SOFTWARE DEFINED RADIO TESTBED OF TELEVISION WHITE SPACE FOR VIDEO TRANSMISSION

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To my beloved mother and father,

to my lecturers, for their guidance and encouragement.

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ABSTRACT

Recently, television white space (TVWS) has grabbed a lot of attention from researchers in the Cognitive Radio (CR) area. This underutilized spectrum is one of the possible solutions for spectrum scarcity problem in wireless communication. Thus, many research works have been carried out in order to find a suitable method to utilize this spectrum in an efficient manner. Nevertheless, the actual hardware implementation on utilizing this spectrum is still lacking. Therefore, in this research, an Orthogonal Frequency Division Multiplexing (OFDM) real-time video transmission is proposed using software defined radio (SDR) platform. Two modulation schemes are used namely Phase-shift keying (PSK) with its Binary-PSK (BPSK) and Quadrature-PSK (QPSK) and Quadrature amplitude modulation (QAM) with 16QAM and 64QAM modes. The free channel used in this work is selected under ultra high frequency (UHF) band based on the energy detection, which is either on channel 54 or channel 56. The proposed system is developed with the physical (PHY) layer design of the transmitter and receiver in GNU Radio and integration of medium access control (MAC) layer functionality. Video capture and display programs are designed based on OpenCV modules. The performance of this design is evaluated based on two types of environment, indoor and outdoor, with packet delivery ratio (PDR) and end-to-end delay (EED) as the performance metrics. Three types of video motion are used in the experimentation which are fast (mobile), medium (foreman) and slow (akiyo). Under allocated bandwidth of 1.0 MHz, optimal performances of PDR and EED for both scenarios are shown. In the indoor scenario, QPSK½ exhibits the best performance with 0.92 of PDR and 24.7 seconds of EED for akiyo. Meanwhile for foreman and mobile, BPSK¾ achieves the best performance with PDR of 0.96 and 0.95 and EED of 33.2 seconds and 35.0 seconds, respectively. In the outdoor scenario, the best performance of PDR is achieved by 16QAM½ with 0.9 and 23.5 seconds of EED for akiyo. For foreman and mobile, QPSK½ exhibits the best performance with 0.94 and 0.9 of PDR and 31.2 seconds and 32.5 seconds of EED, respectively. In conclusion, the proposed design exhibits promising solutions for the OFDM real-time video transmission over TVWS.

ABSTRAK

Kebelakangan ini, ruang putih televisyen (TVWS) telah menarik banyak perhatian para penyelidik dalam bidang radio kognitif (CR). Spektrum yang kurang digunakan ini mungkin menjadi satu penyelesaian bagi masalah kekurangan spektrum dalam komunikasi tanpa wayar. Oleh yang demikian, banyak penyelidikan telah dijalankan untuk mencari kaedah yang sesuai untuk memanfaatkan spektrum ini dengan cara yang cekap. Namun, pelaksanaan perkakasan sebenar dalam memanfaatkan spektrum ini masih kurang. Oleh itu, dalam kajian ini, satu penghantaran video masa nyata pemultipleksan bahagian frekuensi ortogon (OFDM) dicadangkan dengan menggunakan platform radio tentuan perisian (SDR). Dua jenis skema pemodulatan digunakan yang dinamakan kekunci anjakan fasa (PSK) dengan perduaan-PSK (BPSK) dan kuadratur-PSK (QPSK) serta pemodulatan amplitud kuadratur (QAM) dengan mod-mod 16QAM dan 64QAM. Saluran kosong yang digunakan dalam kajian ini dipilih di bawah jalur frekuensi lampau tinggi (UHF) berdasarkan pengesan tenaga, sama ada pada saluran 54 atau saluran 56. Sistem yang dicadangkan dibangunkan dengan reka bentuk lapisan fizikal (PHY) pada pemancar dan penerima dalam GNU Radio serta penyepaduan terhadap fungsi kawalan capaian media (MAC). Program penangkapan dan paparan video direka berdasarkan modul OpenCV. Prestasi reka bentuk ini dinilai berdasarkan dua persekitaran, dalam dan luar dengan nisbah penghantaran bingkisan (PDR) dan lengah hujung-ke-akhir (EED) sebagai metrik prestasi. Tiga jenis pergerakan video digunakan dalam pengujikajian ini iaitu laju (mudah alih), separa laju (fomen) dan perlahan (akiyo). Di bawah lebar jalur 1.0 MHz, prestasi optimum antara PDR dan EED untuk kedua-dua situasi telah dicapai. Dalam senario dalam, QPSK½ mempamerkan prestasi terbaik dengan PDR pada 0.92 dan EED pada 24.7 saat untuk akiyo. Sementara itu, untuk fomen dan mudah alih, BPSK¾ telah mencapai prestasi terbaik dengan PDR pada 0.96 dan pada 0.95 serta EED pada 33.2 saat dan pada 35.0 saat, masing-masing. Dalam senario luar, prestasi terbaik untuk PDR dicapai oleh 16QAM½ pada 0.9 dan EED pada 23.5 saat untuk akiyo. Manakala, untuk fomen dan mudah alih, QPSK½ mempamerkan prestasi terbaik dengan PDR pada 0.94 dan 0.9 serta EED pada 31.2 saat dan pada 32.5 saat, masing-masing. Kesimpulannya, reka bentuk yang dicadangkan mempamerkan penyelesaian yang memberangsangkan untuk penghantaran video masa nyata OFDM melalui TVWS.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TVWS	-	Television White Space
VHF/UHF	-	Very High Frequency/Ultra High Frequency
ISM	-	Industrial, Scientific and Medical
DSO	-	Digital Switchover
CR	-	Cognitive Radio
ECMA	-	European Computer Manufacturers Association
WLAN	-	Wireless Local Area Network
LTE	-	Long-Term Evolution
PHY	-	Physical
MAC	-	Medium Access Control
SDR	-	Software-Defined Radio
OFDM	-	Orthogonal Frequency Division Multiplexing
BPSK	-	Binary Phase Shift Keying
QPSK	-	Quadrature Phase Shift Keying
QAM	-	Quadrature amplitude modulation
QoS	-	Quality of Service
CIF	-	Common Intermediate Format
FCC	-	Federal Communication Commission
Ofcom	-	Office of Communications
UK	-	United Kingdom
WPAN	-	Wireless Personal Network
TDM	-	Time Division Multiplexing
SNR	-	Signal to Noise Ratio
DARPA	-	Defence Advanced Research Projects Agency
XG	-	Next Generation Communications Program
RSPG	-	Radio Spectrum Policy Group
CEPT	-	European Conference of Postal and Telecommunications

		Administrations
CPEs	-	Customer Premises Equipments
CE	-	Coexistence Enabler
CM	-	Coexistence Manager
CDIS	-	Coexistence Discovery And Information Server
ETSI	-	European Telecommunications Standards Institute
RRS	-	Radio Systems and Reconfigurable Radios
KNOWS	-	Networking over White Space
API	-	Application Programming Interface
CDBS	-	Central Data Base Server
RRBS	-	Remote Rural Broadband Systems
IoT	-	Internet of Things
ED	-	Energy Detector
SU	-	Secondary User
COGEU	-	Cognitive radio systems for efficient sharing of TV white spaces in European context
PSD	-	Power Spectral Density
CDMA	-	Code Division Multiple Access
PSK	-	Phase Shift Keying
FDM	-	Frequency Division Multiplexing
ICI	-	Inter-Carrier Interference
DFT	-	Discrete Fourier Transform
IDFT	-	Inverse Discrete Fourier Transform
FFT	-	Fast Fourier Transform
IFFT	-	Inverse Fast Fourier Transform
ISI	-	Inter-Symbol Interference
JPEG	-	Joint Photographic Experts Group
MPEG	-	Motion Picture Experts Group
FPS	-	Frame Per Second
CRN	-	Cognitive Radio Network
GMSK	-	Gaussian Minimum Shift Keying
DSRC	-	Dedicated Short Range Communications
PFR	-	Packet Failure Rate
UDP	-	User Datagram Protocol

IP	-	Internet Protocol
VoIP	-	Voice-over-IP
UHD	-	USRP Hardware Driver
PDR	-	Packet Delivery Ratio
EED	-	End-To-End Delay
M-JPEG	-	Motion JPEG
FPGA	-	Field Programmable Gate Array
RF	-	Radio Frequency
LOS	-	Line Of Sight
GRC	-	GNU Radio companions
DAC	-	Digital-To-Analogue Converter
ADC	-	Analogue-To-Digital Converter
RF	-	Radio Frequency
FCS	-	Frame Check Sequence
BSS	-	Broadcast Service
PDU	-	Protocol Data Unit
MTU	-	Maximum Transfer Unit
MSS	-	Maximum Segment Size
ARP	-	Address Resolution Protocol
PSNR	-	Peak Signal to Noise Ratio
PU	-	Primary User
CSMA/CA	-	Carrier Sense Multiple Access/Collision Avoidance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Television White Space (TVWS) is a well-known term nowadays that refers to the unused spectrum resources of the Very High Frequency (VHF) / Ultra High Frequency (UHF) band at specific times and locations that can be exploited through spectrum sharing [1]. This band specifically ranging from 470 MHz – 790 MHz in Europe [2, 3] and non-continuous 54 MHz – 698 MHz in the United States [4]. Its propagation characteristics make it a desirable and convenient spectrum for many wireless transmission services [5]. In addition, because this band resides under the 1GHz frequency, material obstruction is less harmful than at higher frequencies, allowing non-line-of-sight coverage [6]. This band also presents a path loss advantage over the unlicensed industrial, scientific, and medical (ISM) bands (2.4 GHz and 5.0 GHz band) only due to the operating frequency. However, it still remains under-utilized in a large portion of it. As example, in Malaysia, a study from [7] shows that an amount of 48 MHz of TV spectrum especially in the band of 742 MHz – 790 MHz will be cleared after the Digital Switchover (DSO). Figure 1 depicts the concept of TVWS spectrum where non-contiguous transmissions lead to unused channels that are referred as ‘white spaces’.

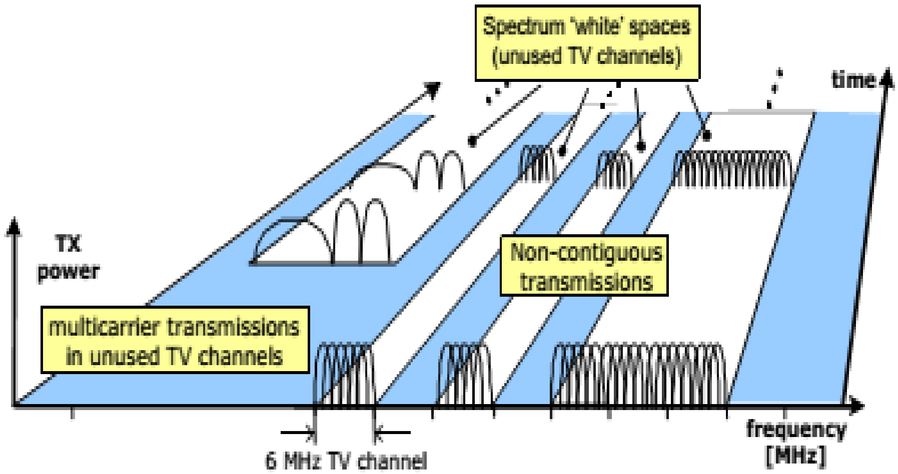

Figure 1.1 TVWS Spectrum [8].

TVWS has several standards based on CR networks such as 802.11af, 802.19, 802.22 and European Computer Manufacturers Association (ECMA)-392 which are prepared to work on this underutilized spectrum [9]. Each of them has its own characteristics such as transmission power, bandwidth, and different system architecture and device types. This project focused only on 802.11af as to create Wi-Fi like application in this spectrum. Generally, the 802.11af is a modified 802.11 standard, which operates in a range of TVWS using the properties of CR.

The fact that the radio spectrum is a limited resource, an increasing demand from different wireless technology such as wireless local area network (WLAN), cellular broadband, WiMAX, long-term evolution (LTE) and other applications has led to the spectrum shortage. Therefore, both communication technology vendors and regulators are seeking for solution to improve spectrum utilisation that can serve this increasing spectrum's demand. As a result, the underutilized spectrum such as TVWS is suggested as one of the potential solutions to the problem. The interesting characteristics of this spectrum compared to ISM band will be beneficial for some applications that utilized it.

1.2 Problem Statement

In current research trend for this area [7, 9, 10], researchers mainly focus on how unlicensed users sense these unused UHF bands and occupy them without causing inappropriate interference to the licensed users. Thus, another favour comes out on what kind of applications can make full use of these UHF bands and how to design their PHY and MAC layer protocols. In particular, one of the highly consumed bandwidth application in multimedia applications like wireless video transmission is an excellent choice to take a full benefit from these potential unused bands. Still, the exploration of this kind of application is very limited in term of hardware's experimentation over TVWS especially using a SDR. A number of researchers are either using an old OFDM framework in GNU Radio [11, 12] which is far from the standard requirements or using Wi-Fi frequencies as the operating frequency [13, 14]. Given the re-configurability and flexibility of SDR, a typical communication system could be easily deployed and implemented.

Apart from that, there is some limitation of this spectrum where high profile application such as video transmission needs to compensate with the limited bandwidth of this channel. To comply with the limited bandwidth and also the range of propagation that is feasible for the video transmission under the UHF frequencies, a good test-bed system is needed. Thus, for this research, an OFDM-based video transmission test-bed using SDR platform is proposed with the aim to achieve acceptable video transmission Quality of Service (QoS).

1.3 Objective

The main purpose of this research work is to develop and evaluate a video transmission over TVWS. In depth, the objectives of this research include:

- To design an OFDM-based video transmission in GNU Radio
- To develop the proposed design using SDR communication system

- To evaluate the performance of the proposed design over TVWS under indoor and outdoor conditions in terms of PDR and EED.

1.4 Scope of Works

This work focuses on development of OFDM-based video transmission using SDR components of USRP B200 and GNU Radio. The main design consists of SDR transmitter and receiver as well as capture and display program. The OFDM design is based on recent framework on the PHY layer with support using four modulation schemes namely Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (16QAM) and 64QAM.

The proposed design is based on point to point communication only. The channel that is used for propagation belongs to UHF band which is either channel 54, 735.25 MHz or channel 56, 751.25 MHz. Both channels have been tested and considered as unused channels. The video format that has been used as a video source is limited to Common Intermediate Format (CIF) format only with 352x288 resolution. Three types of video motion, slow, medium and fast are used as the video source. Parameters chosen for the video properties are based on the best performance as will be shown from the experiment results where a significant evaluation can be made later.

For the experimental work, the indoor location is chosen at UTM-MIMOS laboratory while the outdoor location is on the open road site. The maximum distance chosen for indoor is 20 meter and for the outdoor is 200 meter which are valid within IEEE 802.11 range.

1.5 Significance of the Research

Generally, the design and development of OFDM-based video transmission using SDR platform is the main contribution for this research. The rest of contributions are stated below:

- An OFDM video transmission in GNU Radio software has been designed by using recent OFDM framework on the PHY layer based on point to point communication system.
- A test-bed has been developed for a low bandwidth video transmission over TVWS with an acceptable QoS under indoor and outdoor environments with 20 meter and 200 meter distances respectively.
- The performance evaluation of the developed test-bed has been conducted to measure the performance of the proposed design in terms of PDR and EED.

1.6 Organization of the Thesis

This thesis consists of six chapters and it is organized as follows:

Starting with Chapter 1, the background of TVWS, problem statement of the research, objectives of the work, scope of the work and significance of this project are discussed.

The second chapter is mainly related to theories and information of the research. Three main points are presented which include extended TVWS studies, OFDM characteristics and video transmission studies. Related works are also discussed at the end of this chapter.

The third chapter is about methodology of the proposed design starting from the framework design of the video transmission, SDR transmission system design with focus on the OFDM transmitter and receiver in GNU Radio, performance evaluation and measurement of the experimental work, model of the system and related tools.

In the fourth chapter, the details design of the SDR video transmission including explanations of every function of components used is presented. Furthermore, the design of the video captured and displayed using OpenCV is described in details. This chapter ends with the TV spectrum sensing method description and its results.

On the fifth chapter, the experimental works for this project is explained briefly at the beginning and followed by the analysis and discussion of the results. This chapter mainly presents the indoor and outdoor experimental results with different allocated bandwidths, distances and modulation schemes.

The final chapter is for concluding the whole works that has been done for this project. Some suggestions for future works are discussed later in this chapter.

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APPENDIX A

USRP B200 Specification

Ettus Research™
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USRP™ B200/B210 Bus Series

FEATURES

- RF coverage from 70 MHz – 6 GHz
- GNU Radio, C++ and Python APIs
- USB 3.0 SuperSpeed interface
- Standard-B USB 3.0 connector
- Flexible rate 12 bit ADC/DAC
- Grounded mounting holes

USRP B200

- 1 TX & 1 RX, Half or Full Duplex
- Xilinx Spartan 6 XC6SLX75 FPGA
- Up to 56 MHz of instantaneous bandwidth
- USB Bus powered

USRP B210

- 2 TX & 2 RX, Half or Full Duplex
- Fully-coherent 2x2 MIMO capability
- Xilinx Spartan 6 XC6SLX150 FPGA
- Up to 56 MHz of instantaneous bandwidth in 1x1
- Up to 30.72 MHz of instantaneous bandwidth in 2x2
- Includes DC power supply
- GPIO capability

USRP B200/B210 Product Overview

The USRP B200 and B210 hardware covers RF frequencies from 70MHz to 6 GHz, has a Spartan6 FPGA, and USB 3.0 connectivity. This platform enables experimentation with a wide range of signals including FM and TV broadcast, cellular, Wi-Fi, and more. The USRP B200 features one receive and one transmit channel in a bus-powered design. The USRP B210 extends the capabilities of the B200 by offering a total of two receive and two transmit channels, incorporates a larger FPGA, GPIO, and includes an external power supply. Both use an Analog Devices RFIC to deliver a cost-effective RF experimentation platform, and can stream up to 56 MHz of instantaneous bandwidth over a high-bandwidth USB 3.0 bus on select USB 3.0 chipsets (with backward compatibly to USB 2.0). Because the B200 and B210 are enabled with our USRP Hardware Driver™ (UHD), users can develop their applications and seamlessly port their designs to high-performance or embedded USRPs such as the USRP X310 or USRP E310. UHD is an open-source, cross-platform driver that can run on Windows, Linux, and MacOS. It provides a common API, which is used by several software frameworks, such as GNU Radio. With this software support, users can collaborate with a vibrant community of enthusiasts, students, and professionals that have adopted USRP products for their development. As a member of this community, users can find assistance for application development, share knowledge to further SDR technology, and contribute their own innovations.

Ettus Research™
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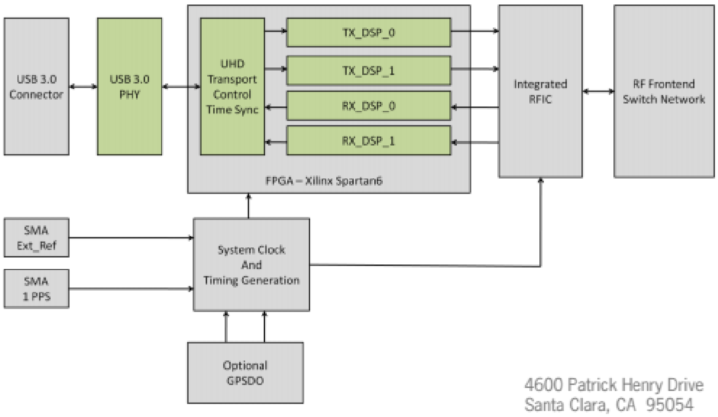
USRP ™ B200/B210 Bus Series

Spec	Typ.	Unit
Power		
DC Input	6	V
Conversion Performance and Clocks		
ADC Sample Rate (max)	61.44	MS/s
ADC Resolution	12	bits
ADC Wideband SFDR	78	dBc
DAC Sample Rate (max)	61.44	MS/s
DAC Resolution	12	bits
Host Sample Rate (16b) **	61.44	MS/s
Frequency Accuracy	±2.0	ppm
W/ GPS Unlocked TCXO Reference	±75	ppb
W/ GPS Locked TCXO Reference	< 1	ppb

Spec	Typ.	Unit
RF Performance (single channel)		
SSB/LO Suppression	-35/50	dBc
3.5 GHz	1.0	deg RMS
6 GHz	1.5	deg RMS
Power Output	>10	dBm
IIP3 (@ typ NF)	-20	dBm
Receive Noise Figure	<8	dB
Physical		
Dimensions	9.7x15.5x1.5	cm
Weight	350	g

*All specifications are subject to change without notice.
** See benchmark results for sample rates in various configurations.



About Ettus Research

Ettus Research is an innovative provider of software defined radio hardware, including the original Universal Software Radio Peripheral (USRP) family of products. Ettus Research is a leader in the GNU Radio open-source community, and enables users worldwide to address a wide range of research, industry and defense applications. The company was founded in 2004 and is based in Santa Clara, California. As of 2010, Ettus Research is a wholly owned subsidiary of National Instruments.

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