Design of Very High Throughput WLAN System for 4K Digital Cinema Transmission

Wahyul Amien SYAFEI[#1] **, Hiroshi OCHI**[*2]

[#1] *Electrical Engineering, Faculty of Engineering, Diponegoro University, Jl. Prof. Soedarto, S.H. Tembalang, Semarang, Indonesia*
wasyafei@undip.ac.id

[*2] *Department of Computer Science and Electronics, Kyushu Institute of Technology, Japan*
ochi@cse.kyutech.ac.jp

***Abstract*— We proposed a design of a Very High Throughput Wireless LAN system. It reaches 33 meter propagation distance by using 80 Mhz bandwidth on 5 GHz band. The proposed preamble has backward compatibility with IEEE802.11n system, allows band sharing and avoids collision within 5 GHz band. The proposed preamble has comparable PAPR and preamble efficiency with IEEE892.11n system. Run test for transmitting 90 frames of 4K image size with 24 bit per pixel resolution for digital cinema simulation under in-door channel model demonstrates the excellent performance of the proposed system.**

Keywords – **VHT WLAN, backward compatibility, PAPR, preamble efficiency, digital cinema transmission**

I. INTRODUCTION

The demand of high throughput wireless communication leads the IEEE802.11ac task group (TGac) to discuss about new standard for WLAN system which has throughput over 1Gbps with carrier frequency lower than 6 GHz [1]. However, since it works in the same band as IEEE802.11n WLAN system [2], the backward compatibility is included in the functional requirements [3]. Other point to evaluate this system is the usage models, such as in-door high definiton video streaming, etc. [4].

Through this paper, we report our work in designing a 1.2 Gbps WLAN system based on IEEE802.11TGac's criteria. It reaches 33 meter propagation distance by utilizing 80 MHz bandwith on 5 GHz band. The proposed preamble has backward compatibility with IEEE802.11n system. This means that when the proposed preamble is transmitted, the IEEE802.11n system can recognize it, allowing band sharing and collision avoidance within 5 GHz band. Further, we propose a novel phase rotation to get the low PAPR signal and provide the data length two times longer than IEEE802.11n's to increase the preamble efficiency. The proposed system uses four transmission streams with five antennas at the receiver which contribute 2^{nd}-order diversity gain to maintain the throughput and performance. Soft viterbi decoder are employed as the forward error correction scheme. Run test for transmitting 90 frames of 4K digital cinema which has resolution of 4096×1714 under in-door channel model proves the excellent performance of the developed system. Channel model B of IEEE802.11TGn [5] is resampled and interpolated to model the in-door channel for performance examination [6].

This paper is organized as follows. The proposed 1.2 Gbps WLAN system with backward compatibility to IEEE802.11n system is briefly explained in section II. Section III describes the configuration of 4K digital cinema transmission for performance examination. In section IV, System performance, link budget analysis and video quality due to wireless transmission errors are presented. Finally, we draw some conclusions and future works in section V.

II. A 1.2-GBPS WIRELESS LAN SYSTEM WITH BACKWARD COMPATIBILITY TO IEEE802.11N SYSTEM

Block diagram of transmitter and receiver of the proposed system is shown in Figs. 1 and 2. Three samples of modulation coding scheme (MCS) which defines the parameteres to calculate the data rate are listed in Table I. The constants to calculate the timing are listed in Table II. Throughput over 1.2 Gbps is accomplished by using 400ns of guard interval (GI) on MCS-3.

A.Mixed Greenfield Preamble

Since the aim is gaining the throughput while maintaining the backward compatibility with IEEE802.11n system, in this paper we propose Mixed Greenfield (MGF) preamble which is an extension of Greenfield (GF) preamble of IEEE802.11n system. It consists of a HT-short training field (HT-STF), a HT-long training field (HT-LTF), a HT-signal field (HT-SIG), a VHT-signal field (VHT-SIG) and VHT-long training fields (VHT-LTFs) in 80MHz channel before the data portion, as illustrated in Fig.3. The proposed MGF preamble is 8μs longer than IEEE802.11n's GF preamble, however the data length is two times longer than that of IEEE802.11n mitigates this overhead. The transmitted signal on each transmit chain can be written as:

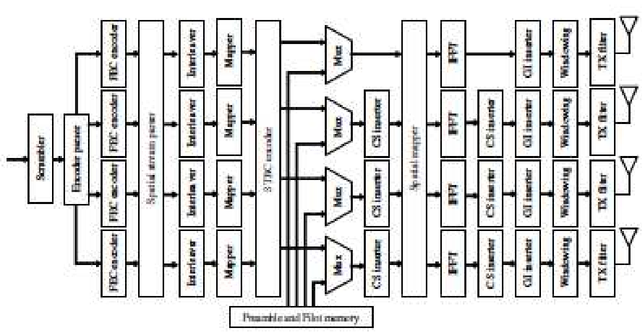


Fig. 1. Proposed Transmitter.

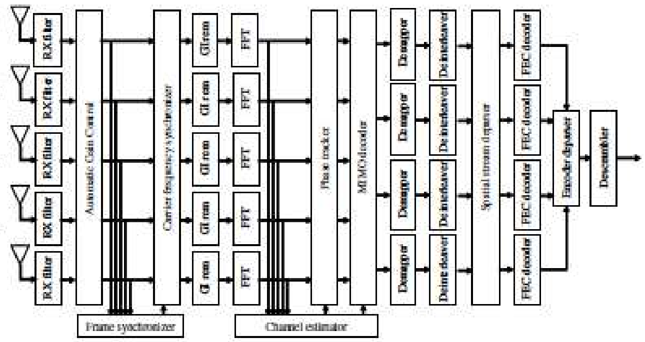


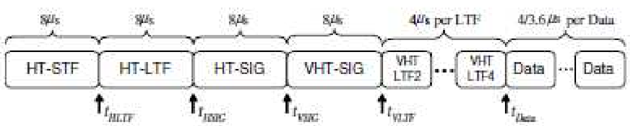
Fig. 2. Proposed Receiver.

TABLE I
SAMPLE OF MODULATION CODING SCHEME

MCS	Modulation	R	N_{BPSC} (i_{ss})	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	N_{SS}	Data rate [Mbps]	
									800ns GI	400ns GI
1	64-QAM	2/3	6	228	8	5472	3648	4	912	1013
2	64-QAM	3/4	6	228	8	5472	4104	4	1026	1140
3	64-QAM	5/6	6	228	8	5472	4560	4	1140	1266

TABLE II
CONSTANTS FOR CALCULATION THE TIMING IN PROPOSED 1.2 GBPS WLAN SYSTEM

Parameter	Value	Parameter	Value
Δ_F	312.5kHz (80MHz/256)	T_{HSTF}	8 (μs)
T_{DFT}	3.2 μs ($1/\Delta_F$)	T_{HLTF}	8 (μs)
T_{GI}	0.8 ; 0.4(μs)	$T_{HSIG,VSIG}$	8 (μs)
T_{SYM}	4 ; 3.6 (μs)	T_{VLTFs}	4 (μs)
T_{TR}	0.1 (μs)	T_{Data}	4 ; 3.6 (μs)



$$s^{(i_{TX})}_{PPDU}(t) = s^{(i_{TX})}_{HSTF}(t) + s^{(i_{TX})}_{HLTF}(t - t_{HLTF}) + s^{(i_{TX})}_{HSIG}(t - t_{HSIG}) + s^{(i_{TX})}_{VSIG}(t - t_{VSIG}) + \sum_{i_{LTF}=2}^{N_{LTF}} s^{(i_{TX}, i_{LTF})}_{VLTF}(t - t_{VLTF} - (i_{LTF} - 2)T_{VLTF}) + s^{(i_{TX})}_{Data}(t - t_{Data}) \quad (1)$$

where $t_{HLTF} = T_{HSTF}$; $t_{HSIG} = t_{HLTF} + T_{HLTF}$; $t_{VSIG} = t_{HSIG} + T_{HSIG}$; $t_{VLTF} = t_{VSIG} + T_{VSIG}$; $t_{Data} = t_{VLTF} + (N_{LTF} - 1)T_{VLTF}$.

1) HT - Short Training Field: is used for start-of-packet detection, automatic gain control setting, initial frequency offset estimation and time synchronization. It is constructed by four times duplicating of IEE802.11a STF symbols [7], frequency shifting and phase rotating, as illustrated in Fig.4. The time domain representation of HT-STF on transmit chain i_{TX} is:

TABLE III
PROPOSED VALUE OF TONE SCALING FACTOR (N^{tone}_{field})

field	N^{tone}_{field}	*field*	N^{tone}_{field}
HT-STF	48	*HT-SIG, VHT-SIG*	228
HT-LTF	228	*Data*	228

TABLE IV
PROPOSED CYCLIC SHIFT VALUES FOR EACH SPACE-TIME STREAM ($T^{i_{STS}}_{CS}$)

T^1_{CS}	T^2_{CS}	T^3_{CS}	T^4_{CS}
0 ns	- 400 ns	- 200 ns	- 600 ns

$$s^{(i_{TX})}_{HSTF}(t) = s_f\, w \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX}, i_{STS}} [\mathbf{P}]_{i_{STS},1} \Upsilon_k S_k . e^{j2\pi k \Delta_F (t - T^{i_{STS}}_{CS})}$$

$$s_f = \frac{1}{\sqrt{N^{tone}_{field} \cdot N_{TX}}} \quad \text{with} \quad N_{TX} = 4 \quad (2)$$

to ensure that the total power of the time domain signal as summed over all transmit chains is either 1 or lower than 1. Table III lists the values of N^{tone}_{field} for each field. w is the time windowing function which is defined as a rectangular pulse $w_T(t)$ of duration T.

$$w_T(t) = \begin{cases} \sin^2(\frac{\pi}{2}(0.5 + \frac{t}{T_{TR}})) & \text{for } (\frac{-T_{TR}}{2} < t < \frac{T_{TR}}{2}) \\ 1 & \text{for } (\frac{T_{TR}}{2} \le t < \frac{T - T_{TR}}{2}) \\ \sin^2(\frac{\pi}{2}(0.5 - \frac{(t-T)}{T_{TR}})) & \text{for } (\frac{T - T_{TR}}{2} \le t < \frac{T + T_{TR}}{2}) \end{cases} \quad (3)$$

where T_{TR} is the transition time between two consecutive symbols. Notation s_f and w will be used to represent the scale factor and time windowing function, respectively in subsequent equations. $\mathbf{Q}_k$ is a spatial mapping matrix which maps the each space-time stream (STS) symbols onto transmit chain symbols. $\mathbf{P}$ is an orthogonal matrix defined as:

$$\mathbf{P} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix} \quad (4)$$

Y*k* represents the proposed phase rotation in 80MHz channel to get low PAPR signal, as:

$$\Upsilon_k = \begin{cases} 1 & \text{for} \quad k \le -64 \;, 0 < k \le 64, \\ j & \text{for} \quad -64 < k \le 0 \\ -j & \text{for} \quad k > 64 \end{cases} \quad (5)$$

k is the subcarier index in the spectral line *S* −128,127. *S k* are the four times duplication of IEEE802.11a STF symbols placed at indices that are a multiple of four. This generates waveforms which has a period of 0.8µs, and the HT-STF includes ten such periods, with a total duration of 8µs. *TiSTS CS* represents the cyclic shift (CS) for each STS *iSTS* to prevent unintentionally beamforming. The values of *TiSTS CS* are specified in Table IV

2) Long Training Fields: consists of HT-LTF and VHTLTFs. The former is used for fine frequency offset estimation, fine time synchronization and estimate the MIMO channel for decoding the SIGNAL fields. The later are used to estimate the MIMO channel for decoding the data fields. Each LTF is constructed by two times duplicating of IEE802.11n HT-LTF symbols, frequency shifting and phase rotating, as illustrated in Fig.5. Each LTF has 4µs duration except the HT-LTF which is twice longer to improve channel estimation accuracy. The time domain of HT-LTF and VHT-LTFs on transmit chain *iTX* are represented in Eq. 6 and Eq. 7, respectively.

$$s^{(1,i_{TX})}_{HLTF}(t) = s_f \; w \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX},i_{STS}} [\mathbf{P}]_{i_{STS},1} \Upsilon_k L_k . e^{j2\pi k \Delta_F (t-\tau)} \quad (6)$$

$$s^{(n,i_{TX})}_{VLTFs}(t) = s_f \; w \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX},i_{STS}} [\mathbf{P}]_{i_{STS},n} \Upsilon_k L_k . e^{j2\pi k \Delta_F (t-\tau)} \quad (7)$$

where τ = 2*TGI* + *TiSTS CS* for HT-LTF, τ = *TGI* + *TiSTS CS* for VHTLTFs and *Lk* are the two times duplication of IEEE802.11n HT-LTF symbols.

3) Signal fields: consists of HT-SIG and VHT-SIG.

The former has the same format as IEEE802.11n HT-SIG so that it can be decoded by IEEE802.11n system. The later contains information about the transmitted frame and has special format as shown in Fig. 6. It composed of VHT-SIG1 and VHTSIG2 each containing 24 bits. All are convolutional encoded at rate=1/2, interleaved and BPSK mapped. The stream of 96 complex numbers generated by these steps is divided into two groups of 48 complex number: *Dk,n*, 0 ≤ *k* ≤ 47, *n* = 0, 1. VHTSIG1 provides data length up to 217 octets which is two times longer than that in IEEE802.11n system.

The time domain form of the VHT-SIG in transmit chain *iTX* is:

$$s^{(i_{TX})}_{VSIG}(t) = s_f \sum_{n=0}^{1} w \sum_{k=-26}^{26} \sum_{i_{STS}=1}^{4} [\mathbf{P}]_{i_{STS},1}(jD_{k,n} + p_n P_k) \Big([\mathbf{Q}_{k-96}]_{i_{TX},i_{STS}}(e^{j2\pi(k-96)\Delta_F(t-\tau)} + [\mathbf{Q}_{k-32}]_{i_{TX},i_{STS}}\, j.e^{j2\pi(k-32)\Delta_F(t-\tau)} + [\mathbf{Q}_{k+32}]_{i_{TX},i_{STS}}\, e^{j2\pi(k+32)\Delta_F(t-\tau)} - [\mathbf{Q}_{k+96}]_{i_{TX},i_{STS}}\, j.e^{j2\pi(k+96)\Delta_F(t-\tau)}\Big) \quad (8)$$

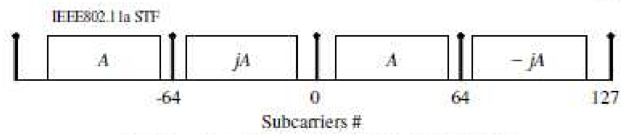


Fig. 4. Construction of the proposed HT-STF.

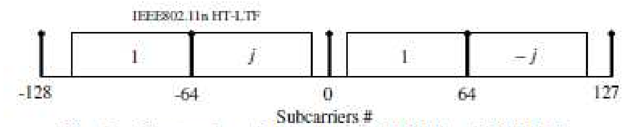


Fig. 5. Construction of the proposed HT-LTF and VHT-LTFs.

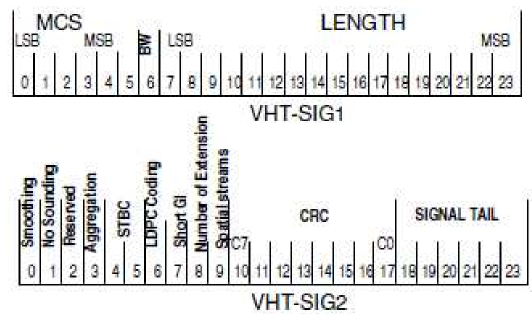


Fig. 6. Format of the proposed VHT-SIG. VHT-SIG1 provides the Data length two times longer than that in IEEE802.11n system to mitigate the overhead problem.

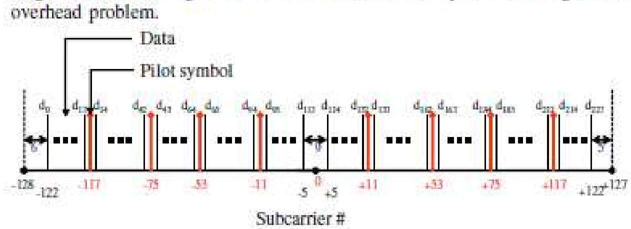


Fig. 7. Proposed data and pilot subcarriers allocation on OFDM symbol.

where τ = *nTSYM* + *TGI* + *TiSTS CS* . *Dk,n* is the data of VHTSIG which allocated on the *k*-th subcarrier of *n*-th OFDM symbol. *pn* is pilot polarity controller sequence which can be generated by IEEE802.11a's scrambler. Equation 8 results in a BPSK modulation in which the constellation of the data tones is rotated 90*o* relative to HT-LTF.

B. Preamble contribution

In this part we compare the proposed MGF preamble with the GF preamble of IEEE802.11n system. The preamble efficiency can be approached by:

$$\eta = \left(\frac{T_{SYM}.N_{SYM}}{T_{PREAMBLE} + T_{SYM}.N_{SYM}}\right)100\% \qquad (9)$$

Where $N_{SYM} = \lceil \frac{8.LENGTH+16+6.N_{ES}}{N_{DBPS}} \rceil$ is number of OFDM symbol in data field, and N_{ES} is number of FEC encoder. The preamble efficiency of both system for maximum LENGTH aggregation with *TSYM* = 4μs for four spatial streams is listed in Table VII.

PAPR of time domain OFDM signal which has *N* samples can be calculated by:

$$PAPR\ (\text{dB}) = 10\log_{10}\frac{max(|s_n|^2)}{E\{|s_n|^2\}},\ n = 0, \cdots, N-1 \qquad (10)$$

The PAPR comparison between both preambles is shown in Table VIII.

C. The Data Field

The Data field consists of 16-bit SERVICE field, physical sublayer service data unit (PSDU), 24 TAIL bits and PAD bits. All bits in the Data field are scrambled, convolutional encoded, punctured, interleaved and mapped to QAM symbols. Eight pilot signals are inserted in the sub-carriers *k* = −117, −75, −53, −11, 11, 53, 75 and 117. Each spatial time stream *iSTS* = 1, 2, 3, 4 has a different determined pilot pattern denoted as *Pki STS ,n*, *n* = 1, 2, · · · , 8. Pilots allocation in one OFDM symbol is illustrated in Fig. 7. After performing an IFFT, the output is cyclically extended as a GI. Two options of GI length are available to get the desired data rate. The time domain waveform of the VHT-Data on transmit chain *iTX* can be written as:

$$s_{Data}^{(i_{TX})}(t) = s_f \sum_{n=0}^{N_{SYM}-1} w \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX},i_{STS}} (D_k + p_{n+2} P_{i_{STS},n}^k) \Upsilon_k . e^{j2\pi k\Delta_F(t-\tau)} \qquad (11)$$

where $\tau = nT_{SYM} + T_{GI} + T_{CS}^{i_{STS}}$.

D. The Receiver Side

In this part we introduce very briefly the receiver side. After frequency and frame are synchronized and the GIs are removed each stream is demodulated using FFT. The minimum mean square error (MMSE) MIMO decoder which is used to cancel the interference signals contributes 2*nd* order diversity gain. This comes from MIMO linear decoder diversity which is stated as *NT* −*NR*+1, where *NT* and *NR* are number of transmit and receive antennas, respectively [8].

III. CONFIGURATION OF 4K DIGITAL CINEMA TRANSMISSION

The configuration of 4K digital cinema transmission to examine the performance of the proposed 1.2 Gbps WLAN system is shown in Fig. 8. It consists of pre and post processor, JPEG2000 part and WLAN system part. Pre-processor separates the data from a video player into video and audio data plus control. JPEG2000 encodes the images using Kakadu ver.6, ten layers with equal distance. At the receiver side, after the received data is decoded, the post-processor returns the video data to its original 4K digital cinema format. The JPEG2000 has seven error resilience tools (ERT) which make it has a high durability against the error.] [9]. The ERT will work optimally with system that has bit error rate (BER) lower than 10−6.

IV. SIMULATION

MCS-1, MCS-2 and MCS-3 with 400ns of GI duration are observed. Channel model B of IEEE802.11TGn is resampled to model the in-door channel for examining the proposed system. Table V lists the simulation parameters and fig. 9

TABLE V
PARAMETER FOR PERFORMANCE EXAMINATION

Parameter	Value
MCS Index	1; 2; 3
Frequency Carrier (f_c)	5.2 GHz
Antenna Configuration	4×5 MIMO
Bandwidth	80 MHz
Format Packet	Mixed Greenfield Mode
FEC Encoder	BCC with soft Viterbi decoder
Spatial Mapping	Direct
MIMO Decoder	Linear MMSE
Guard Interval Length	400 ns
Antenna Gain (G_{TX}, G_{RX})	0 dB
Noise Figure (NF)	7 dB
Implementation Margin (IM) *	5 dB
Transmit Power per BW (P_x)	2.5 mW/MHz
Boltzmann Constant (k)	1.381×10^{-23} J/K
Temperature (T)	290^o K
Light speed (c)	3.01×10^8 m/s
Channel	80 MHz in-door channel model

* : possible performance degradation in the implementation.

TABLE VI
PARAMETER FOR SIMULATING DIGITAL CINEMA TRANSMISSION

Parameter	Value
Frame Size	4096×1714 pixel
Color Depth	24 bits per pixel
Frame Rate	30 frames per second
JPEG2000 coding	Kakadu ver.6, 10 layers, with ERT
Target Compression	6 bits per pixel
Image Coding Rate	1.2 Gbps
WLAN Setting	MCS-3, 400 ns GI, 40 dB of SNR
Channel	80 MHz in-door channel model

shows the performance comparison. As expected, the lower coding rate shows better performance with the cost of throughput reduction. For target BER 10−6 the MCS-1, MCS-2 and MCS- 3 need 32dB, 35dB and 40dB of SNR, respectively. The throughput versus propagation distance of above scenarios is shown in Fig. 10. For LOS case all scenarios give throughput over 1 Gbps for 45 meter propagation distance, while for NLOS case they reach 18 meter propagation distance. MCS-3 achieves throughput 1.2 Gbps for 33 meter propagation distance. During digital cinema simulation total 90 frames with resolution 4096×1714 pixels per frame are transmitted. The image transmission's quality is evaluated using the peak-signal-tonoise ratio (PSNR) in dB. Typical values for the PSNR in lossy image and video compression are between 30 and 50 dB, where higher is better. Acceptable PSNR values for wireless transmission are considered to be about 20 dB to 25 dB [10]. However our target PSNR is over 40 dB to guarantee digital cinema transmission satisfactory. The parameters for simulating the image transmission are listed in Table VI. Since the image coding rate is 1.2 Gbps, only MCS-3 with 400 ns GI can be used to transmit those images. Fig. 11 shows the PSNR result, as the target BER is 10−6, MCS-3 which transmits the images using 40dB of SNR can achieve average PSNR of 51.31dB. Surprisingly, this value exceeds our target PSNR. Fig. 12 displays one sample of the received images which can not be distinguished from the original one by

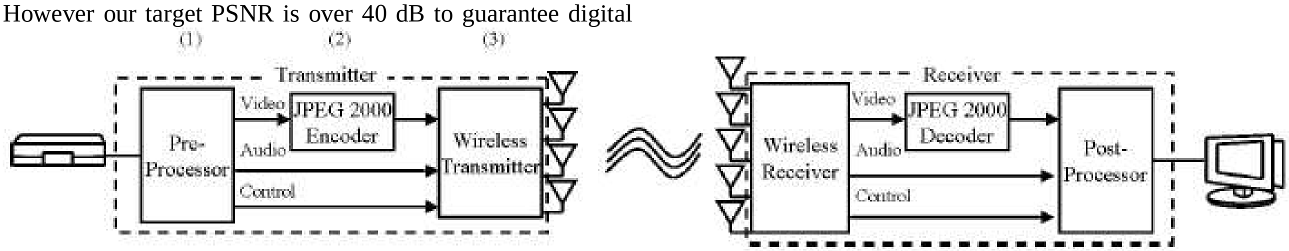


Fig. 8. Configuration of 4K digital cinema transmission system for performance examination of the proposed 1.2Gbps WLAN.

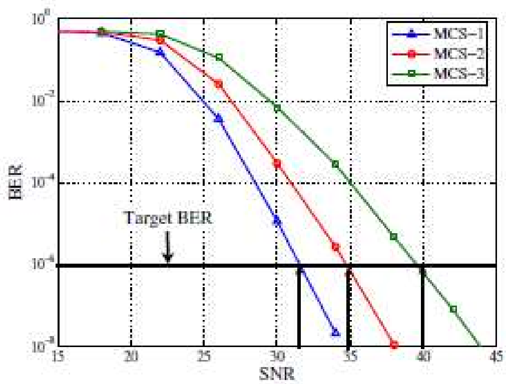


Fig. 9. Performance comparison between different MCS.

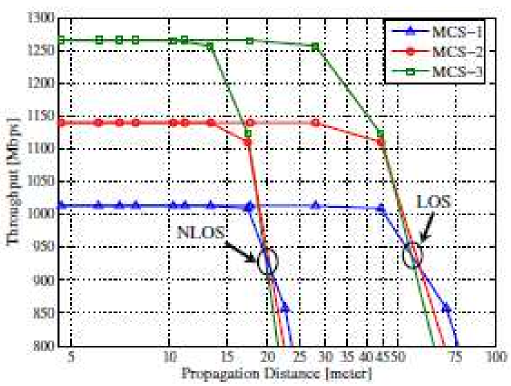


Fig.10. propagation distance in LOS and NLOS envoiroment.

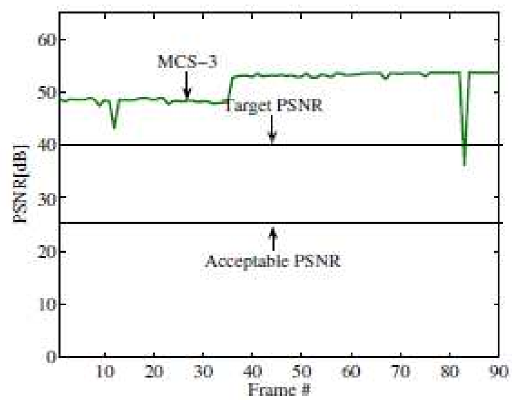


Fig. 11. Digital cinema transmission quality in PSNR.

TABLE VII
PREAMBLE EFFICIENCY (η) COMPARISON FOR FOUR SPATIAL STREAMS

Preamble	LENGTH	N_{SYM}	$T_{PREAMBLE}$	η
IEEE802.11n GF	65536 octet	243	36μs	96.43 %
Proposed MGF	131072 octet	230	44μs	95.44 %

TABLE VIII
PAPR COMPARISON

Field	IEEE802.11n GF	Proposed MGF
HT-STF	2.05 dB	2.23 dB
HT- LTF	3.16 dB	3.16 dB
HT- SIG	7.03 dB	7.06 dB
VHT- SIG	- dB	6.91 dB
Data	10.03 dB	10.16 dB

human's eye. These results demonstrate that the proposed 1.2 Gbps WLAN system has high performance and can be employed to provide excellent 4K digital cinema transmission.

V. CONCLUSION

We have been developing a 1.2 Gbps MIMO WLAN system which has backward compatibility with IEEE802.11n

WLAN system. The proposed preamble has comparable PAPR and preamble efficiency with IEEE802.11n GF preamble. Simulation results prove that the proposed system can be used to provide excellent 4K digital cinema transmission service. We will implement and evaluate this system on FPGA chips as a future work.

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Fig. 12. One sample of received image during digital cinema transmission simulation using MCS-3 with 40 dB of SNR.