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A 1.2 Gbps Wireless LAN System for 4K Digital Cinema Transmission

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***Abstract*—**

We propose an over 1.2 Gbps throughput wireless LAN system based on IEEE802.11TGac's requirements. It reaches 33 meter propagation distance by using 80MHz of bandiwdth on 5GHz band. 4 × 5 antennas configuration contribute 2^{nd}-order diversity gain and maintain both the high throughput and the high performance. The proposed Greenfield format preamble has high preamble efficiency. Novel phase rotation is employed to get low PAPR signal of preamble and data fields. 3 different coding rates are examined for 64-QAM constellation which all accomplish over 1 Gbps with maximum throughput 1.266 Gbps. Run test for transmitting 90 frames of 4096×1714 pixels/frame digital cinema under in-door channel model proves the excellent performance of the proposed system.

***Index Terms*—Gigabit wireless LAN, IEEE802.11 TGac, digital cinema transmission**

I. Introduction

In line with the exponential increment of the demand of high throughput wireless communication, the IEEE802.11n work group have been discussing to increase the system throughput based on user's experience. The IEEE802.11n PHY maximum throughput of 600 Mbps is achieved by using modulation coding scheme (MCS)-31 with short guard interval (GI) on 40MHz bandwidth [1]. The IEEE802.11n very high throughput (VHT) study group is formed for this purpose and divided to focus the discussion into VHTL6 and VHT60. The aim is making the standard for VHT WLAN system with carrier frequency lower than 6GHz and 60GHz [2]. After September 2008 the VHTL6 and VHT60 study groups become task groups of 802.11TGac and 802.11TGad, respectively. One of the points to be considered in developing the VHT system is the usage models, i.e. the kind of applications that can be supported by VHT system, such as high definiton (HD) video streaming, high-speed data transfer, etc. [3], [4].

In this paper, we propose a very high throughput (VHT) wireless LAN system based on IEEE802.11TGac's requirements and examine its performance through digital cinema transmission under in-door channel model. Channel model B of IEEE802.11TGn [5] is resampled to model this in-door environment [6]. It gives throughput over 1.2 Gbps for 33 meter propagation distance by utilizing 80MHz bandwith on 5Ghz band frequency. Greenfield format is proposed due to its compact form to endorse the throughput. Novel phase rotation is employed to get low peak-to-average-power ratio (PAPR) signal of preamble fields and the data fields on each stream. 4 transmission streams with 5 antennas at the receiver which contribute 2^{nd}-order diversity gain, maintain both the high throughput and the high performance. Binary convolutional code (BCC) with soft viterbi decoder are employed as forward error correction (FEC) scheme. Three different coding rate of are observed for transmitting 90 frames of 4096 × 1714 pixels/frame (4K) digital cinema. Simulation results prove the excellent performance of the proposed system whichever is the coding rate.

This paper is organized as follows. The proposed 1.2 Gbps WLAN system with greenfield preamble is briefly explained in section II. Section III deals with 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 analyzed. Finally, we draw some conclusions and future works in section V.

II. The 1.2 Gbps Wireless LAN system with Greenfield Preamble

Block diagrams of transmitter and receiver of the proposed system is shown in Figs. 1 and 2. Three samples of MCS which define the parameteres to calculate the data rate of this system is listed in Table I. The constants to calculate timing used in this system is listed in Table II. The throughput over 1.2 Gbps is accomplished by using 400ns of GI length on MCS-3.

Since the aim is getting the very high throughput (VHT), greenfield (GF) format preamble is the choice. GF has efficient frame format which consists of a VHT-short training field (VHT-STF), VHT-long training fields (a VHT-LTF1 and VHT-LTFs), and a VHT-Signal field (VHT-SIG) before the data portion (VHT-Data). However, same as IEEE802.11n, the GF format has no backward compatibility with the previous WLAN system [1]. Each preamble field has 8μs duration, except the VHT-LTFs that are used for channel estimation purpose has 4μs duration for each. The duration of data fields vary depend on the intended data rate. The placement of these fields with time boundaries is shown in Figure 3.

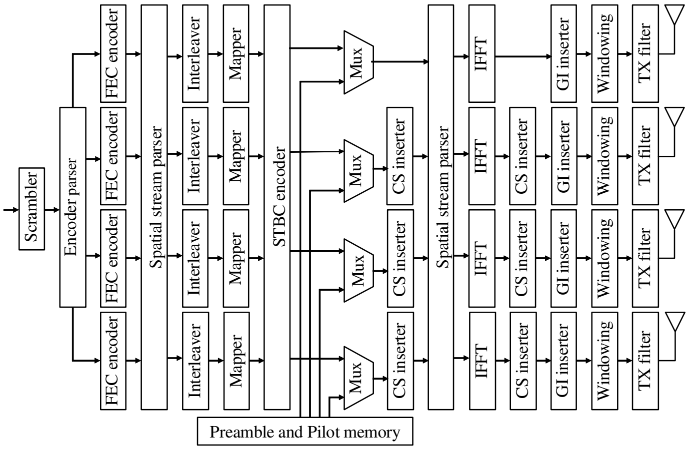

Fig. 1. Proposed Transmitter.

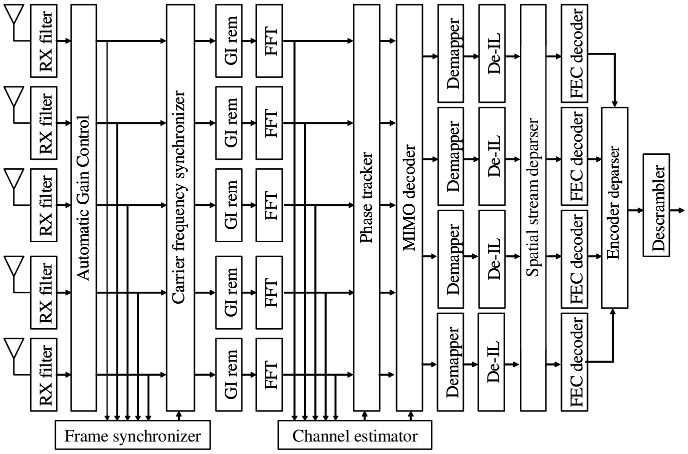

Fig. 2. Proposed Receiver.

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_{VSTF}	8 (μs)
T_{DFT}	3.2 μs (1/Δ_F)	T_{VLTF1}	8 (μs)
T_{GI}	0.8 ; 0.4; 0.2(μs)	T_{VSIG}	8 (μs)
T_{SYM}	4 ; 3.6 (μs)	T_{VLTFs}	4 (μs)
T_{TR}	0.1 (μs)	T_{Data}	4 ; 3.6 (μs)

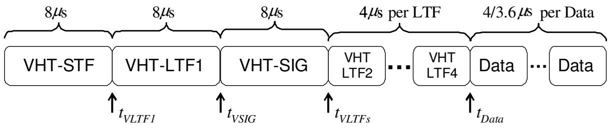

Fig. 3. Proposed Greenfield format preamble with time boundaries.

A. Signal Description

In the VHT GF format, the transmitted signal on each transmit chain $i_{TX}, i = 1, 2, 3, 4$ is:

$$\begin{aligned} s^{(i_{TX})}_{PPDU}(t) = {} & s^{(i_{TX})}_{VSTF}(t) + s^{(i_{TX})}_{VLTF1}(t - t_{VLTF}) + s^{(i_{TX})}_{VSIG}(t - t_{VSIG}) \\ & + \sum_{i_{LTF}=2}^{N_{LTF}} s^{(i_{TX},i_{LTF})}_{VLTF}(t - t_{VLTF} - (i_{LTF} - 2)T_{VLTF}) \\ & + s^{(i_{TX})}_{Data}(t - t_{Data}) \end{aligned} \tag{1}$$

where $t_{VLTF} = T_{VSTF}$;
$t_{VSIG} = t_{VLTF} + T_{VLTF}$;
$t_{VLTFs} = t_{VSIG} + T_{VSIG}$;
$t_{Data} = t_{VLTFs} + (N_{LTFs} - 1).T_{VLTF}$.

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

$$s^{(i_{TX})}_{VSTF}(t) = s_f\, w \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX},i_{STS}} [\mathbf{P}]_{i_{STS},1} \Upsilon_k S_k . e^{j2\pi k \Delta_F (t - T^{i_{STS}}_{CS})} \tag{2}$$

where $s_f = \frac{1}{\sqrt{N^{tone}_{field} \cdot N_{TX}}}$ with $N_{TX} = 4$ is the scale factor 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 which descibes the number of used subcarriers in OFDM symbol. w is the time windowing function which is defined as a rectangular pulse $w_T(t)$ of duration T.

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

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 $x^{(i_{TX})}_k$. For line of sight (LOS) environment $\mathbf{Q}_k$ is an identity matrix. For No LOS (NLOS) environment, expansion mapping of $\mathbf{Q}_k$ is applied. $\mathbf{P}$ is an orthogonal matrix defined as:

$$\mathbf{P} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix} \tag{4}$$

TABLE III

PROPOSED VALUE OF TONE SCALING FACTOR (N_{field}^{tone})

field	N_{field}^{tone}
VHT-STF	48
VHT-LTF	228
VHT-SIG	228
Data	228

TABLE IV

PROPOSED CYCLIC SHIFT VALUES FOR EACH SPACE-TIME STREAM ($T_{CS}^{i_{STS}}$)

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

Υ_k represents the proposed rotation of the tones in 80MHz channel to get low PAPR signal, as:

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

where 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 L-STF includes ten such periods, with a total duration of 8μs. $T_{CS}^{i_{STS}}$ represents the cyclic shift (CS) for each STS to prevent unintentionally beamforming. The values of $T_{CS}^{i_{STS}}$ are specified in Table IV.

2) VHT-LTF: is used for fine frequency offset estimation, time synchronization, and estimate the MIMO channel characteristics for decoding the SIGNAL fields. It is constructed by two times duplicating of IEE802.11n HT-LTF [1], frequency shifting and phase rotating, as illustrated in Fig.5. Each VHT-LTF has 4μs duration except the VHT-LTF1 which is twice longer to improve channel estimation accuracy. The VHT-LTF1 is assigned for decoding the SIGNAL fields while the subsequent VHT-LTFs are intended for the Data portion. The time domain of the VHT-LTF1 and VHT-LTFs on transmit chain i_{TX} are represented in Eq. 6 and Eq. 7, respectively.

$$s_{VLTF1}^{(1,i_{TX})}(t) = s_f \ w \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX},i_{STS}} [\mathbf{P}]_{i_{STS},1} \Upsilon_k L_k . e^{j2\pi k \Delta_F (t-\tau)} \tag{6}$$

where $\tau = 2T_{GI} + T_{CS}^{i_{STS}}$,

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

where $\tau = T_{GI} + T_{CS}^{i_{STS}}$, L_k are the two times duplication of IEEE802.11n HT-LTF symbols.

3) VHT-SIG field: contains information about the transmitted frame and has special format as shown in Fig. 6. It composed of VHT-SIG1 and VHT-SIG2 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: $D_{k,n}, 0 \le k \le 47, n = 0, 1$. VHT-SIG1 field provides data length up to 2^{17} octets which is two times longer than that in IEEE802.11n system to mitigate frame's overhead problem. The time domain form of the VHT-SIG in transmit chain i_{TX} is:

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

where $\tau = t - nT_{SYM} - T_{GI} - T_{CS}^{i_{STS}}$. $D_{k,n}$ and P_k are the data of VHT-SIG and pilot which allocated on k-th subcarrier of n-th OFDM symbol as illustrated in Fig. 7. p_n is the sequence generated by the scrambler with the "all ones" initial state and by replacing all "1's" with -1 and all "0's" with 1.

B. Preamble contribution

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

$$\eta = \Big(\frac{T_{SYM}.N_{SYM}}{T_{PREAMBLE} + T_{SYM}.N_{SYM}} \Big) 100\% \tag{9}$$

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 GF preamble efficiency of both system for maximum LENGTH aggregation with $T_{SYM} = 4\mu$s for four spatial streams is listed in Table VII.

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

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

The PAPR comparison between both preambles is shown in Table VIII. The PAPR value for the STFs and LTFs are constant, while for SIG and data fields are vary depend on contained information.

C. The Data Field

The Data field consists of the 16-bit SERVICE field, the PHY sublayer service data unit (PSDU), 24 TAIL bits for 4 encoding streams, and PAD bits. All bits in the Data field are scrambled.

The SERVICE field is used for scrambler initialization. It is composed of 16 bits, all set to zero before scrambling. The TAIL bits are 6 bits of zero for each stream which are required to return the convolutional encoder to the "zero state". These TAIL bits are produced by replacing 6 scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

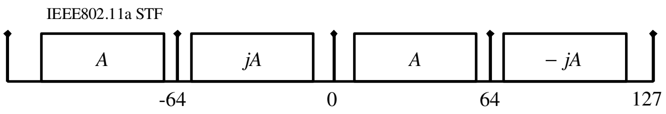

Fig. 4. Construction of the proposed VHT-STF.

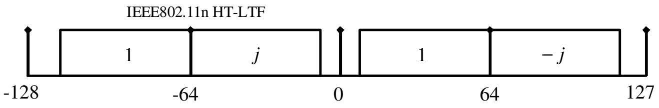

Fig. 5. Construction of the proposed VHT-LTF.

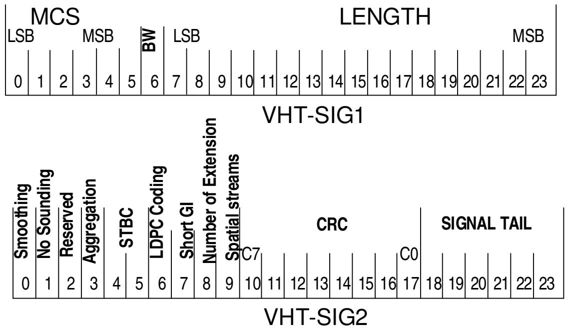

Fig. 6. Format of the proposed VHT-SIG. VHT-SIG1 provides the Data length two times longer than that in IEEE802.11n system to mitigate the overhead problem.

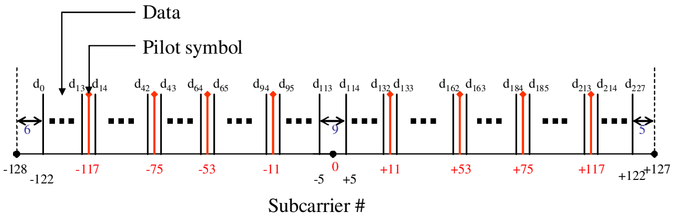

Fig. 7. Proposed data and pilot subcarriers allocation on OFDM symbol.

The PAD bits is appended so that the number of bits in the DATA field is a multiple of N_{CBPS}.

To reduce the probability of long sequences of zeros or ones, the Data field is scrambled by using frame synchronous scrambler which has generator polynomial $G(x) = x^7 + x^4 + 1$.

The scrambled data is convolutionally encoded to enhance the performance against channel noise. The scrambled data bits are divided between 4 BCC encoders which has generator polynomials $G_0 = 133_8$ and $G_1 = 171_8$ of rate $R = 1/2$. After encoding, the encoded data is punctured to achieve the rate selected by the MCS index.

Spatial stream parser divides the encoded data into blocks of $N_{CBPSS}(i_{SS})$, $i_{SS} = 1, 2, 3, 4$ bits. Each block is interleaved by a three steps permutation interleaver in frequency domain then mapped to QAM symbols

Two options of Spatial mapper $[\mathbf{Q}]$ are available, direct and extension mapping. The later mapping promises robust communication in NLOS environment.

Eight pilot signals are inserted in the sub-carriers $k = -117, -75, -53, -11, 11, 53, 75$ and 117. Each spatial time stream $i_{STS} = 1, 2, 3, 4$ has a different determined pilot pattern denoted as $P^k_{i_{STS},n}$, $n = 1, 2, \cdots, 8$. Pilots allocation in one OFDM symbol is illustrated in Fig. 7.

The 256 inverse fast Fourier transform (IFFT) point is used to get the time domain OFDM signals. The indices 1 to 122 are mapped to the same numbered IFFT inputs, while the indices -122 to -1 are copied into IFFT inputs 134 to 255. The rest of the inputs: 123 to 133 and the 0 (dc) input are set to zero. 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 i_{TX} can be written as:

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

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

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 the fast Fourier transform (FFT). Five streams of received training sequences are exploited to estimate the MIMO channel characteristics including phase error, the output is the 5 × 4 estimated channel matrix. 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 $N_T - N_R + 1$, where N_T and N_R are number of transmit and receive antennas, respectively [8]. Before errors are corrected by soft decision Viterbi decoder, the deinterleaver returns the data block to original sequence. Finally, descrambler returns the data to its original order.

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 3 main parts, (1) Pre and post processor, (2) JPEG2000 part and (3) Wireless LAN system part.

The Pre-processor separates the data from a video player into video and audio data plus control. In JPEG2000 encoder the images are encoded using Kakadu ver.6 one layer with Wavelet transform level 5. 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}.

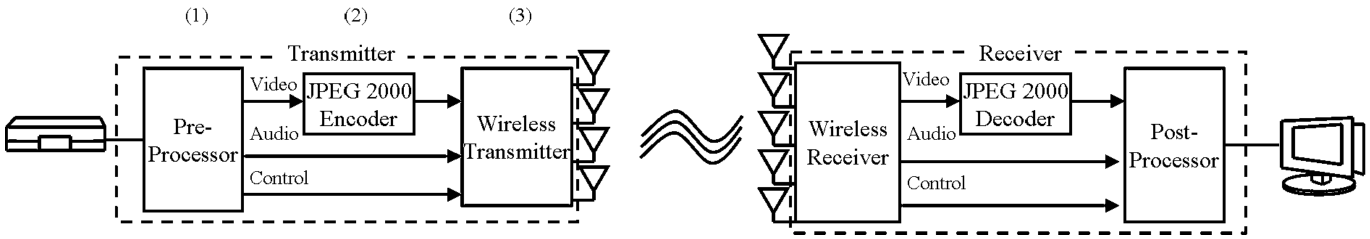

Fig. 8. Configuration of 4K digital cinema transmission system for performance examination of the proposed 1.2Gbps WLAN.

IV. Simulation

We observe three scenarios MCS-1, MCS-2 and MCS-3 with 400ns of GI duration. Channel model B of IEEE802.11TGn is resampled to model the in-door environment for examining the proposed system. Table V lists the simulation parameters. Fig. 9 shows the curve of 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 link budget analysis to calculate the propagation distance can be approached by:

$$d = \frac{\lambda}{4\pi 10^{\frac{L}{20}}} \tag{12}$$

where λ is transmitted wave length, $L = L_{d\leq 5} = 10\log_{10}(P_x B\alpha) + G_{TX} - G_{RX} - (SNR + 10\log(kTB) + NF + IM)$ is the path loss for $d \leq 5$ m, and $L = L_{d\leq 5} + 35\log_{10}(d/5)$ for $d > 5$ m. These parameters and their values are included in Table V. $\alpha \leq 1$ is the eficiency factor and constant 5 is the LOS break-point distance. The propagation distance of three scenarios is shown in Fig. 10. For the LOS case all scenarios give throughput over 1 Gbps for 45 meter propagation distance, while for the NLOS case they reach 18 meter propagation distance. The throughput 1.2 Gbps can propagate up to 33 meter using MCS-3.

During digital cinema simulation total 90 frames with resolution 4096×1714 pixels per frame are transmitted for 3 seconds of show. The image transmission's quality is evaluated using the peak signal to noise ratio (PSNR) in dB which is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. For $m \times n$ size colour image red-green-blue (RGB) the PSNR is calculated by.

$$PSNR = 10\log_{10}\frac{Peak^2}{\frac{1}{3mn}\sum_{c=0}^{2}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}||O(c,i,j) - R(c,i,j)||^2} \tag{13}$$

where O and R are the original and received image respectively. Since 8 bits are used to represent each color the *Peak* is 255. 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 quality loss are considered to be about 20 dB to 25 dB [10], [11]. 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 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.

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	VHT Greenfield Mode
FEC Encoder	BCC with soft Viterbi decoder
Spatial Mapping	Direct
MIMO Decoder	Linear MMSE
Guard Interval Length	400 ns
System Throughput	1.013; 1.140; 1.266 [Gbps]
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 Resolution	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

V. Conclusion

We have been developing a 1.2 Gbps MIMO WLAN system based on IEEE802.11TGac's criteria. The proposed preamble and new phase rotation gives comparable efficiency and PAPR

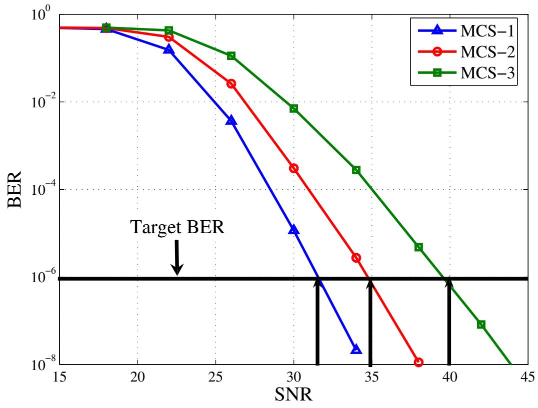

Fig. 9. Performance comparison between different MCS.

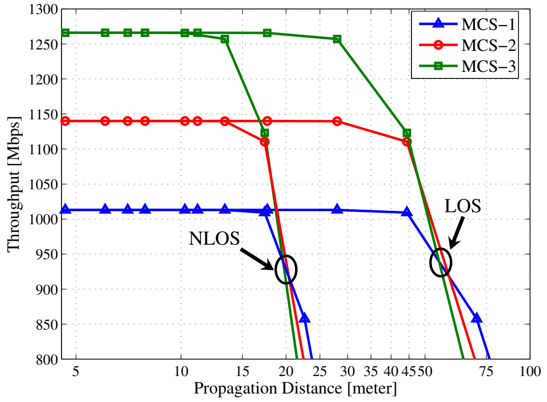

Fig. 10. Propagation distance in LOS and NLOS environment.

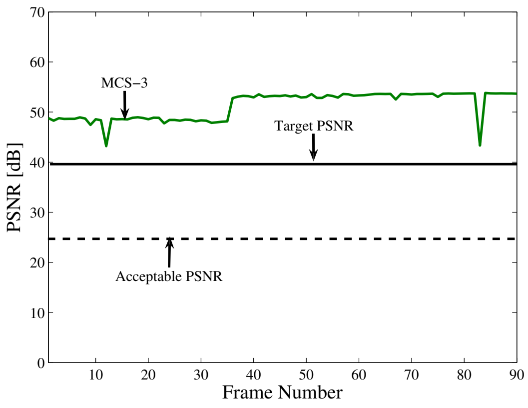

Fig. 11. Digital cinema transmission quality.

TABLE VII

Preamble Efficiency (η) comparison for four spatial streams with $T_{SYM} = 4\mu s$

Preamble	LENGTH	N_{SYM}	$T_{PREAMBLE}$	η
IEEE802.11n GF	65536 octet	243	$36\mu s$	96.43 %
Proposed GF	131072 octet	230	$36\mu s$	96.23 %

TABLE VIII

PAPR comparison

Field	IEEE802.11n GF	Proposed GF
STF	2.05 dB	2.23 dB
LTF	3.16 dB	3.16 dB
SIG	5.76 dB	5.91 dB
Data	10.03 dB	10.16 dB

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. [12]

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References

[1] ”Draft STANDARD for Information Technology - Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks - Specific Requirements”, IEEE P802.11n./D9.0, March 2009.

[2] E. Perahia, ”IEEE P802.11 Wireless LANs: VHT below 6GHz PAR Plus 5C’s”, doc.:IEEE 802.11-08/0807r4, 2008.

[3] H. Jeon, ”IEEE P802.11 Wireless LANs: 802.11 TGac Functional Requirements”, doc.:IEEE 802.11-08/1285r0, 2008.

[4] Mark G and Rolf de V, ”Introduction to VHT Usage Models”, doc.:IEEE802.11-08/1323r0, 2008.

[5] V. Erceg et al ”TGn Channel Models,” doc.:IEEE 802.11-03/0940r4, 2003.

[6] Minho C and Peter L, ”Proposal for TGac Evaluation Methodology”, doc.:IEEE802.11-09/0376r1, March 2009.

[7] ”Suplement to IEEE STANDARD for Information Technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements”, IEEE Std 802.11a-1999(R2003), June 2003.

[8] Proakis and Salehi, ”Digital Communications” Fifth Edition. Mc. Graw Hill. International Edition, 2008.

[9] ISO/IEC, ”Information technology - JPEG 2000 image coding system - Part 1: Core coding system,” ISO/IEC 15444-1, 2000.

[10] Thomos, N., Boulgouris, N. V., Strintzis, M. G. ,”Optimized Transmission of JPEG2000 Streams Over Wireless Channels”. IEEE Transactions on Image Processing, January 2006.

[11] Xiangjun, L., Jianfei, C.,”Robust Transmission of JPEG2000 Encoded Images Over Packet Loss Channels.” IEEE ICME 2007, July 2-5, 2007, Beijing, China.

[12] W.A. Syafei, Y. Nagao, R. Imashioya, M. Kurosaki, B. Sai and H. Ochi, ”FPGA Implementation of High Throughput 600 Mbps WLAN System using 4×2 MIMO OFDM,” 42nd Asilomar Conference on Signals, Systems and Computers, CA, USA, Oct. 26-29, 2008.

Fig. 12. Received image using MCS-3 of the proposed 1.2 Gbps MIMO WLAN system. Throughput >1.2 Gbps, propagation distance 33 meter. Image was encoded using JPEG-2000 Kakadu ver. 6, 10 layers, 1/4 compression ratio, with ERT and transmitted using 40 dB of SNR. Digital cinema transmission quality in average PSNR is 51.31 dB.