parallel, and 4-parallel configurations.	56
Table 4.4	The comparison of the measured and new reliability value from 2-parallel configuration of MTBF 10 years.	57
Table 4.5	The comparison of the simulated value and new operational cost model value from 2-parallel configuration of MTBF 10 years.	59
Table 4.6	The reliability and operational cost models' percentage fractional error, RMS error calculation and validation.	60
Table 4.7	The proposed maintenance activities.	63

LIST OF FIGURES

Figure 2.1	Satellite control Earth Station system general block diagram.	6
Figure 2.2	Basic satellite Earth station system.	8
Figure 2.3	A 2-parallel configured network.	9
Figure 2.4	A 3-parallel configured network.	10
Figure 2.5	*n*-Parallel Earth Station system model.	11
Figure 2.6	2-Parallel Earth Station System Model.	12
Figure 2.7	3-Parallel Earth Station System Model.	12
Figure 2.8	4-Parallel Earth Station System Model.	13
Figure 2.9	Algorithm Process Flow of Monte Carlo System Analysis	14
Figure 2.10	System Adaptation Cycle	19
Figure 2.11	Affordability Trade Space	20
Figure 2.12	Data processing interaction diagram.	24
Figure 2.13	Sensitivity of MTTF as function of Time.	26
Figure 2.14	Sensitivity of MTTF as function of Failure Rate	26
Figure 2.15	Progression in the statistical analysis of satellite and satellite subsystem failures	27
Figure 3.1	Flowchart of research methodology	34
Figure 3.2	Step function for maintenance repair	36
Figure 3.3	Linear function for maintenance cost	37
Figure 3.4	Cost associated with maintenance categories.	38
Figure 3.5	Overview of maintainability of Earth Station system.	40
Figure 3.6	State diagram for RF/antenna subsystems.	42
Figure 3.7	Flowchart of the technical simulation to determine the Reliability by using Monte Carlo.	44
Figure 4.1	The random failure rate of Earth Station subsystems for 2-parallel configuration with MTBF of 1 year, 3 years, 5 years, 7 years, and 10 years.	49

Figure 4.2	The random failure rate of Earth Station subsystems for 3-parallel configuration with MTBF of 1 year, 3 years, 5 years, 7 years, and 10 years.	49
Figure 4.3	The random failure rate of Earth Station subsystems for 4-parallel configuration with MTBF of 1 year, 3 years, 5 years, 7 years, and 10 years.	50
Figure 4.4	The reliability graph of 2-parallel configuration with MTBF of 1 year, 3 years, 5 years, 7 years, and 10 years.	51
Figure 4.5	The reliability graph of 3-parallel configuration with MTBF of 1 year, 3 years, 5 years, 7 years, and 10 years.	52
Figure 4.6	The reliability graph of 4-parallel configuration with MTBF of 1 year, 3 years, 5 years, 7 years, and 10 years.	52
Figure 4.7	Affordability profile distribution of potential cash flow of Earth Station operating service with MTBF of 10 years for 2-parallel configuration.	54
Figure 4.8	Affordability profile distribution of potential cash flow of Earth Station operating service with MTBF of 10 years for 3-parallel configuration.	55
Figure 4.9	Affordability profile distribution of potential cash flow of Earth Station operating service with MTBF of 10 years for 4-parallel configuration.	55
Figure 4.10	Reliability graph of 2-parallel configuration with 10-year MTBF Earth Station configuration model and measured.	57
Figure 4.11	Operational Cost Model graph of 2-parallel configuration with 10-year MTBF Earth Station configuration model and measured.	59
Figure 4.12	Operational Cost Model exponential graph of 2-parallel configuration with 10-year MTBF Earth Station configuration model and measured.	60
Figure 4.13	Operational Cost Model polynomial graph of 2-parallel configuration with 10-year MTBF Earth Station configuration model and measured.	60

LIST OF ABBREVIATIONS

ACU	Antenna Control Unit
ATL	Acquisition, Technology & Logistic
CAT	Category
COGS	Costs Of Goods Sold
CPU	Central Processing Unit
CW	Clean Wave
DC	Down-Converter
DOD	Department Of Defence
DSS	Dynamic Satellite Simulator
DTH	Direct-To-Home
EHF	Extremely High Frequency
HLA	High Level of Architecture
HPA	High Power Amplifier
INCOSE	The International Council on Systems Engineering
LCC	Life Cycle Cost
LNA	Low Noise Amplifier
M&C	Monitor And Control
MATLAB	Matrix Laboratory
MEASAT	Malaysia East Asia Satellite
MLE	Maximum Likelihood Estimation
MOC	Mission Operations Center
MoEs	Measures Of Effectiveness
MTBF	Mean Time Between Failure
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
OAS	Orbital Analysis Station
PBCM	Performance-Based Cost Modelling

RAM	Reliability, Availability and Maintainability
RF	Radio Frequency
RMS	Root Mean Square
SAC	Equipment Status and Control Station
SCS	Satellite Control Station
SES	Satellite Engineering Station
SG&A	Selling, General, And Administrative
SLA	Service Level Agreements
SMSP	Single-Satellite Multiple-Ground Station Scheduling Problem
SOC	Science Operations Center
SOI	System Of Interest
SOS	System Of Systems
SPN	Stochastic Petri Net
TOC	Total Ownership Cost
TTC	Telemetry, Tracking, And Control
TTF	Time To Failure
TTR	Time To Repair
TVRO	Television Receiver Only
UC	Up-Converter
VSAT	Very Small Aperture Terminal

LIST OF SYMBOLS

R	Reliability
λ	Failure Rate (per hour, h)
M	MTBF (hour, h)
C_M	Maintenance Costs (RM)
C_F	Failure Costs (RM)
P_F	Probability of Failure
ε_f	Percentage Fractional Errors (%)

LIST OF PUBLICATIONS

Scopus Indexed Journal

Nur Shazana Abdul Rahman & Nadirah Abdul Rahim (2023). *Sustainable Framework for A Geostationary Satellite Control Earth Station System Using Parallel Configuration*. International Journal of Electrical Engineering and Informatics (IJEEI), 30(3), pp. 1498-1508. ISSN 2502-4752.

Nadirah Abdul Rahim, Nur Shazana Abdul Rahman, Shiva Abdoli, Subramaniam Jeevan Rao, Mohammed Imtiaz Mohamad Mokhtar (2022). *Analysis of Failure Frequency and Failure Rate of RF/ Antenna Subsystems for an Earth Station System*. NeuroQuantology, 20(10)., pp 3862-3871. ISSN 1303-5150.

Conference Paper

Nur Shazana Abdul Rahman & Nadirah Abdul Rahim (2022). *Analysis of Reliability Prediction and Maintainability Activities of an Earth Station System using Parallel Configurations. 12th International Workshop on Computer Science and Engineering (WCSE 2022)*, 24th – 28th June 2022, Sanya, China.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Over time, communications satellite has been widely used in television, telephone, and internet applications, accommodating over billions of users across the globe. The satellite acquires uplink signal from a transmitting Earth Station which then re-transmits the amplified signal back to at least one Earth Station (Pelton et al., 2013). However, failures that lead to system abnormalities and breakdowns are to be expected. The improvements of the reliability of Earth Station system can be accomplished via redundancies of the subsystems, multiple testing in the planning stage and the selection of only the best components for its subsystems (Bouwmeester et al., 2022).

Suitable maintenance activities of an Earth Station from time to time also play an important role to prevent any unwanted failures. Therefore, in this research, analysis of the Earth Station system reliability is proposed using Monte Carlo simulations from MATLAB software. The parallel configurations which indicate the *n*-redundancies respectively in the Earth Station system are applied to analyse the Earth Station system reliability. In this research, 2-parallel, 3-parallel, and 4-parallel configurations are analysed accordingly. Suitable maintenance activities were proposed based on the suitability of the Earth Station system. The results attained would then show the pattern of reliability between 2-parallel, 3-parallel, and 4-parallel configurations. On top of that, the obtained results are expected to show that the simulation of a configuration with more redundancies in the subsystem can increase the reliability performance, thus lowering the failure rate.

Nonetheless, will the cost increase if redundancies increase? How can we attain the balance between the technical (reliability and operational) and cost? In addition to ensure optimum operational cost allocation, suitable maintenance activities in the Earth Station must be performed once the satellite is launched.

Hence, a new design of a sustainable framework that consists of a reliability model within the range of an affordable operational cost model along with the maintainability framework are proposed to enhance the robustness of a geostationary satellite control Earth Station system. The framework is ought to be capable to sustain the Earth Station system operating at its optimum.

1.2 PROBLEM STATEMENT

Each subsystem in the Earth Station system has its own failure rate. The failure rate is very important to indicate whether the subsystem works or fails throughout the designated mission. Therefore, the question of the reliability and maintainability of the system come into picture. How reliable is the Earth Station system and how is it maintained? The answer to this question is that the design for reliability in the Earth Station system is very crucial because it makes sure that the system runs smoothly without any disruptions. If the system fails, the suitable maintenance activities must be performed to confirm that the system is up and running steadily.

In essence, a typical Earth Station is categorised into three core systems: computer control, baseband and RF/antenna (Ebadi, 2017). Based on the data retrieved from Malaysia East Asia Satellite (MEASAT) Satellite, it can be summarised that failure occurs in the RF subsystems which consist of antenna, uplink and downlink transmit chains. Thus, the design of Earth Station system reliability is crucial in ensuring that the operation service runs smoothly. This could be possible with higher redundancies involved in the system.

Apart from that, most existing reliability models designed by (Bouwmeester et al., 2022) and (Sugama, 2018), are too complex to understand. Hence, in this research, a simple but robust reliability model and suitable maintenance framework are proposed. Additionally, this research is also focused on the operational cost model which informs the system design expert whether the reliability model and the maintenance framework developed are worth to be spent or not.

1.3 HYPOTHESIS

It is hypothesized that by developing a simple but robust reliability model incorporating the failure rate of each subsystem in the Earth Station with a suitable maintenance framework, the breakdown of the Earth Station system can be avoided. Consequently, it also helps in optimising the cost allocation. Hence, these three elements (reliability, maintainability, and operational cost) constitute the sustainable framework which is proposed in this research.

1.4 RESEARCH OBJECTIVES

This research is focused on the Earth Station system configurations: 2-parallel, 3-parallel, and 4-parallel indicate the *n*-redundancies respectively. Hence, the objectives of this research are:

i. To identify the factors that contribute to the problems of Earth Station system failures that can cause cost blow up.
ii. To develop a simple but robust reliability model of the Earth Station system based on which parallel configuration gives the highest reliability.
iii. To propose preventive maintenance activities for Earth Station system.
iv. To develop a suitable operational cost model which helps in setting an optimum cost allocation specifically in maintaining the Earth station system.

1.5 RESEARCH SCOPES AND RESEARCH DATA

This research focuses on the development of a reliability model of a geostationary satellite control Earth Station system focusing on RF and antenna subsystems through MATLAB simulation by using the Monte Carlo generator. Furthermore, only the parallel configurations (2, 3 and 4) are included in the analysis of the reliability to develop a reliability model and the maintenance framework are proposed based on the development of the cost model. In terms of cost modelling, only operational cost is included. The operational cost consists of both operation and maintenance costs which was provided by MEASAT, but the exact amounts were concealed.

1.6 THESIS ORGANIZATION

This thesis is divided into five chapters. Chapter One elaborates on the introduction of the sustainable framework. Furthermore, it also discusses the problem statement, hypothesis, research objectives and research scopes and research data. Chapter Two describes the literature review of the geostationary satellite control Earth Station System and its related topics. Chapter Three explains the research methodology and how the research was conducted in detail. Meanwhile, Chapter Four demonstrates the results, modelling, and discussion. Finally, this thesis is concluded in Chapter Five in which it elaborates on the research contribution and future work that can be carried out to improve the existing research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

A satellite communication system is divided into two stations – Earth Station system and Space Station system. The Earth Station system is also known as a ground station system, consists of tracking, telemetry, and command system (Pratt & Allnutt, 2019). Whereas the Space Station solely consists of the satellites. The Earth Station system is mostly connected by a terrestrial network to the end-user terminal. Similarly, small stations known as Very Small Aperture Terminal (VSAT) are directly connected to the end-user's terminal (Maassen et al., 2017). Stations are categorised by their various size which depending on its traffic volume and type of traffic to be transported on the satellite link. One of its many applications includes Direct-to-Home satellite broadcasting or DTH for short (Rahim et al., 2022). The application functions as the widespread distribution of television signals from geostationary satellites to its many receivers like small dish antennas across the globe (Gandla, 2013).

Although, certain stations can be both transmitter and receiver, there are a few that act as a receiver only or also known as TVRO (television receiver only) stations (Maral et al., 2020). The stations receive downlink signal for a broadcasting satellite system which is a system that distributes data or television signals. Figure 2.1 shows the typical architecture of an Earth Station for both transmitting and receiving, which consists of the user, terrestrial system, Earth Station, and the satellite.