Transmission Characteristics of OFDM Packets in 5 GHz Band Using USRP

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Abstract—**In this paper, an experiment is conducted to transmit and receive orthogonal frequency division multiplexing (OFDM) modulated packets in the 5 GHz band with a software defined radio (SDR) platform composed of universal software radio peripherals (USRPs) and GNU Radio. The OFDM modulation is complied with the 1:4 scale model of IEEE 802.11a standard. The observed OFDM signals do not satisfy the spectral mask of IEEE 802.11a standard so that an overlapped windowing will be required to satisfy it. The experimental results show that the received sensitivity of −59 dBm attains at the packet error rate (PER) of 1% when subcarriers are modulated by quadrature phase shift keying (QPSK) and the received sensitivity of −61 dBm attains at 1% PER when subcarriers are modulated by binary PSK (BPSK).**

I. Introduction

The number of users in wireless communications with ultra high frequency (UHF) band of 300 MHz to 3 GHz will be increasing so that the wireless traffic will be explosively increasing and it is worried about the shortage of limited wireless resources. The overlapped frequency spectra among wireless LANs will also cause the degradation of their communication qualities. The future wireless networks such like 5G (5th generation mobile networks) will consider to exploit the super high frequency (SHF) band of 3 to 30 GHz higher than the UHF band. The SHF band has extensively broad available bandwidth so that the use of SHF band helps us to resolve the shortage of wireless resources but the transmission range of the SHF band will be short because of high attenuation.

A cooperative wireless communications system has been proposed to cancel interference in the UHF band by assisting short-range SHF band signals [1]. In the system, single-antenna mobile terminals (MTs) receive the UHF band signal transmitted from multiple antennas in a base station (BS) but the multiple streams from BS will interfere each other. A MT shares the received signals of the other peripheral MTs with the short-range SHF band so that it cancels the interference and acquires the desired signal transmitted from BS. However, a high-rate and efficient medium access control (MAC) protocol should be required for the SHF-band communications.

In this paper, we present a wireless communications testbed with 5.1 GHz band to develop the efficient MAC protocol for the cooperative system. The testbed is composed of GNU radio and universal software radio peripherals (USRPs). GNU radio is a software development toolkit that provides digital baseband signal processing blocks to implement software defined radios (SDRs). USRP is a radio-frequency (RF) front-end that provides analog/digital mixed signal processing with various daughter board. In this paper, we show the characteristics of orthogonal frequency division multiplexing (OFDM) packet transmissions in the 5.1 GHz with daughter-boards for operation 2.4 GHz and 5 GHz.

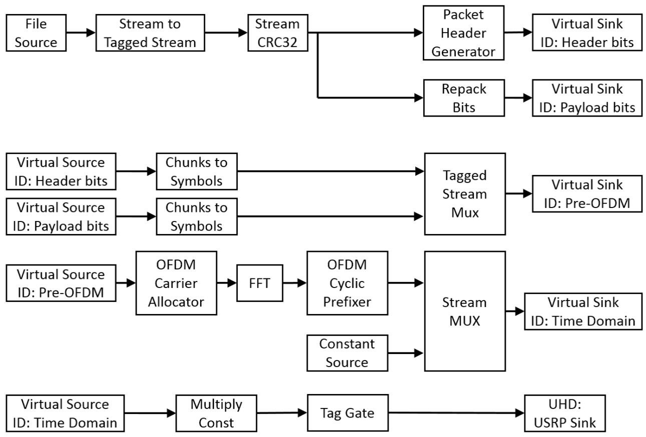

Fig. 1. The TX flow-graph. This flow-graph is intended to send packets by OFDM modulation.

II. Experimental Environments

The GNU Radio version is 3.7.5.1, and the USRP hardware driver (UHD) version is 003.008.000.55. The TX flow-graph and the RX flow-graph are shown in Figs. 1 and 2, respectively.

In the TX flow-graph, signal processing is conducted as follows. The File Source block reads binary data from a specified file. The Stream to Tagged Stream block converts the binary data into a tagged stream. The tagged stream uses tags to identify packet boundaries. The Stream CRC-32 block appends 32-bit cyclic redundancy check (CRC-32) to the tagged stream. The Packet Header Generator block generates a header per packet. Figure 3 illustrates the packet and header configuration. The Repack Bits block converts 8 bits per byte into 2 bits or 1 bit per byte, and the payload is modulated by quadrature phase shift keying (QPSK) or binary PSK (BPSK), respectively. A Virtual Sink block is connected to the Virtual Source block with the same ID. The header is

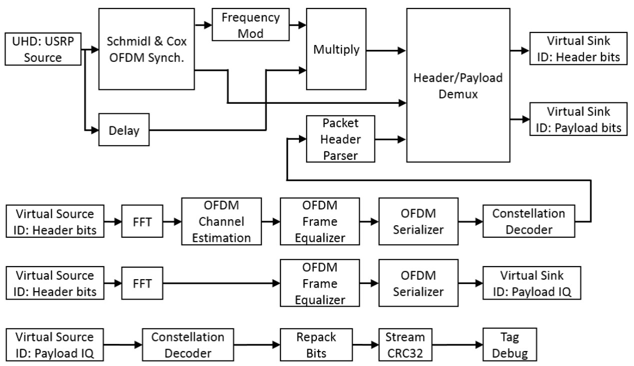

Fig. 2. The RX flow-graph. This flow-graph is intended to receive packets by OFDM modulation.

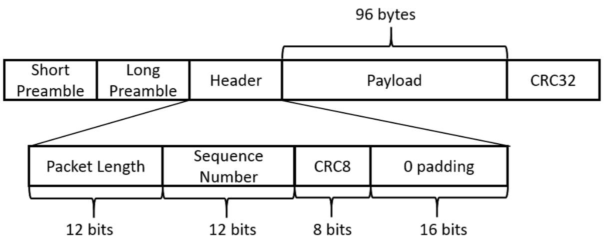

Fig. 3. The packet and header configuration. A packet has 12 and 20 OFDM symbol length when the payload is modulated by QPSK and BPSK, respectively.

modulated by BPSK and the payload is modulated by QPSK or BPSK in the Chunks to Symbols block. The header and payload are concatenated in the Tagged Stream Mux block. The OFDM Carrier Allocator block assigns modulated data symbols to corresponding subcarriers, inserts pilot subcarriers, and appends the short preamble and long preamble. This block has the parameters of Occupied Carriers, Pilot Carriers, Pilot Symbols, and Sync Words. The Occupied Carriers parameter provides the range of used subcarriers. The Pilot Carriers parameter assigns the pilot subcarrier IDs and the Pilot Symbols parameter assigns the modulated symbols of pilot subcarriers. The Sync Words parameter provides the modulated symbol sequences for the short and long preambles which are the same as the IEEE 802.11a standard but has half the length of 802.11a preambles. The FFT block works as an inverse fast Fourier transform (IFFT) in the TX flow-graph. The OFDM Cyclic Prefixer appends the guard interval (GI) to an OFDM symbol. The Constant Source block provides the inter-frame space (IFS) and the Stream Mux block concatenates one OFDM packet and one IFS. In this paper, this IFS has quarter of the OFDM symbol length. The Multiply Const block multiplies the signal by $1/\sqrt{520}$ because the transmit signal should lay in the dynamic range of the transmitter. The Tag Gate block removes the tags from the tagged data. The UHD: USRP Sink block controls USRP with UHD to transmit the digital IQ data on radio.

In the RX flow-graph, signal processing is conducted as follows. The UHD: USRP Source block controls USRP to receive the digital IQ on radio. The Schmidl & Cox OFDM Synch. block extracts the symbol timing and frequency offset from the RX signal [2]. The Delay block delays the RX signal by 1 OFDM symbol. The frequency offset is frequency-modulated (FD) via the Frequency Mod block and the delayed RX signal is compensated via the Multiplexing block. The RX packet is divided into the header and payload tagged streams through Header/Payload Demux block. The signal processing in header stream is conducted before that in payload stream is conducted. The FFT Block works as an FFT, corresponding to the OFDM demodulator. The OFDM Channel Estimation block estimates the channel state information (CSI) each subcarrier with the common long preamble and the OFDM Frame Equalizer operates the equalization for the header with the estimated CSI. The OFDM Serializer block removes the pilot subcarriers and converts parallel into serial. The Constellation Decoder block demodulates the header with BPSK. The Packet Header Parser block converts the header data into the packet information as tags. The signal processing in payload stream is almost the same as that in header stream except to obtain the estimated CSI from the tags and demodulate with the payload modulation. The Repack Bits block converts the modulation-order bits per byte into 8 bits per byte. The Stream CRC-32 block passes the RX data if no error is detected with CRC-32. The Tag Debug block displays the packet sequence number on a console.

TABLE I
THE SPECIFICATIONS FOR SDR EQUIPMENT.

Control PC	
CPU	Core i7 4.0 GHz
Memory	8.17 GiB
OS	Ubuntu 14.04 LTS
USRP N210	
Interface	Gigabit Ethrnet
A/D converter	100 Msamples/sec, 14-bit
D/A converter	400 Msamples/sec, 16-bit
Local oscillator	TCXO (optional GPSDO)
XCVR2450	
Frequency range	2.4 – 2.5 GHz, 4.9 – 5.9 GHz
Conversion type	Direct conversion
VERT2450	
Element	Omni-directional vertical antenna
Frequency range	2.4 – 2.5 GHz, 4.9 – 5.9 GHz
Antenna gain	3 dBi
GPSDO-KIT	
Oscillator	OCXO (Oven Controlled Xtal Oscillator)

Table I shows the specification for SDR equipment [3]. XCVR2450 is a dual-band daughter board and VERT2450 is a dual-band omni-directional vertical antenna for 2.4 and 5 GHz bands. GPSDO-KIT is an optional board for USRP, which generates 10 MHz reference clock and 1 pulse per second (PPS) by global positioning system (GPS).

Experiments are conducted in a room at Kyoto Institute of Technology. Some USRPs obtain an experimental radio station license from the ministry of internal affairs and communications (MIC) of Japan so that they can transmit radio signal with 5.1 GHz band. The system parameters are listed in Table II in

TABLE II
THE SYSTEM PARAMETERS.

System parameter	Value
Carrier frequency	5.1 GHz
RX Gain	15 dB
Sampling rate	5 Msamples/sec
Bandwidth	5 MHz
Header modulation	BPSK
Payload modulation	BPSK, QPSK
Payload size	96 bytes
FFT size	64
GI size	16
Bit rate	3, 6 Mbits/sec
Distance between antennas	0.2 m

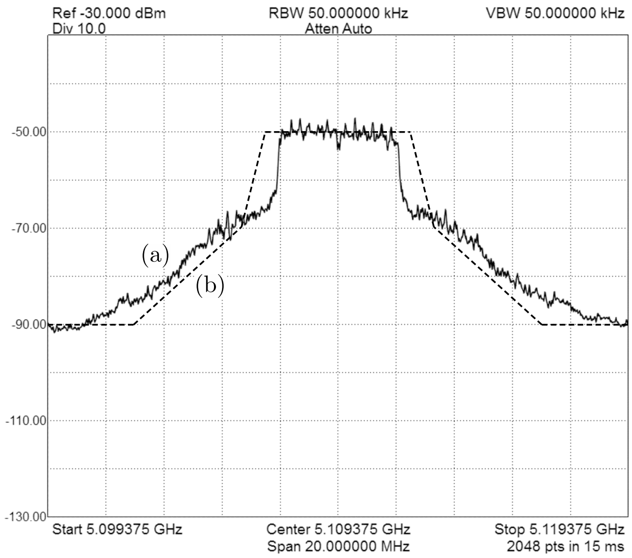

Fig. 4. (a) is the observed RX signal spectrum where the payload modulation is QPSK and the RX power is −34 dBm. (b) is the spectrum mask of the IEEE 802.11a standard which is scaled to 1/4.

the experiments. A spectrum analyzer, Signal Hound BB60C, is used to observe the signal spectrum.

III. Experimental Results

The observed RX signal spectrum and spectrum mask of IEEE 802.11a standard are illustrated in Fig. 4 where the payload modulation is QPSK, the RX power is −34 dBm, and the spectrum mask is scaled to 1/4. As shown in Fig. 4, the RX spectrum is beyond the mask in some frequency range. The clipping effect may be a factor because the OFDM signal has large peak-to-average power ratio (PAPR). No windowing will be a factor because it will be useful to reduce the out-band radiation so that it should be implemented in the future.

The packet error rate (PER) versus RX power is illustrated in Fig. 5 when the payload is modulated with BPSK and QPSK. Let us define PER as the ratio of the number of missing and erroneous packets to the total number of TX packets where packet losses occur by synchronization error and packer errors are detected by CRC-32. The RX power is configured with TX Gain on GNU Radio. The RX sensitivity of −61 dBm attains at PER of 10^{-2} in the case of BPSK and that of −59 dBm attains

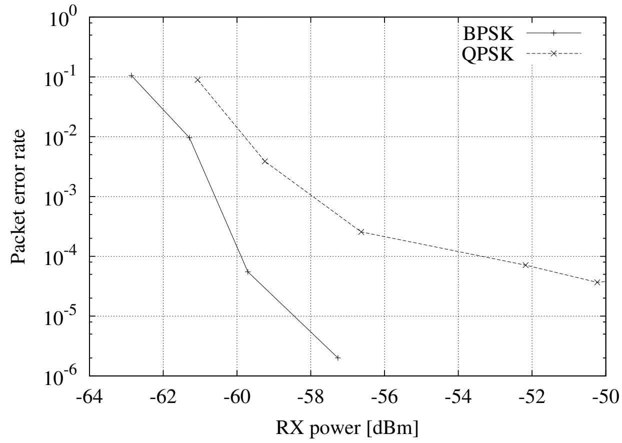

Fig. 5. Packet error rate versus RX power when the payload is modulated with BPSK and QPSK.

at it in the case of QPSK. BPSK has 3 dB gain to QPSK in carrier-to-noise power ratio (CNR) theoretically because the minimum distance between modulated bits in BPSK is 3 dB larger than that in QPSK. As shown in Fig. 5, the difference in RX power between BPSK and QPSK will be about 1 to 3 dB when PER is larger than 10^{-3}.

IV. Conclusion

We have constructed a wireless communications testbed employing GNU Radio and USRP, and have shown the experimental results in this paper. In our testbed, the received spectrum will be beyond the scaled spectrum mask of IEEE 802.11a standard so that windowing should be implemented in the future. The experimental results have shown that the received sensitivity of −61 dBm attains at 1% PER in BPSK and that of −59 dBm attains at 1% PER in QPSK. In the next step, we will construct a higher band wireless communications testbed to provide the feasibility of cooperative wireless systems proposed by our research group.

Acknowledgment

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