AFFINE-BASED TIME-SCALE ULTRA WIDEBAND WIRELESS CHANNEL SIMULATOR FOR TIME-VARYING COMMUNICATION ENVIRONMENT

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To my beloved supervisors, families and friends

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ABSTRACT

Wireless communication systems require reliable wireless link to provide high quality services for all subscribers around the world. This can be ensured by using a combination of different techniques and technologies whose performance depend on wireless channel. Therefore, an appropriate channel model based on affine approach needs to be developed to describe its performance, availability, and wide range assessments in term of Ultra Wideband (UWB) propagation characteristics. In order to develop a future communication system, knowing the channel behaviour is important to seamlessly integrate many different communication systems and enhance services to users. In a typical laboratory environment, knowledge of channel behaviour is obtained from channel simulators which are designed to mimic the physical channel. The Fourier-based channel eigenstructure employed in designing most conventional simulators and their applications for UWB channels are limited due to wider bandwidth. Therefore, by considering affine-based time-scale operator, a discrete channel model is developed. The UWB channel simulator is developed based on affine time-scale channel model. The model and simulator are developed by using LabVIEW® software platform. Then, the developed UWB simulator is implemented on Field-Programmable Gate Array (FPGA) hardware platform. This UWB channel simulator is designed for short distance, at range (0-30m) with the frequency range at (3.1-5.3GHz). This simulator is also be simulated for different channel parameters such as different operating environment for indoor and/or outdoor to observe its performance. The channel effect toward signals is obtained by analyzing the simulation and the measurement results of the root means square (RMS) delay spread. The received signal, power delay profile and RMS delay spread are presented to evaluate the UWB channel simulator performance. The RMS delay spread for non line-of-sight (NLOS) is obtained around 1.8843ns and LOS is around 1.6894ns. It shows that RMS delay spread for NLOS is high than the LOS. The maximum RMS delay spread for indoor and outdoor environments are 4ns and 7ns, respectively. The difference in the RMS delay spreads describes different propagation phenomenon operating environment. In addition, these numerical values indicate the UWB channel simulator performance for small-scale fading. Affine shows a flexible approach in analyzing the non-stationary environment compared to Fourier analysis and Fourier analysis needs to count every frequency change and may increase system complexity. The results are validated based on measurement and comparison from previous work. Finally, the UWB channel simulator has been implemented into FPGA device as a UWB channel simulator-hardware platform.

ABSTRAK

Sistem komunikasi tanpa wayar memerlukan kebolehan pautan tanpa wayar untuk menyediakan kualiti perkhidmatan yang tinggi terhadap semua pelanggan di seluruh dunia. Ini dapat dicapai dengan menggunakan gabungan teknik dan teknologi yang berbeza di mana prestasinya bergantung kepada saluran tanpa wayar. Oleh itu, model saluran yang sesuai diperlukan seperti memiliki kadar data yang tinggi, kebolehsediaan dan penilaian pelbagai. Dalam usaha membangunkan satu sistem komunikasi masa depan, mengetahui tingkah laku saluran membolehkan kita untuk mengintegrasikan dengan lancar, menyediakan perkhidmatan sistem komunikasi yang berbeza dan meningkatkan perkhidmatan kepada pengguna. Dalam persekitaran makmal, pemerolehan pengetahuan tentang saluran diperolehi daripada penyelaku saluran yang direka berdasarkan fizikal saluran yang dikehendaki. Disebabkan batasan saluran struktur eigen Fourier yang telah digunakan dalam reka bentuk penyelaku secara konvensional adalah terhad dan penggunaan untuk saluran jalur lebar juga terhad. Berdasarkan pengendali skala masa afin saluran diskret direka, saluran ini direka untuk penggunaan penyelaku saluran jalur lebar dan juga boleh digunakan untuk saluran radio yang lain, sama ada jalur lebar atau jalur sempit. Semua program dan simulasi yang dibangunkan dalam perisian LabVIEW®. Penyelaku direka dan kemudiannya dilaksanakan pada binaan perkakasan tata susunan get boleh aturcara medan. Kesan saluran ke atas isyarat diperolehi dengan menganalisis simulasi dan keputusan pengukuran parameter saluran. Saluran ini direka bentuk bagi jarak pengukuran yang pendek sekitar (0-30m) dengan frekuensi (3.1-5.3GHz). Saluran ini juga dianalisis dalam persekitaran yang berbeza iaitu persekitaran luar dan persekiran dalam. Kesan saluran dikenalpasti dengan menganalisis keputusan rebakan lengah punca min kuasa dua daripada simulasi dan pengukuran. Isyarat yang diterima, profil kelewatan kuasa dan rebakan lengah punca min kuasa dua yang diperolehi menentukan keberkesanan saluran jalur lebar itu. Rebakan lengah punca min kuasa dua untuk bukan garis nampak adalah 1.8843ns dan garis nampak sebanyak 1.6894ns. Rebakan lengah punca min kuasa dua ini menunjukkan bahawa bukan garis nampak adalah lebih tinggi berbanding garis nampak. Manakala rebakan lengah punca min kuasa dua yang maksimum untuk persekitaran dalam dan luar masing-masing adalah 4ns dan 7ns. Rebakan lengah punca min kuasa dua yang berbeza menunjukkan fenomena persekitaran yang berbeza. Selain itu, nilai-nilai yang diperolehi daripada penyelakuan ini menunjukkan bahawa saluran jalur lebar dikategorikan sebagai saluran skala kecil. Afin menunjukkan bahawa saluran yang direka adalah sangat fleksibel di mana dapat digunakan dalam pelbagai persekitaran dan fenomena cuaca berbanding Fourier. Berdasarkan Fourier setiap frekuensi yang berubah disebabkan persekitaran hendaklah dikira mengikut perubahan nilai frekuensi dan menyebabkan rekaan saluran menjadi lebih rumit. Keputusan saluran ini disahkan dan dibandingkan dengan pengukuran dan perbandingan dengan keputusan penyelidikan yang lepas. Akhirnya, rekaan penyelaku saluran ini di pindahkan ke dalam bentuk perkakasan yang dikenali sebagai tata susunan get boleh aturcara medan penyelaku saluran.

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$a(t)$ - Amplitude
B_C - Coherence bandwidth
B_f - Fractional bandwidth
d - Separation distance
G_1 - Antenna gain
h_t - Antenna height of transmitter
h_r - Antenna height of receiver
m - Scale
n - Actual delay
P_t - Transmitted power
P_0 - Power at a distance d_0
s_Δ - Scale sizes
τ_Δ - Fixed delay
$x(t)$ - Transmitted signal
λ - Wavelength
$\Delta m\tau$ - Metric separation
$\Delta \mathrm{t}$ - Time difference variable
$\mathfrak{f}_{\tau,s}(t)$ - The eigenfunction
$\mathfrak{f}(t)$ - Mother function
τ - Time shifting, time delay
s - Time scaling
α - The path loss exponent

χ	-	Effect of shadowing
σ	-	Standard deviation
ADC	-	Analogue Digital Converter
AOA	-	Angle of Arrival
AWGN	-	Additive White Gaussian Noise
BW	-	Bandwidth
CWT	-	Continuous Wavelet Transform
DAC	-	Digital Analogue Converter
dB	-	Decibel
DSP	-	Digital Signal Processing
F	-	Frequency
FCC	-	Federal Communication Commission
FIR	-	Finite Impulse Response
FPGA	-	Field Programmable Gate Array
GSM	-	Global System for Mobile Communication
IIR	-	Infinite Impulse Response
ISI	-	Intersymbol Interference
LOS	-	Line of Sight
LTE	-	Long Term Evaluation
LTV	-	Linear Time-Varying
NB	-	Narrowband
NLOS	-	Non Line of Sight
Non-WSSUS	-	Wide Sense Nonstationary Uncorrelated Scattering
PC	-	Personal Computer
RMS	-	Root Mean Square
RX	-	Receiver
S-V	-	Saleh-Valenzuela
TOA	-	Time of Arrival
TOD	-	Time of Departure
TF	-	Transfer Function

TX - Transmitter
UMTS - Universal Mobile Telecommunication System
US - Uncorrelated Scattering
VI - Virtual Instrument
WB - Wideband
WSS - Wide Sense Stationary
WSSUS - Wide Sense Stationary Uncorrelated Scattering
UWA - Underwater Acoustic
UWB - Ultra Wideband
3D - Three Dimensional
2D - Two Dimensional

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CHAPTER 1

INTRODUCTION

1.1 Background

The performance of wireless communication system mostly depends on the channel, which allows the transmitted signal to travel and reach the receiver properly. Therefore, an appropriate channel needs to be modeled that describes the operating environments. Such channel model enables it to reduce the system complexity and achieve the system performance. In order to evaluate the effectiveness of the channel model, a simulator must be developed. Therefore, the function of a simulator is generally to simulate the channel model. The channel simulator is used for simulating the channel model due to the environment of interest. It is also used to reproduce the channel model based on the defined environment. Other than that, it is applied for evaluating the channel behaviour due to the propagation medium. The channel simulator also provides a fast performance evaluation.

The existing channel simulator such as the radio frequency (RF) channel simulator that has been designed by Hewlett Packard (HP) is ideally suitable for narrowband like Global System for Mobile communication (GSM) under the multipath environment [1-4]. While the high frequency (HF) channel simulator is normally used for the communication system in the military, aeronautics and maritime at the frequency band (2 to 30 MHz) and can also be used for long distance broadcasting-based amplitude modulation (AM). This HF channel simulator is developed for stationary conditions. Although most of the HF channels are mobile, this model shows to be valid for short time with the channel bandwidth nearest to 10 kHz [2]. Another channel simulator is designed for the narrowband mobile satellite channel based on the Rayleigh and Rician distribution [3]. There is also the narrowband channel simulator that has been modeled based on statistical model. It has been designed for the bandwidth from 4 kHz to 1MHz [4]. This channel simulator has been modeled under the time-varying system and all the frequency components are assumed to have the same phase shift and attenuation when travelling in the channel. So this channel is known as non-selective frequency or flat fading. It is invalid for wideband or ultra wideband (UWB) channel.

Most of the channel simulator designs are based on the conventional Fourier transform by approaching the sum-of-sinusoidal (SoS) modeling [1-8]. The authors in [2] presented the Gaussian distribution approach to model the channel simulator. The deterministic (SoS) is applied to model the channel simulator for simulating wideband fading channel [6]. In such a model, the generations of multiple uncorrelated Rayleigh fading waveforms are generated at specific parameters. This is because to make a boundary and prevent from being uses a large numbers of sinusoids to simulate the wideband fading channel. This channel simulator is designed by considering the summation of the sinusoid groups. Each sinusoid is varied in terms of frequencies, gains as well as phases which present the fading channel. The sum-of-sinusoids is done by assuming the limit of Gaussian random process that is related to the superposition of the required sinusoids. This superposition describes the number of propagation path L , which is used to describe the channel characterization. The number of propagation path use in designing the channel can affect the accuracy of the received signal and the channel response as well. So that, the deterministic SoS channel simulator was used $L = 16$ for simulating the wideband fading channel as well as the multiple-input multiple-output (MIMO) wideband channel.

The existing channel simulator for UWB meets the problem of the limitations due to the multipath mechanism which is frequency dependent [5-9]. During multipath propagation, the received signal/channel response is the summation or modification of pulse with the different delays and attenuations. For example, the narrowband system is assumed to have zero dispersion within the pulses therefore the received signal may the representation of the superposition of the selected path. Unfortunately for UWB time-varying system, the assumption of zero dispersion is not valid as stated in [6] and [9]. The directional statistical channel simulator for UWB is designed by modifying the narrowband channel simulator to meet the UWB specifications and generates the multipath profile. Based on this channel simulator design approached, some of the assumption may be valid for the UWB channel simulator design for this thesis considering the different factors of delays and attenuations obtained from the multipath components. The other assumption such as the frequency shift is not considered in developing the channel for wideband due to the spectrum bandwidth problem [9]. It is because, the frequency shift will produce the variation of time and frequency of the transmitted signal that is propagated in this multipath time-varying environment [1-10].

Therefore, the channel simulator for UWB based on time-scale operator is necessary to mimic the real-life propagation. The multipath time-varying system caused the interaction between the transmitted signal and the channel, and then contributed to the different time and frequency which are known as time and frequency dispersion. In time-varying system, the narrowband channel is good in frequency resolution while for wideband channel is opposite. So, a small bandwidth has no problem in measuring every frequency changes of the signal due to the system mobility. The frequency resolution in wideband/UWB channel can be solved by applying the time-scale operator which is scaling (frequency shift). It can be used to represent the time-frequency operator. In this thesis, the attenuations, delays and scales are considered as the multipath components together with the Affine time-scale operator (wavelet), in generalizing the channel response as the channel simulator representation for UWB measurement.

1.2 Problem Statement

A channel simulator modeling for UWB has gained much interest among the researchers due to its wider application and advantages to a wireless communication system.

Most of the existing channel simulators have limited applications due to the representational limitations of the fundamental Fourier-based channel analysis. Based on the Fourier analysis, it requires a sinusoidal waveform as an eigenstructure/eigenfunction. Sometimes, a Gaussian distribution is also employed in characterizing the channel behaviour. These limitations are caused due to the spectrum bandwidth of the channel design and the input signal localization especially for UWB channel. A signal with wide-bandwidth is hard to analyze based on Fourier compared to signal with narrow-bandwidth. The same issues are discussed in [10-13]. While in [13] shown that the channel modeling based on time-varying system eliminates the Doppler shift from the measurement to gain the channel response with the right Doppler spectrum of the channel. Some of the existing UWB channel simulator model based on measurement approach applying some model such as clustering [9]. It gives a good idea in analyzing the received signal. It said that the received signal comes from the different pulses with the different multipath components within the cluster. But the received signal obtained by this clustering has small amplitude distortion because it used the spherical geometrical model so the path travel by the signal is quite same depends on the radius of the spherical area which has the same radius [12]. Normally, the received signal amplitude is affected by path distance and the number of scatterers. In order to have a good received signal, most the channel simulator model obtains the received signal by summation of the modified signals as stated in [10-16]. An appropriate model is important in modeling the channel simulator. Some of well known model is Saleh-Valenzuela (S-V) model [17-19]. It used Lognormal distribution and Nakagami distribution in characterizing the arrival times of the signal. This model employed the frequency domain analysis in collecting the data and it assumed the power attenuates at a constant rate.

The time-frequency characterizations provide basis for understanding the channel reaction in multipath time-varying channel. Based on Affine class theory, the analysis of the time-scale operator corresponds to the time-frequency operator by applying wavelet waveform [20]. Wavelet waveform has a short pulse that can work well in the wider-bandwidth. For example, all bounded input signals, return bounded output signals and the unbounded input signals will obtain the output signal near infinity of local graph according to an Affine function analysis [20]. This means the probability to get the received signal as same as the transmitted signal response is high. Therefore, the concept of Affine is used to present time-varying propagation channel phenomenon. The Affine-based is also used as transformation to match with the perspective transformation of the design. This transformation contains of the dilation (signal compression), translation (signal expansion), scaling, rotation and skewing. All the transformations mentioned in [17-25] are basically the properties of Affine and Cohen class theory. These two theories will be briefly discussed in Chapter 2 later. There are some applications of Affine in generalizing the channel characteristic but the different models and techniques are approached [20-25]. Affine provides a basic concept time-scale extension with the wavelet representation in a natural way for mobile radio system [20]. This paper used the continuous wavelet transform based on Affine group operator concept to present the mobile radio channel characterization. In this thesis will use the discrete wavelet transform based on Affine to model the UWB channel simulator later. Affine is also used as a multicarrier [21] [23]. They used the Affine based on Fourier transform to present the Fourier and fractional Fourier transform. Affine acts as modulation in transmitting the signal and good in minimizing the interference between channel and transmitted signal with LOS component and narrow beamwidth of scattered components. Affine wavelet-based representation for invariant function is presented in [22] and [25]. The relationship between Affine and wavelet in channel modeling are also discussed in [17-25]. As discussed in this part, the concept of Affine is actually referred to the wavelet waveform application in characterizing the channel behaviour which it will be model in this thesis. The discrete wavelet waveform will be developed and used it as the transmitted signal in this thesis.

By using the Affine time-scale base eigenstructure, a generic channel simulator design is developed. However, to implement such channel simulator in real life, it will require the software-based platform that can be directly implemented into hardware platform. LabVIEW is used in this research as software platform for channel simulator design. It offers a good module of FPGA application. So, the UWB channel simulator can be model with the FPGA application and implement it into FPGA hardware platform.

1.3 Aim and Objectives

The aim of this research is to develop an Affine-based time-scale UWB channel simulator for time-varying communication environment. To achieve this aim, a number of research objectives have been identified, as outlined below:

I. Develop a discrete Affine-based time-scale channel model and channel simulator in LabVIEW software for UWB communication channel.
II. Implement the Affine-based time-scale UWB channel simulator on FPGA device.
III. Validate the UWB channel simulator by the measurement and the existing channel simulator results.

1.4 Scope

In this thesis, the characterizations of mobile communication channel will be approached based on the simulations and measurements. The UWB frequency range used in the channel simulator development is from 3.1-5.3 GHz and the bandwidth is 2.2 GHz. The UWB channel simulator is simulated and measured under both indoor and outdoor propagation at the distance around 0-30m. The numbers of scatterers are varied due to the operating environments. The simulation and measurement at various distances and the different number of scatterers will be tested to observe the variation of the channel responses due to different operating environment. The speed of mobile is assumed around 0-3m/s. The channel simulator is designed using LabVIEW-based software and implemented on Field-Programmable-Gate-Array (FPGA).This UWB channel simulator design is for small-scale fading channel and is not for large-scale fading thus the path loss and other related network parameters are not considered in this thesis. The multipath time-varying environment is considered to obtain the multipath values of the delays, scales and attenuations. For validation, the propagation data of UWB channel simulator design are compared with the measurement data and the existing results of channel simulator.

1.5 Research Contributions

In this research, there are two contributions delivered; the discrete channel model and channel simulator for UWB are developed based on Affine time-scale operator.

The time-scale representations parallel to time-frequency representation in indicating the multipath phenomenon. In multipath phenomenon, the channel response/received signal are the replicas of the shifted transmitted signal. The multipath effects the signals arrive at different time. This different time is called the delay and the length of delay is known as the delay spread which is in time phenomenon. So, the time-scale is able to replace the relative effect of Doppler shift with the other relative function of Affine class/group. The continuous time-scale channel model based on Affine has been developed in [20]. Based on this development, the continuous time-scale channel model is modified to model the discrete time-scale channel for the UWB time-varying communication environment. The discretization of various variables needed for the channel simulator development and for the computer simulation as well. The discrete time-scale representation is done by sampling the time delay and the time scaling. The discrete time-scale channel model has been developed by Jang and Papandreou-Suppappola based on Mellin transform for wideband time-varying system [24]. In the same way, the discrete time-scale channel model for UWB time varying environment is modeled based on the Affine type in this thesis. This discrete time-scale is developed by using the frame theory based approach. The received signal representation is the summation of the discrete time shift and Doppler scaling of the transmitted signal.

The discrete time-scale channel simulator for UWB is developed based on the discrete time-scale channel model. The Development of UWB channel simulator by using LabVIEW as software-platform channel simulator is appropriate due to its wider tools and functions. This software provides tools and modules to test the design that is able to demonstrate and implement on FPGA. Besides that, it can also be used for designing a graphical model of the complex wireless communication system and can be easily observed the response of wireless communication system for various designs and modifications. The development of this UWB channel simulator on LabVIEW gives a lot of benefit to the researcher because the channel simulator can be changed quickly and easily to allow for new simulation and measurement. It usually takes a long time to modify the design for new experiment/measurement in the lab. Moreover, the LabVIEW-based software provides the FPGA modules. So the UWB channel simulator can be directly implemented into FPGA devices. The FPGA devices contain Hardware Description Languages (HDLs) in providing the simulation and synthesis of the design. These HDLs can be used effectively to implement the target of the design, for example in this thesis needs to implement the UWB channel simulator design on LabVIEW on FPGA to check the accuracy of the channel simulator design. The software implementation using FPGA are widely described in [26-28]. The LabVIEW-based software has been used in developing and simulating the channel such as space channel simulator, mobile Rayleigh fading channel, land mobile channel and others [26-30]. These applications show that the LabVIEW is efficiently used for different channel design. The FPGA-based channel simulator presents as the hardware part of UWB channel simulator and the LabVIEW-based software as software part UWB channel simulator. This FPGA-based hardware platform can also act as emulator when it combines with another communication devices.

1.6 Thesis Outline

This thesis contains five chapters. Chapter 1 presents the introduction of the channel simulator design, Chapter 2 presents the literature review, Chapter 3 presents the development of the discrete channel model and channel simulator for UWB time varying environment, Chapter 4 describes the simulator performance assessment and validation. Lastly, Chapter 5 presents on the conclusions and future works.

In Chapter 1, the background of the channel simulator is highlighted at the beginning to give the early information about the channel simulator application and development. This chapter presents the problems, scope of the research, aims, objectives as well as contribution to this thesis

In Chapter 2, the fundamental theories of the related studies and works on the channel model and channel simulator designs are presented. It generalizes the main issues and validates the concepts of the channel simulator for wireless communication system especially for UWB applications based on the existing channel simulator design such as narrowband. The concept of Affine class/group is discussed and shown its relationship to time-scale characterization and some information of wavelet. The model and technique of the channel simulator development are also presented. The advantage of time-scale as operator base is discussed for generalizing the channel simulator representation. The difference between Cohen and Affine class is also presented and discussed why this class is employed to represent the time-scale operator as channel simulator representation due to the wavelet used in developing the channel model. This Affine time-scale operator is supposedly to present the effect of multipath time-varying system on the transmit signal. The purpose of channel simulator application is highlighted for wireless communication system and other applications. Discuss on how the time-scale channel simulator representation suits the mobile or fixed UWB scenarios and shows the correspondent of the time-scale operator with the time-frequency operator applied in the most existing channel simulator designs. The limitation of the existing channel simulator is also presented. The scattering model/function is also discussed, it will be used in the channel modeling later. The channel characterization in indoor and outdoor propagation environment is presented.

Chapter 3 presents the methods and techniques that will be used in designing the discrete channel model and discrete channel simulator for UWB. Based on the existing channel simulator designs, many techniques are applied depending on the type of applications and environment such as parameters, model, and design. The discrete channel model and channel simulator for UWB time varying environment are modeled based on Affine time-scale operator using the wavelet signal. The discrete UWB channel simulator is developed using LabVIEW software.

Chapter 4 presents the Affine-based time-scale UWB channel simulator performance and assessments. The validation of this UWB channel simulator is also discussed based on measurement and comparison with the existing channel simulator data or result. The analysis of UWB channel simulator simulation results are obtained and presented. The channel responses of the UWB channel simulator are also presented. The RMS delay spread for different distance and number of scatterers are obtained and measured due to operating environment. The implementation of UWB channel simulator on FPGA is also presented.

Lastly, Chapter 5 concludes the UWB channel simulator design in this thesis and presents the recommendation for further research of the channel simulator design.

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