Development of Real-time FHD Loss-Less Video Communication over an 8×8 MIMO-OFDM System

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***Abstract*—This paper shows the total system of real-time FHD video communication over wireless system. The wireless system can realize the data rate of 3Gbps by use of an 80-MHz baseband bandwidth and a 8×8 MIMO-OFDM scheme. A low-latency and the optimum pipelined architecture are realized into all processing blocks. In addition, the video compression is based on loss-less coding/decoding. By using this mechanism, the original video can be transferred by a wireless system. In addition, the minimum latency can be realized by using a small size block based video coding. It provides the real-time operations of video communications. The proposed architecture realizes low power consumption.**

Keywords—8×8 MIMO-OFDM, Real-Time Lossless Video Coding, Highspeed Wireless System, Low Power Comsuption

I. Introduction

As a wireless communication standard [1], IEEE802.11ac based wireless LAN supports the maximum throughput of 1.5Gbps at a 40-MHz frequency band width (BW), 3.0Gbps at 80-MHz BW and 6.0Gbps at 160-MHz BW by using a multiple-input and multiple-out (MIMO) stream technique with orthogonal frequency division multiplexing (OFDM).

The above high throughput can be in particular expected for the use of high quality video wireless communications. In the case of IEEE802.11n, several video communications over the wireless systems have been already developed. However, all of them requires high compression rate for the inputted video because of low wireless communication throughput. Accordingly, the compressed video data have a lot of unclear and low quality parts. In addition, when these data are transferred over the wireless, many wireless communication errors are unfortunately happened. In order to avoid these errors, a buffering mechanism has been implemented and thus it is currently difficult to realize a real-time video wireless communication with high quality.

In this paper, high quality video wireless transmission, i.e., FHD lossless video wireless transmission is designed and developed. Based on [2]-[5], our developed system has achieved the data rate of 3Gbps by use of an 80-MHz baseband bandwidth and a 8×8 MIMO scheme. In addition to the specification of such high throughput, a low-latency and the optimum pipelined architecture are realized for all processing blocks. It can provide the real-time operations on OFDM modulation and MIMO detection.

The proposed architecture also realizes low power consumption. In order to realize low power consumption, the algorithm of MIMO-OFDM has been revised. This system has been applied for high-quality video communication. With some of results on field experiments, the system performance for video communications is described in this paper.

II. The Developed Total System

Fig. 1 shows the block diagram of our proposed total system. It consists of TX and RX wireless communications where the upper part in this figure shows TX system and the lower part shows RX system. In the TX, the lossless video coding module with hierarchical average and copy prediction (HACP) algorithm is implimented first [6], [7]. The HACP is explained in the next section. In addition to HACP, the Reed-Solomon encoding module (RS module) is applied in the next step. Using both of encodings, the video data become robust against errors of wireless communications. After RS module, the data are divided into some of data symbols which are fed into the modules of OFDM. The main modules of OFDM are prepared with 8 parallel. After OFDM modules, the analog RF modules including high performance amplifier (HPA) transfer all data to high frequency data into 8 anntenas.

The RX receives the wireless data with 8 anntenas. There are some synchronizations in the front-end processing. Although the clock rates in TX and RX are the same, these clocks in TX and RX are not synchronized. Accordingly, in order to synchronize both clocks, a module of clock synchronization has been applied at the front end of RX. In addition, after the clock synchronization, the frame used in OFDM should be also synchronized. For the frame synchronization, the short training field (STF) data in the first frame of a frame stream are used in RX. The frame synchronization module has been also added in the front end of RX.

After these synchronization modules, some of OFDM modules have been built in RX. Using the module of symbol bonding, lossless encoded data can be obtained and thus the data are fed into the modules of RS decoding and HACP lossless video decoding.

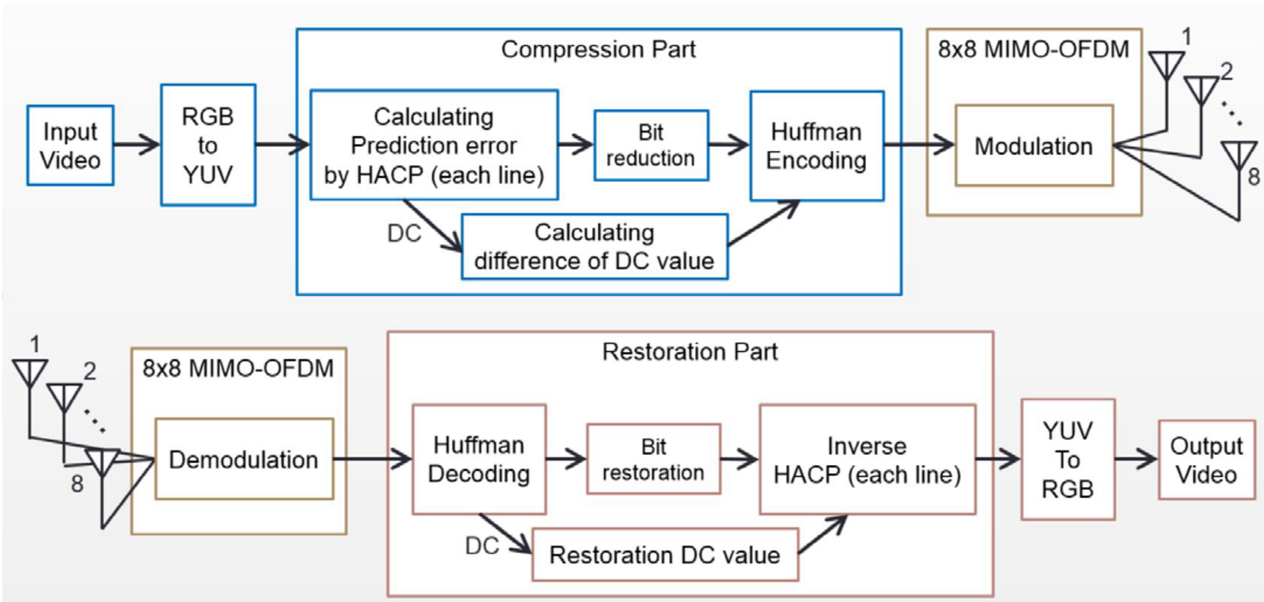

Fig. 1 The total system of lossless video communication using 8×8 MIMO-OFDM

III. HACP ALGORITHM [8]

The basic process of lossless compression is based on predictive image generation. Considering the cost of hardware implementation, we adopt the hierarchical average and copy prediction (HACP) [6], [7] since HACP has the following two advantages: (1) capability of macroblock-based parallel processing and (2) low cost implementation by simple arithmetic.

Fig. 1 shows the interface between the lossless video coding/decoding modules and MIMO-OFDM TX/RX. The HAPC procedure is generally based on several macro blocks for its lossless coding. The macro block means for example 8×8 pixel block. Into the macro block, the column and line prediction for the nearest pixels is executed and its prediction errors are coded. If we send these coded data over the wireless system, the macroblock level transportation seems to be good at the point of compression rate. In other words, high compression rate can be obtained by using large macro block.

However, in order to improve the lower latency and to realize the real time processing on the wireless system, one line in each frame level wireless transformation has been applied in the developed system (30 fps transmission capacity by FPGA).

The video data are first converted from RGB expressions to YUV expressions. As for the color spaces, we evaluated the compression rate using RGB and YUV. The video using YUV can show better efficiency than RGB. General approaches of converting color space from RGB to YUV cause a little image quality deterioration. The deterioration is slight but unavoidable. Therefore, in this paper, we have adopted reversible color transform (RCT) [11] employed in JPEG2000. This transform is employed as the lossless color space transformation.

After the color space transformation, one line HACP is applied. Since only one line processing is used into this processing, the memory buffer is saved to one line space. Accordingly, the power consumption in this module is drastically reduced.

IV. 8×8 MIMO-OFDM

As shown in Fig. 1, the standard OFDM system has been implemented in our system. The wireless communication protocol of IEEE 802.11ac is applied. In our application, a single user MIMO-OFDM using 8 streams with 80MHz bandwidth has been developed [1].

Fig. 2 shows the circuits evaluations of 8×8 MIMO-OFDM TX and RX modules. The total gate counts are about 13.3

Transmitter	Gate Count	Power (mW)
Scramble	4,830	0.57
Encoding	5,390	0.60
Interleave	104,020	14.2
Mapping	5,480	0.52
Pilot Insertion	218,970	29.9
IFFT	573,680	57.9
GI & Preamble	330,720	44.5
Total	1,243,090	148.2

Receiver	Gate Count	Power (mW)
Synchronization	21,410	2.5
FFT	573,920	81.0
Re-order & Pilot	235,370	33.4
MIMO Detection	7,800,630	956.6
De-mapping	14,580	1.1
De-interleave	676,930	73.4
Viterbi Decoding	2,711,330	257.6
De-Scramble	4,830	0.30
Total	12,039,000	1,405.9

Fig. 2 Circuits Evaluations of 8×8 MIMO-OFDM TX and RX modules

Millions. Among them, 60% gates are used for the MIMO Detection which includes channel estimation and memory buffers. The power dissipation is about 148mW at TX and 1,405mW at RX (1/3 lower than the previous system). They are evaluated as digital baseband (BB) circuits. In addition to these specification, the RF analog circuits and lossless video digital modules should be considered for the total gate counts and the total power dissipation.

In Fig. 3, the bit error rates (BER) of this system in Fig. 1 are given in cases of several conditions used in Read Solomon algorithm where the wireless system is based on 8×8 MIMO-OFDM with 80 MHz bandwidth and the simulation condition is assumed to be TGn Model D. The BER are given in cases of (16QAM, Coding Rate=3/4) and (64QAM, Coding Rate=3/4). In our experiments, if BER is less than 0.00001 (= e-005), all recovered video images can be observed without errors. In this case, the system can hold the good performance in case of (16QAM, R=3/4). However, in case of (64QAM, R=3/4), the strict conditions of RS and CNR are required, i.e., 30dB CNR and RS (Total Bit=255, Error Correction=127).

8x8 MIMO-OFDM 80MHz : TGn Model D	16QAM R=3/4	64QAM R=3/4
30dB not RS	1.8726e-005	3.8006e-002
30dB RS(63,43)	1.4406e-006	2.5491e-002
30dB RS(255,239)	3.7280e-006	3.0866e-002
30dB RS(255,215)	3.3592e-007	1.0263e-001
30dB RS(255,199)	0	4.4595e-002
30dB RS(255,159)		1.7983e-002
30dB RS(255,127)		1.2711e-002
40dB not RS	0	9.6794e-007

Fig. 3 BER of Lossless Video Communication over 8×8 MIMO-OFDM [10].

V. FIELD EXPERIMENTS OF THE SYSTEDM

This section shows some results of its field experiments. Fig. 4 shows the overview of our developed total system. For each

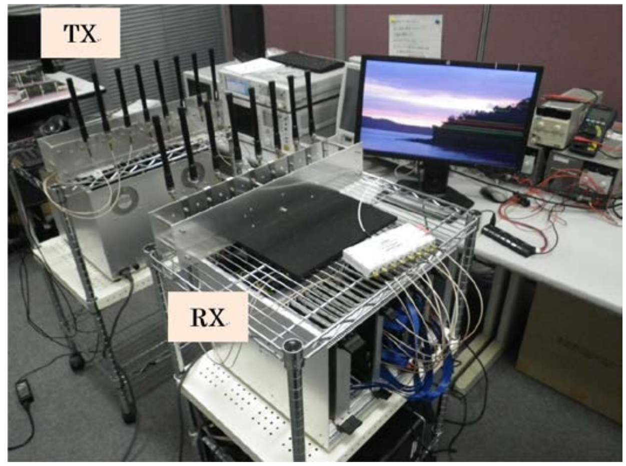

Fig. 4 Real-Time FHD Video Wireless Communication Systems

TX and RX, there are three evaluation boards for analog RF LSI, digital BB (8×8 MIMO-OFDM) LSI and digital Loss-less LSI. In order to evaluate each module separately, the different boards are designed and developed for these LSIs.

In the field experiments, the conditions of NLOS and LOS have been considered. In case of LOS, the 2m, 4m and 8m distance between RX and TX were applied in the same room. The specifications of wireless communication are given as MCS 4, i.e., 16QAM, Coding Rate 3/4 and MCS6, i.e., 64QAM and Coding Rate 3/4.

In case of NLOS, the distance between TX and RX was set as 8m and 10m. The same specifications were applied.

Compared with the simulation results, about 5 dB is deteriorated in cases of MCS4 and MCS6. In addition, about 10 dB is deteriorated in cases of MCS7. The 10 dB behind of MCS7 is unexpected wrong and it is not used in the real communication for video data.

Table 1 BER of MCS4 and MCS6 in Case of LOS

Spec	Distance	Power from TX	Gain of RX	CNR	BER
MCS4	2m(LOS)	-5dBm/1ch	+12dB	44.5dB	0
	4m(LOS)	-5dBm/1ch	+12dB	43.3dB	0
	8m(LOS)	-5dBm/1ch	+12dB	40.2dB	0
	8m(NLOS)	-5dBm/1ch	+12dB	35.4dB	5.90E-04
	8m(NLOS)	-5dBm/1ch	+12dB	32.5dB	8.16E-03
	8m(NLOS)	-5dBm/1ch	+12dB	28.4dB	5.06E-02
MCS6	2m(LOS)	-5dBm/1ch	0dB	38.7dB	3.93E-03
	4m(LOS)	-5dBm/1ch	+6dB	40.9dB	1.82E-03
	4m(LOS)	-5dBm/1ch	+12dB	42.5dB	1.33E-03
	8m(LOS)	-5dBm/1ch	0dB	31.9dB	1.16E-01
	8m(LOS)	-5dBm/1ch	+12dB	39.0dB	2.07E-03
	8m(NLOS)	-5dBm/1ch	+12dB	32.8dB	1.29E-01
	8m(NLOS)	-5dBm/1ch	+12dB	36.3dB	1.22E-02
	10m(NLOS)	0dBm/1ch	+20dB	40.3dB	6.24E-03

The interface between MIMO-OFMD and Loss-less Image LSI has been carefully designed with new protocol. If a memory buffer was employed between Loss-less Image module and MIMO-OFDM module, a large power consumption must be required. In addition, any certain latency also must be required because of the memory buffer.

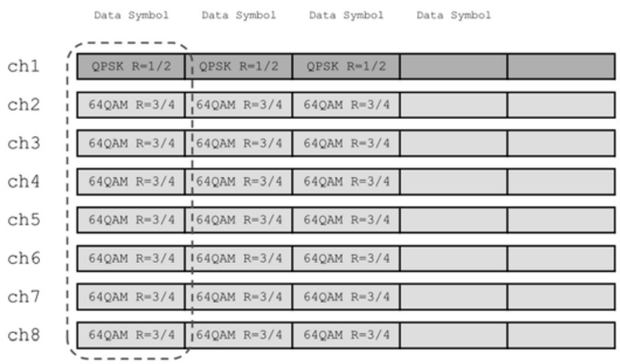

Fig. 5 Micro-packet Protocol

In our system, a real time data communication protocol is applied. Firstly, the HACP Loss-less Image processing is applied to a line-by-line. In order words, only one line is compressed and transferred between two modules. Our target image consists of 1920 pixel by 1080 pixel with 30 frames/second and thus the raw data are estimated around 1.5Gbps. By using one line HACP compression, we can get the 50% image loss-less compression. Accordingly, over 800Mbps communication throughput should be realized.

For the video wireless communication, the information about video compression rate, horizontal synchronizing signals, image size, and start/end points of compressed image data are always required in addition to the compressed video data itself. These side-information are quite important and thus they must be transferred without wireless communication errors. Fig. 5 shows our designed macro-packet protocol. In this figure, there are 8 channels. Among them, the first channel is selected for sending the above important side-information with noise robust amplitude/phase modulation, i.e., QPSK. For the other channels, 64 QAM is applied. In other words, the first channel transfers all of side-information with high QoS and other channels transfer coded video data with high throughput.

Finally, in the interface of the wireless module, 1 packet capacity consists of 20 data symbols and 1 symbol has 486 bits (= 108 * 3/4 * 6 in Ch.2 – 8) or 162 bits (= 108*3/4*2 in Ch.1) where the specification of the MIMO-OFDM are 40MHz Bandwidth, BPSK - 64QAM, 3/4 Coding Rate, 1.08GBPS throughput.

VI. Conclusions

In this paper, the real-time wireless communication system of lossless video data over 8×8 MIMO-OFDM wireless system has been introduced. The system has been developed by using LSI modules. Using the developed system, some of field experiments were demonstrated. In particular, new video transmission protocol to the wireless system has been proposed in order to realize both low power consumption and real-time video transmission.

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