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END-TO-END DVB-S2X SYSTEM DESIGN WITH DEEP LEARNING-BASED CHANNEL ESTIMATION OVER SATELLITE FADING CHANNELS

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By

SUMAYA DHARI AWAD MFAREJ

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

March 2021

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DEDICATIONS

To the soul of my father, the man who is the reason and the motive behind this achievement.

To my mother, for her steadfastness in prayer.

To my husband, for his love and encouragement.

To my kids, Yaseen and Ruwaida: You are the reason that I keep strong.

To my sisters and brother, for their unlimited support.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

END-TO-END DVB-S2X SYSTEM DESIGN WITH DEEP LEARNING-BASED CHANNEL ESTIMATION OVER SATELLITE FADING CHANNELS

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March 2021

Chairman: Prof. Ir. Aduwati Binti Sali, PhD
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Digital Video Broadcasting – Satellite Second generation extension (DVB-S2X) has been introduced with a relatively higher number of modulation schemes and code rates (MODCODs) to satisfy the demand for high data rates and qualified broadcasting services. However, the atmospheric impairments are considered a serious problem in satellite communication in tropical regions, which are mostly characterized by heavy precipitation, especially at high frequencies.

For these reasons, the design of satellite fading channels for tropical regions becomes an urgent necessity not only to study the effect of heavy fading caused by these impairments on the performance of such a satellite system but also to find solutions to enhance the performance of the DVB-S2X system in these heavy fading channels. In this thesis, the contribution can be divided into four main parts:

In the first part, the end-to-end DVB-S2X system with most of its MOCODs and two frame sizes were introduced. Monte Carlo simulation is used to implement the system model with two scenarios; the Additive White Gaussian Noise (AWGN) channel is used in the first scenario to validate the DVB-S2X system by comparing the results with the European Telecommunications Standards Institute (ETSI) standard. In the second scenario, the system is evaluated with a Rician channel which represents the real channel for satellite transmission. Comparisons in bit error rates have been made between those two models to observe the impact for Shannon channel capacity and spectral efficiency for different (MODCODs). Moreover, the study improves the assessment level of DVB-S2X system performance with different types of channels and MODCODs.

The atmospheric impairments on the Ka-band satellite channel are considered in the channel design, especially the rainfall effect, which is the most effective atmospheric

impairment that degrades the system performance. For this reason, two rainy fading channels are designed in the second part of this thesis, one for the tropical region termed as (Tropical channel) and the other for the temperate region termed as (Temperate channel), using real rain data from these two areas.

In the third part, the first full design of the DVB-S2X system with multi-user-multiple-input-single-output (MU-MISO DVB-S2X), with most of its modulation and coding schemes (MODCODs), over rainy fading channels is presented. The proposed model mitigates the fade in heavy fading channels by utilizing zero-forcing beamforming (ZFBF) and semi-orthogonal user selection (SUS) techniques.

Besides, the user scheduling influence on the bit error rate (BER) performance of the MU-MISO DVB-S2X system is tested and compared with the conventional MISO DVB-S2X system. Simulation results show that the proposed system can achieve a significant improvement in terms of BER performance with at least 20 dB for 128 amplitude and phase-shift keying (128APSK) MODCOD over the tropical channel and 14 dB for 32APSK MODCOD over temperate channel when the number of users is six. The BER performance is more improved when the number of users increased to 20. The enhancement in error rates proves that the MU-MISO DVB-S2X system with scheduling can be the key solution for DVB-S2X system performance degradation in fading channels, especially rainy fading channels.

In the fourth part a deep learning (DL) algorithm of channel estimation for two fading channel models, Tropical and Temperate in the satellite communication system is presented. The Normalized Mean Square Error (NMSE) and the BER performances for different DVB-S2X system MODCODs are investigated and the results for these algorithms are compared with the conventional Minimum Mean Square Error (MMSE) and Least Square (LS) channel estimation techniques. Two DL-based channel estimators are proposed termed as (DL_{BLSTM}) and (DL_{GRU}).

The channel estimation results indicate that the adopted DL architectures are more robust than conventional techniques when fewer training pilots are used for both fading channels. Although the conventional algorithm, MMSE, outperforms the proposed algorithms when the number of pilots increased but it is not applicable in real transmission as it is required prior knowledge about the channel statistic which is not the case with DL-based estimators which rely only on the pilots. For example, when the number of pilots $p = 37$, the NMSE performance for the MMSE estimator is 5.147×10^{-4} for the normal frame. Whereas, the DL_{BLSTM} estimator gives slightly lower performance than the MMSE with 7.216×10^{-4}. The DL_{GRU} estimator achieves 8.849×10^{-4} which is the worst performance among all estimators. In addition, the complexity of the proposed schemes is lower than those of competitive algorithms. Finally, we can conclude that DL still has potential although more efficient architectures are required.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKA BENTUK SISTEM DVB-S2X HUJUNG-KE-HUJUNG DENGAN PENGANGGARAN SALURAN BERASASKAN PEMBELAJARAN MENDALAM DI ATAS SALURAN PEMUDARAN SATELIT

Oleh

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Penyiaran Video Digital - Satelit Sambungan generasi kedua (DVB-S2X) telah diperkenalkan dengan jumlah skema modulasi dan kadar kod (MODCOD) yang lebih tinggi untuk memenuhi permintaan untuk kadar data yang tinggi dan perkhidmatan penyiaran yang berkelayakan. Walau bagaimanapun, gangguan atmosfera dianggap masalah serius dalam komunikasi satelit di kawasan tropika, yang kebanyakannya dicirikan oleh hujan lebat, terutama pada frekuensi tinggi.

Atas sebab-sebab ini, reka bentuk saluran pudar satelit untuk kawasan tropika menjadi keperluan mendesak bukan hanya untuk mengkaji kesan pudar berat yang disebabkan oleh gangguan ini terhadap prestasi sistem satelit seperti itu tetapi juga untuk mencari penyelesaian untuk meningkatkan prestasi DVB- Sistem S2X di saluran pudar berat ini. Dalam tesis ini, sumbangan dapat dibahagikan kepada empat bahagian utama:

Pada bahagian pertama, sistem DVB-S2X hujung-ke-hujung dengan sebahagian besar MOCOD dan dua ukuran bingkai diperkenalkan. Simulasi Monte Carlo digunakan untuk menerapkan model sistem dengan dua senario; saluran Additive White Gaussian Noise AWGN digunakan dalam senario pertama untuk mengesahkan sistem DVB-S2X dengan membandingkan hasilnya dengan standard European Telecommunications Standards Institute (ETSI). Dalam senario kedua, sistem dinilai dengan saluran Rician yang mewakili saluran sebenar untuk penghantaran satelit. Perbandingan dalam kadar ralat bit telah dibuat di antara kedua-dua model tersebut untuk melihat kesan kapasiti saluran Shannon dan kecekapan spektrum untuk berbeza (MODCOD). Lebih-lebih lagi, kajian ini meningkatkan tahap penilaian prestasi sistem DVB-S2X dengan pelbagai jenis saluran dan MODCOD. Kerosakan atmosfera pada saluran satelit Ka-band dipertimbangkan dalam reka bentuk saluran, terutamanya kesan hujan, yang merupakan gangguan atmosfera yang paling berke-

san yang menurunkan prestasi sistem. Atas sebab ini, dua saluran hujan yang pudar dirancang di bahagian kedua tesis ini, satu untuk kawasan tropika yang disebut sebagai (saluran Tropika) dan yang lain untuk wilayah beriklim yang disebut sebagai (Saluran suhu), menggunakan data hujan sebenar dari kedua-dua ini kawasan-kawasan. Pada bahagian ketiga, reka bentuk penuh pertama sistem DVB-S2X dengan multi-user-multi-input-single-output (MU-MISO DVB-S2X), dengan sebahagian besar modulasi dan skema pengkodannya (MODCODs), ketika hujan saluran, pudar bentangkan. Model yang dicadangkan untuk mengurangkan fade pada saluran pudar berat dengan menggunakan teknik zero becing forming beamforming (ZFBF) dan semi-orthogonal user (SUS)

Sebagai tambahan, pengaruh penjadualan pengguna terhadap prestasi bit error rate (BER) pada sistem MU-MISO DVB-S2X diuji dan dibandingkan dengan sistem MISO DVB-S2X konvensional. Hasil simulasi menunjukkan bahawa sistem yang dicadangkan dapat mencapai peningkatan yang signifikan dari segi prestasi BER dengan sekurang-kurangnya 20 dB untuk 128 amplitud dan moding pergeseran fasa (128APSK) di atas saluran tropika dan 14 dB untuk 32APSK MODCOD di atas saluran sedang apabila bilangan pengguna adalah enam. Prestasi BER lebih baik apabila jumlah pengguna meningkat menjadi 20. Peningkatan pada kadar ralat membuktikan bahawa sistem MU-MISO DVB-S2X dengan penjadualan dapat menjadi penyelesaian utama untuk penurunan prestasi sistem DVB-S2X dalam saluran yang semakin pudar, terutama hujan pudar saluran.

Di bahagian keempat algoritma pembelajaran mendalam (DL) estimasi saluran untuk dua model saluran pudar, Tropical dan Temperate dalam sistem komunikasi satelit disajikan. Ralat Persegi Min Normalisasi (NMSE) dan persembahan BER untuk MODCOD sistem DVB-S2X yang berbeza disiasat dan hasil untuk algoritma ini dibandingkan dengan teknik anggaran Ralat Minimum Min Square (MMSE) dan Least Square (LS) konvensional. Dua penganggar saluran berasaskan DL dicadangkan disebut sebagai (DL_{BLSTM}) dan (DL_{GRU}).

Hasil anggaran saluran menunjukkan bahawa seni bina DL yang diadopsi lebih mantap daripada teknik konvensional apabila pilot latihan yang lebih sedikit digunakan untuk kedua-dua saluran yang semakin pudar. Walaupun algoritma konvensional, MMSE, mengungguli algoritma yang dicadangkan apabila bilangan juruterbang meningkat tetapi ia tidak berlaku dalam transmisi sebenar kerana diperlukan pengetahuan sebelumnya mengenai statistik saluran yang tidak berlaku dengan penganggar berdasarkan DL yang hanya bergantung pada juruterbang. Contohnya, apabila bilangan juruterbang $p = 37$, prestasi NMSE untuk penganggar MMSE adalah 5.147×10^{-4} untuk bingkai biasa. Manakala, penganggar DL_{BLSTM} memberikan prestasi yang sedikit lebih rendah daripada MMSE dengan 7.216×10^{-4}. Penganggar DL_{GRU} mencapai 8.849×10^{-4} yang merupakan prestasi terburuk di antara semua penganggar. Di samping itu, kerumitan skema yang dicadangkan lebih rendah daripada algoritma persaingan. Akhirnya, kita dapat menyimpulkan bahawa DL masih berpotensi walaupun diperlukan seni bina yang lebih cekap.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APSK	Amplitude and Phase Shift Keying
ADAM	Adaptive Moment Estimation
AWGN	Additive White Gaussian Noise
BBFRAME	Base Band Frame
BCH	Bose–Chaudhuri–Hocquenghem
BER	Bit Error Rate
BLSTM	Bidirectional Long-Short Term Memory
BPSK	Binary Phase Shift Keying
CSIT	Channel State Information at the Transmitter
DL	Deep Learning
DNN	Deep Neural Network
DPC	Dirty Paper Coding
DVB-C	Digital Video Broadcasting for Cable
DVB-H	Digital Video Broadcasting for Handheld
DVB-RCS	Digital Video Broadcasting for Return Channel Satellite services
DVB-S	Digital Video Broadcasting for Satellite-First Generation
DVB-S2	Digital Video Broadcasting for Satellite-Second Generation
DVB-S2X	Digital Video Broadcasting for Satellite-Second Generation Extension
DVB-SH	Digital Video Broadcasting for Satellite and Handheld services
DVB-T	Digital Video Broadcasting for Terrestrial

ELG	Electronic Launching Group
ETSI	The European Telecommunications Standards Institute
FECFRAME	Forward Error Correction Frame
FER	Frame Error Rate
FLOP	Floating Point Operation
FMT	Fade Mitigation Techniques
GEO	Geosynchronous
GRU	Gated Recurrent Unit
GW	Gate Way
IUI	Inter-User Interference
ITU-R	International Telecommunication Union Radiocommunication Sector
LDPC	Low Density Parity Bits
LLR	Log Likelihood Ratio
LOS	Line Of Sight
LS	Least Square
LSTM	Long-Short Term Memory
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMSE	Minimum Mean Square Error
MODCOD	MODulation and CODing
MRT	Maximum Ratio Transmission
MU	Multi User
NMSE	Normalized Mean Square Error
NN	Neural Network
OB	Opportunistic Beamforming

OFDM	Orthogonal Frequency Division Multiplexing
PLFRAME	Physical Layer Frame
PRBS	Pseudo Ramdom Binary Sequence
QPSK	Quadrature Phase Shift Keying
RNN	Recurrent Neural Network
RRC	Root Raised Cosine
R-ZF	Regularized Zero Forcing
SDMA	Spatial Division Multiple Access
SF	Super Frame
SFFI	Super Frame Format Indicator
SGD	Stochastic Gradient Descant
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SOF	Start Of Frame
SOSF	Start Of Super Frame
SUS	Semi-ortogonal User Selection
THP	Tomlinson Harashima Precoding
UWA	Under Water Acoustic
VH-SNR	Very High-SNR
VL-SNR	Very Low SNR
VSAT	Very-Small-Aperture Terminal
WH	Walsh Hadamard
ZFBF	Zero Forcing Beamforming

LIST OF SYMBOLS

h_R	The mean annual rain height above mean sea level
h_0	The $0°C$ iso therm height
L_s	The slant path length
h_s	Earth station height above sea level
Θ	The path elevation angle
L_G	The horizontal projection
$R_{0.01}$	Rainfall rate at $\mathscr{P} = 0.01\%$
γ_R	The specific attenuation
κ	The frequency dependent coefficient
τ	polarization tilt angle relative to the horizontal
$r_{0.01}$	The horizontal reduction factor
$v_{0.01}$	The vertical adjustment factor
φ	The latitude of The earth station in degrees
L_E	The effective path length
$A_{0.01}$	The predicted rain attenuation
$A_{\mathscr{P}}$	The estimated rain attenuation
A_{rain}	The calculated rain attenuation
L_Q	The total columnar content of liquid water
E_l	The specific attenuation coefficient
A_{cloud}	The calculated cloud attenuation
A_{scint}	The calculated scintillation attenuation
σ_s	The standard deviation
A_{Gases}	The calculated Gases attenuation
γ_{WV}	The specific attenuation value of water vapor
γ_O	The specific attenuation value of oxygen

L_{WV}	The effective path length of water vapor
L_O	The effective path length of oxygen
N_t	No. of transmit antennas
$\boldsymbol{W}_0$	Unnormalized precoding matrix
$\boldsymbol{H}$	Downlink channel matrix
$\boldsymbol{W}_{zf}$	The normalized ZFBF matrix
$\hat{\boldsymbol{h}}$	The estimated channel response
$\hat{\boldsymbol{h}}_{LS}$	The LS estimated channel response
$\boldsymbol{y_p}$	The received pilot symbols
$\boldsymbol{x_p}$	The transmitted pilot symbols
$\hat{\boldsymbol{h}}_{MMSE}$	The MMSE estimated channel response
$\boldsymbol{R}_{hh}$	The auto correlation matrix
σ_n^2	The noise variance
x_t	The input of the DL cell
h_{t-1}	The previous output of the DL cell
$\boldsymbol{h_t}$	The hidden state
$\boldsymbol{c_t}$	The memory cell
$\sigma(\cdot)$	Sigmoid activation function
$\tanh(\cdot)$	Hyperbolic tangent activation function
$\boldsymbol{W}_{xi}$	Weight parameter
$\boldsymbol{b}_i$	Bias parameter
$\boldsymbol{W}_h$	Weight parameter
$\boldsymbol{b}_h$	Wias parameter
$\boldsymbol{W}_{xf}$	Weight parameter
$\boldsymbol{W}_{hf}$	Weight parameter
$\boldsymbol{b_o}$	Bias parameter

$\boldsymbol{W}_{xo}$	Weight parameter
$\tilde{\boldsymbol{h}}$	The candidate hidden state
$\boldsymbol{W}_{xc}$	Weight parameter
$\boldsymbol{W}_{hc}$	Weight parameter
$\boldsymbol{b_c}$	Bias parameter
$\boldsymbol{W}_{xr}$	Weight parameter
$\boldsymbol{W}_{xz}$	Weight parameter
k_{bch}	Size of frame before bose-chaudhuri-hocquenghem (BCH) encoder
$m(x)$	Message signal
$g(x)$	The generator polynomial
n_{ldpc}	Size of frame after low density parity check (LDPC) encoder
χ	M-APSK constellations
E_s/N_o	The symbol energy to the noise power
E_b/N_o	The bit energy to the noise power
R_c	The code rate
M	The modulation order
h_{LOS}	The line of sight component of h_{Rice}
h_{NLOS}	The scattered component of h_{Rice}
h_{Rice}	Rician channel
K_r	The Rician factor
K	No. of users
a_τ	The τ-th signal constellation
γ_k	The effective channel gain of the k-th user
χ_j^0	The subsets of the constellation candidate
$\tilde{\boldsymbol{h}}_k$	The corresponding rain fading coefficients

$b_{max}(k, j)$	The free space losses for the k-th user in the j-th beam
k_b	Boltzmann constant
$d_{k,j}$	The distance for the k-th user from the center of the j-th beam
d_0	The distance between the GEO orbit and the earth's surface
T	The receiver noise temperature
G_R^k	The k-th user receive antenna gain
Θ_{3dB}	The angle which corresponds to 3-dB power loss
J_1	The first-kind Bessel function of order 1
u	The first-kind Bessel function of order 3
G_s^j	The j-th beam transmit antenna gain
Λ_{zf}	The scheduled users set
$\boldsymbol{Z}_i$	Data blocks of length
$\boldsymbol{Z}_p$	Pilot blocks of length
Θ	Optimized parameter
$\boldsymbol{X}_{in}$	The input vector to the NN
$\hat{\boldsymbol{h}}_p^{LS}(\ell)$	The estimated value of the channel at the pilot locations
$\boldsymbol{y}(\ell)$	The received signal of ℓ-th frame
Θ_T	The trained parameters
$\hat{h}$	The estimated channel
i_s	Input size of DL estimators
h_s	Hidden size of DL estimators
o_s	Output size of DL estimators
n_h	The number of hidden layers

CHAPTER 1

INTRODUCTION

This chapter presents an overview of the research aspects and architecture. The overview of the satellite system and channel modeling in this system is presented taking into account the ideology with the drawbacks that motivated doing this research. The overview discusses how the problem statements were formed through satellite communication technology development and became significant before listing the problems that are currently failed to be solved. The research scope and study module are then discussed before presenting the research aim and objectives. A brief methodology to overcome the aforementioned problems and to achieve the research objectives is then introduced. Finally, the research contributions are enlisted before ending the chapter with the thesis organization.

1.1 Background

DVB-S2X was presented in 2014 [1] to extend the range of operations for DVB-S2 [2] with a very low-SNR (VL-SNR). Particularly, DVB-S2X extends the functionality in the noise compromised environments, low power applications such as very-small-aperture terminal (VSAT) networks, and a very high-SNR operation range (VH-SNR). This improves the throughput on the high-capacity trunk and contribution links. Moreover, DVB-S2X enhanced the physical layer signaling to provide a finer granularity of operative points (i.e. more MODCODs), and more flexibility concerning optimizing channel usage. DVB-S2X allows the use of reduced roll-off factors to decrease the occupied bandwidth and to optimize satellite transmissions in the linear channel as the case of multi-carrier per transponder in Ka-band [3].

Fixed satellite communication systems above 10 GHz operate under a line of sight (LOS); the satellite channel essentially corresponds to an additive white gaussian noise (AWGN) channel. However, channel and propagation characteristics are the major constituents of a channel matrix at Ku and Ka bands, which are subjected to various atmospheric fading mechanisms originating in the troposphere that severely degrade the system performance and availability [4].

The rain at Ku and Ka-bands have a paramount impact on signal attenuation in space, followed by clouds, water vapor, and oxygen as a minor effect on signal level variation [5, 6, 7]. Consequently, channel impairments increase the need for developing channel models to predict the atmospheric induced fade level as well as proposing a proper fade mitigation technique (FMT). Furthermore, the atmospheric variations increased in the tropical regions compared to the temperate areas due to their different weather parameters [5, 8, 9]. Moreover, modern satellite communication techniques, particularly the FMT, require an accurate satellite channel model suitable for highly natural tropical weather dynamics [10]. The channel dynamics in tropical environments accompanied by the lack of accurate and reliable channel models for satellite networks in tropical regions increase the need to develop such a channel model that is related to tropical regions.

With the fast development of satellite technology and the increasing demand for high data rate broadband services in satellite communications, multi-beam satellite systems in concurrence with aggressive frequency re-use are the most proper candidates for the next generation satellite communications[11],[12].

In this context, MU-MISO techniques with precoding techniques are introduced to manage interferences with the assistance of the new superframe (SF) of DVB-S2X [1], which was designed to be suitable for precoding techniques [13]. DVB-S2X has been introduced recently with its novel superframe structure, which is a key enabler for applying interference management techniques, such as precoding, to multi-beam high throughput geosynchronous (GEO) satellite systems operating in the Ka-band.

Satellite channels fall within the category of fading channels, i.e., channels evolving with time with responses fluctuating in such a way that the receiver needs to keep track of those changes. Channel tracking can be used for power control purposes and adaptive coding and modulation, and the channel estimates can be used for equalization in frequency-selective channels, in such a way that the quality of the channel estimates has an important effect on the overall receiver performance [14, 15]. For a coded system such as the DVB-S2X system, channel estimation is essential for coherent detection and demodulation. The heavy fading due to atmospheric impairments that the satellite channels suffer from especially in tropical regions at high frequencies rise the need for efficient channel estimation algorithms in such systems.

1.2 Problem Statements

The problems related to satellite communication in this thesis are as follow:

- The existing end-to-end DVB-S2X system models only consider AWGN channel [16] which is not sufficient to reflect the actual performance of satellite channels. Therefore, it is important to model this system with more realistic fading channel models.
- The tropical regions suffer from distinctive weather impairments, especially at high frequencies, thus, it is important to design channel models which consider the heavy fading caused by these impairments to investigate the performance of the DVB-S2X system over these channels at Ka-band.
- The existing MU-MISO-DVB-S2X investigate the sum-rate performance only [12, 13, 17]. However, it is important to exploit multi-user diversity for this

system to mitigate the effect of heavy fading and to test the error performance of this system with this kind of channels and maintain high signal quality.

- The presence of time-varying and heavy fading due to the atmospheric impairments, especially at high frequencies, add more complexity to the channel estimation. The conventional algorithms in the DVB-S2X system rely on the pilot-aided channel estimation algorithms which are either not applicable in real transmission due to high complexity and the need for prior knowledge of the channel statistics such as the MMSE or the LS estimator.

1.3 Research Aim and Objectives

- To provide end-to-end DVB-S2X system design over Rician fading channel and compare the performance with the existing model over AWGN channel.
- To design two satellite fading channels for tropical and temperate regions, based on actual data measurements. The designed channels consider the significant weather impairments in tropical and temperate regions at Ka-band. The performance of the DVB-S2X system is investigated with these channels and compared with the Rician fading channel.
- To propose a fade mitigation model for multi-beam satellite (MISO-DVB-S2X) in which multi-user diversity gain is exploited to mitigate the effect of heavy fading channels in tropical and temperate environments.
- To integrate the existing DVB-S2X with deep learning-based channel estimators which are more robust with less complexity than the conventional methods.

1.4 Research Scope and Study Module

This work is dedicated to studying the DVB-S2X satellite system over fading channels. In particular, the full system design of DVB-S2X is introduced in which: Firstly, the system performance in terms of bit error rate (BER) and sum-rate is investigated, tested over Rician fading channel, and compared with the conventional AWGN channel. Secondly, the SISO system is extended to the MISO system and a new MISO fading channel design is introduced for two regions tropical and temperate. For this system, the multiuser diversity gain is exploited to mitigate the effect of heavy fading channels and hence enhancing the performance of the DVB-S2X system. Thirdly, a new channel estimation strategy based on deep learning is presented for the DVB-S2X system to enhance the BER performance over fading channels.

The summary of chosen approaches in this thesis is illustrated in Figure 1.1, where the solid lines along with the colored boxes denote the followed direction to achieve determined objectives, and the uncolored boxes show the other research directions which are not covered in this thesis.

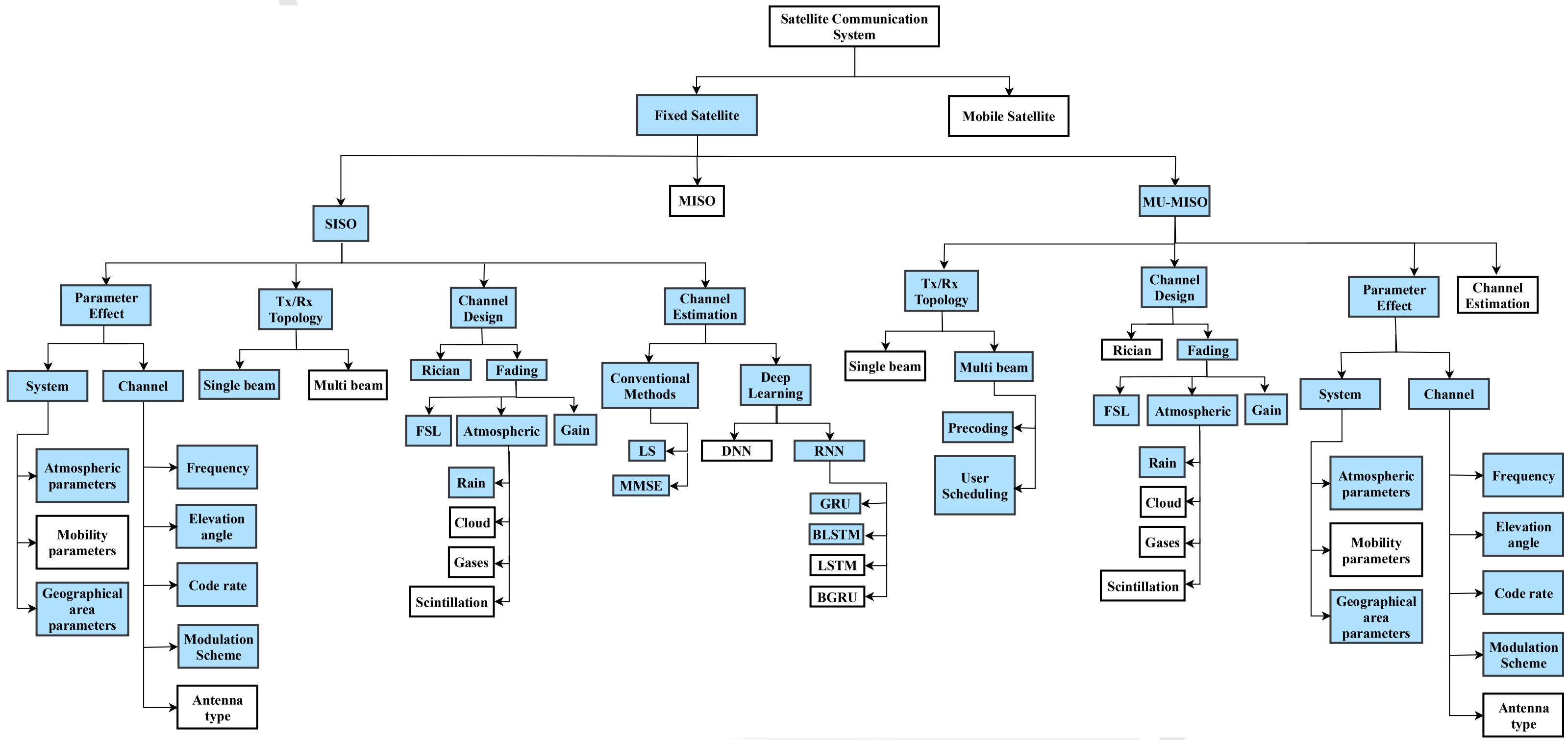

Figure 1.1: Study Module

1.5 Brief Methodology

Based on the aforementioned four specific objectives, the method used to achieve the main aim of this thesis is divided into three stages as shown in Figure 1.2.

In the first stage, a full DVB-S2X system design over the AWGN channel is required to validate the system model with the error performances of the ETSI standard then the design is developed with a Rician fading channel. The performance of the DVB-S2X system over the Rician fading channel is investigated and compared with the AWGN channel in terms of BER and sum-rate. The details of this stage are presented in chapter 3.

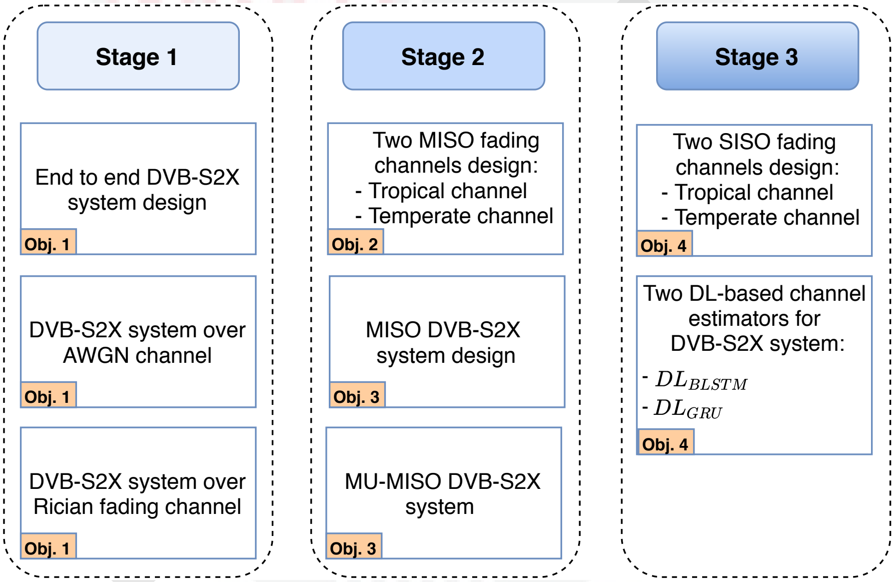

Figure 1.2: Methodology Stages

More realistic scenarios are taken into considerations in the second stage, these scenarios include the effect of the atmosphere, frequency, and free space losses in satellite fading channel design. In particular, the rainfall rates of two regions with different weather conditions are utilized in the channel design; tropical region, and temperate region, to study the effect of atmospheric impairments on DVB-S2X system performance especially the heavy fading caused by rain in tropical regions that suffer from worse climatic conditions compared to the temperate regions.

Moreover, the Multiuser MISO DVB-S2X system is designed to test and enhance the BER performance of the system over the tropical and temperate fading channels by mitigating the effect of fading using multiuser diversity gain. The details of this stage from the MISO fading channels design to the MISO system design are introduced in chapter 4.

Finally, as the DVB-S2X system is a coded system, channel estimation is very important for coherent detection in such a system. Therefore, a new DVB-S2X system model with DL-based channel estimators is introduced in the third stage. Specifically, two DL-based estimators termed, DL_{BLSTM} and DL_{GRU}, are designed and the performance is tested with the tropical and temperate fading channels in terms of BER and normalized minimum mean square error (NMSE) and compared with conventional estimators. The details of this stage are presented in chapter 5.

1.6 List of Contributions

The main contributions of this thesis can be summarized as follows:

- The absence of adapting full MODCODs related to the DVB-S2X model with its frame sizes, to the best of our knowledge, makes the models proposed in the previous studies not valid. Consequently, growing demand to propose a valid DVB-S2X simulation model that is equivalent to the DVB-S2X standard with its MODCODs was established. Moreover, proposing DVB-S2X simulation is needed to be evaluated in satellite rainy fading channel. For these reasons, This thesis presents and validates the DVB-S2X simulation model that considers most of the MODCODs presented in the DVB-S2X standard. Moreover, the performance of the proposed model is investigated with the Rician fading channel in terms of BER and sum-rate performances taking into account two frame sizes: normal and short.

- The atmospheric impairments are considered a serious problem in satellite communication in tropical regions, which are mostly characterized by heavy precipitation, especially at high frequencies. For this reason, we introduce two rainy fading channel models, the first model is designed for tropical regions (high-fading channel termed as Tropical channel), and the second model is designed for temperate regions (low-fading channel termed as Temperate channel). Real measured rain data for two cities are used in our channel models; Penang-Malaysia [18] and Athens-Greece [19] to represent the tropical and temperate regions, respectively.

- Propose a full MU-MISO-DVB-S2X system with most DVB-S2X MODCODs for a multi-beam satellite communication system works at Ka-band using zero-forcing beamforming (ZFBF) technique and semi-orthogonal user selection (SUS) scheduling algorithm[20]. In the previous works, only throughput performance is considered for DVB-S2X, which does not require a full system design. The BER performance of our proposed MU-MISO-DVB-S2X system using the designed channel models is investigated to give a prior visualization about DVB-S2X MODCODs functionality and error rates in these areas.

- Two DL-based channel estimators, termed as DL_{BLSTM} and DL_{GRU}, are proposed for a satellite communication system over two rainy fading channels (tropical and temperate). The performance of the proposed estimators are evaluated in terms of BER and NMSE performances with different MODCODs with code rates utilizing tropical and temperate channels to examine the robustness of the proposed estimators in these kinds of channels. Besides, the complexity of the proposed estimators is analyzed and compared with conventional estimators' complexity. Moreover, the effect of the channel coding technique on the performance of the proposed system with DL-based estimators is investigated and the effect of low-density bit (LDPC) decoder on the BER performance is explored with a different number of the decoder iterations. Finally, the thesis investigates the effect of frame length on the proposed estimators' performance using two frame sizes: normal size (64800) bits and short size (16200) bits.

1.7 Thesis Organization

The thesis is structured into six chapters which organized as follows:

Chapter1 This chapter provides an overview of the DVB-S2X system, satellite channel characteristics, and drawbacks, and enabling technologies in the satellite system. Then, the motivation for the study, statement of the problems, research scope, and study module, aim of the research and the objectives, a brief methodology are presented before ending with a list of major contributions of the study.

Chapter 2 provides an overview of the theories used in satellite channel analysis and modeling. This also includes discussing the effects of transmission parameters, atmospheric (rain, cloud, tropospheric scintillation, and water vapor). The precoding technique in multi-beam satellite system and channel estimation methods are introduced in this chapter with a review of the previous works.

Chapter 3 A full DVB-S2X system design is implemented in this chapter with two types of channels: the AWGN channel is considered in the beginning to validate the system model and then the system performance is investigated with the Rician fading channel in terms of BER and sum-rate. The results show a comparison of the system performance with these kinds of channels.

Chapter 4 MU-MISO-DVB-S2X system with perfect CSI is introduced in this chapter. The effect of precoding on the performance of the multi-beam satellite system is investigated with two fading scenarios. Two satellite fading channels are designed one represents heavy fading termed as Tropical channel and the other represents low fading termed as Temperate channel. Multiuser diversity gain is also explored in this chapter and the effect of these techniques on the BER performance of the DVB-S2X system over fading channels is investigated.

Chapter 5 presents a new DVB-S2X system model with DL-based channel estimators. As perfect CSI is assumed in chapters 3 and 4, this chapter considers a more realistic assumption with two-channel estimators are proposed to estimate the satellite fading channel using deep learning methods. The performance of the proposed system with these two estimators is tested in terms of BER and NMSE. A comparison with the conventional methods is done in this chapter. Moreover, the performance of the proposed estimators are investigated with two different fading scenarios utilizing two fading channels; the Tropical channel and the Temperate channel.

Chapter 6 concludes this thesis and suggests some recommendations for future works.

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LIST OF PUBLICATIONS

The following are the list of publications that arise from this study.

[1] **Awad, Sumaya D.**, A. Sali, Ali M. Al-Saegh, RSA Raja Abdullah, and J. S. Mandeep. "On Capacity and Error Performance of DVB-S2X System Over Rician Fading Channel." In 2019 6th International Conference on Space Science and Communication (IconSpace), pp. 68-72. IEEE, 2019.

[2] **Awad, Sumaya D.**, Aduwati Sali, Ali M. Al-Saegh, Mohanad M. Al-Wani, RSA Raja Abdullah, and Mandeep SJ Singh. "Beamforming and Scheduling Techniques for Multibeam DVB-S2X Over Rainy Fading Satellite Channel." IEEE Access 8 (2020): 41116-41127.

[3] **Awad, Sumaya D.**, Aduwati Sali, Ali M. Al-Saegh, Mohanad M. Al-Wani, RSA Raja Abdullah, and Mandeep SJ Singh. "Deep Learning-based Channel Estimation for DVB-S2X System over Satellite Fading Channels." IEEE Transactions on Broadcasting (2020). Submitted.

[4] M. M. Al-Wani, A. Sali, **Awad, Sumaya D.**, N. K. Noordin, S. J. Hashim, C. Y. Leow, and Z. Ding, "Interference Cancellation via D2D CSI Sharing for MU-MISO-NOMA System with Limited Feedback," IEEE Transactions on Vehicular Technology (2020). Accepted.

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