Design Implementation of Next Generation Wireless LAN for Mass Digital Cinema

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Abstract—We have been designing an over 1.2 Gbps throughput wireless for next generation WLAN system conform with IEEE802.11TGac’s requirements. It reaches 33 meter propagation distance by using 80MHz of bandwidth on 5GHz band. 4 × 5 antennas configuration contribute 2nd-order diversity gain and maintain both the high throughput and performance. The Greenfield format preamble was proposed for its high efficiency. Novel phase rotation is employed to lower the PAPR signal. Run test for transmitting 90 frames of 4096 × 1714 pixels/frame under in-door channel model proves that the proposed system shall be considered for providing an excellent performance mass digital cinema.

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 definition (HD) video streaming, high-speed data transfer, etc. [3], [4].

In this paper, we design and examine a very high throughput (VHT) wireless LAN system conform with the 802.11TGac’s requirements to provide an excellent mass digital cinema. [5] Channel model B of 802.11TGN [6] is resampled to model in-door environment for system examination [7]. The designed system can provide throughput over 1.2 Gbps for 33 meter propagation distance by utilizing 80MHz bandwidth 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 on each stream [8]. Four transmission streams with five antennas at the receiver which contribute 2nd-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 an excellent performance of the designed system for mass digital cinema.

The rest of this paper is organized as follow. The designed 1.2 Gbps WLAN system with greenfield preamble is briefly explained in section II. Section III deals with the configuration of mass digital cinema transmission. In section IV, System performance, link budget analysis and video quality due to wireless transmission errors are analyzed. Finally, some conclusions and future works are drawn in section V.

II. THE 1.2 Gbps WIRELESS 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 guard interval (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 systems [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 is 3.6μs or 4μs depend on the intended data rate. The placement of these fields with time boundaries is shown in Figure 3.
TABLE I
SAMPLE OF MODULATION CODING SCHEME

<table>
<thead>
<tr>
<th>MCS</th>
<th>Modulation</th>
<th>$R$</th>
<th>$N_{BPSK}$($i_{tx}$)</th>
<th>$N_{DF}$</th>
<th>$N_{SF}$</th>
<th>$N_{CBP}$</th>
<th>$N_{DBPS}$</th>
<th>$N_{SS}$</th>
<th>Data rate [Mbps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64-QAM</td>
<td>2/3</td>
<td>6</td>
<td>228</td>
<td>8</td>
<td>5472</td>
<td>3648</td>
<td>4</td>
<td>912</td>
</tr>
<tr>
<td>2</td>
<td>64-QAM</td>
<td>3/4</td>
<td>6</td>
<td>228</td>
<td>8</td>
<td>5472</td>
<td>4104</td>
<td>4</td>
<td>1026</td>
</tr>
<tr>
<td>3</td>
<td>64-QAM</td>
<td>5/6</td>
<td>6</td>
<td>228</td>
<td>8</td>
<td>5472</td>
<td>4500</td>
<td>4</td>
<td>1140</td>
</tr>
</tbody>
</table>

Fig. 2. Block Diagram of Gigabit WLAN Receiver.

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta F$</td>
<td>312.5 kHz (80MHz/256)</td>
<td>$\Delta F$</td>
<td>312.5 kHz (80MHz/256)</td>
</tr>
<tr>
<td>$T_{DFT}$</td>
<td>5.2 $\mu$s (1/$\Delta F$)</td>
<td>$T_{VSTF}$</td>
<td>8 $\mu$s</td>
</tr>
<tr>
<td>$I_{F}$</td>
<td>0.8 ; 0.4, 0.2 ($\mu$s)</td>
<td>$T_{VSIG}$</td>
<td>8 $\mu$s</td>
</tr>
<tr>
<td>$T_{SYM}$</td>
<td>4 ; 3.6 ($\mu$s)</td>
<td>$T_{VSTF}$</td>
<td>4 $\mu$s</td>
</tr>
<tr>
<td>$T_{TX}$</td>
<td>0.1 ($\mu$s)</td>
<td>$T_{Data}$</td>
<td>4 ; 3.6 ($\mu$s)</td>
</tr>
</tbody>
</table>

Fig. 3. The Greenfield format with time boundaries for efficient preamble.

A. Signal Description

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

$$s_{PPE}_{(i_{tx})}(t) = s_{PPE}(t) + s_{VSTF}_{(i_{tx})}(t-I_{VSTF}) + s_{VSTF}(t-I_{VSTF})$$

$$+ \sum_{i_{ts}=1}^{N_{ts}} s_{VSTF}(t-I_{VSTF} - (i_{ts}-2)T_{VSTF})$$

$$+ s_{VSTF}(t-I_{Data})$$

(1)

where $I_{VSTF} = I_{VSTF}$;
$I_{VSIG} = I_{VSTF} + T_{VSTF}$;
$I_{VSTF} = I_{VSTF} + T_{VSTF}$;
$I_{Data} = I_{VSTF} + (N_{ts} - 1)T_{VSTF}$.

1) VHT-STF: Very high throughput - Short training field 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 duplication of IEE802.11a STF [9], followed by frequency shifting and phase rotating, as illustrated in Fig.4. The time domain representation of the VHT-STF on transmit chain $i_{tx}$ is:

$$s_{VSTF}(t) = s_{f} w \sum_{k=1}^{122} [Q]_{i_{tx},i_{ts}} [P]_{i_{ts},i}T_{S} S_{k} e^{j 2\pi k}$$

(2)

where $s_{f} = \frac{1}{N_{tx}}$ 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 $N_{F}$ for each field which describes 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 $T$.

$$w_{T}(t) = \begin{cases} \sin\left(\frac{\pi}{T_{2}} (0.5 + \frac{t}{T_{2}})\right) & \text{for } (T_{2} - T_{s}) < t < \frac{T_{2}}{2} \\ 1 & \text{for } (\frac{T_{2}}{2} \leq t < \frac{T_{2}}{2} + T_{s}) \\ \sin^{2}\left(\frac{\pi}{T_{2}} (0.5 - \frac{t-T_{s}}{T_{2}})\right) & \text{for } (\frac{T_{2}}{2} + T_{s}) < t \leq \frac{T_{2}}{2} + T_{s} \end{cases}$$

(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. $Q_{k}$ is a spatial mapping matrix which maps the each space-time stream (STS) symbols onto transmit chain symbols $X_{k}^{(i_{tx})}$. For line of sight (LOS) environment $Q_{k}$ is an identity matrix. For No LOS (NLOS) environment, expansion mapping of $Q_{k}$ is applied. $P$ is an orthogonal matrix defined as:

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

(4)
IEEE802.11n HT-LTF symbols are 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 duplication of IEEE802.11a HT-LTF [1], followed by frequency shifting and phase rotating, as illustrated in Fig. 5. Each VHT-LTF has 4μs duration except the VHT-LTFI which is twice longer to improve channel estimation accuracy. The VHT-LTFI is assigned for decoding the SIGNAL fields while the subsequent VHT-LTFS are intended for the Data portion. The time domain of the VHT-LTFI and VHT-LTFS on transmit chain \(i_{TX}\) are represented in Eq. 6 and Eq. 7, respectively.

\[
s_{\text{VHT-LTF}1}^{(i_{TX})}(t) = s_f \sum_{k=128}^{127} \sum_{i_{STF}=1}^{4} [Q_k]_{i_{STF}1} T_{\delta} L_k e^{j2\pi k (t-t)}
\]

where \(T_{\delta} = 2T_{GI} + T_{CS}^{\text{VHT-LTF1}}\),

\[
s_{\text{VHT-LTFS}}^{(i_{TX})}(t) = s_f \sum_{k=128}^{127} \sum_{i_{STF}=1}^{4} [Q_k]_{i_{STF}1} T_{\delta} L_k e^{j2\pi k (t-t)}
\]

where \(T_{\delta} = T_{GI} + T_{CS}^{\text{VHT-LTFS}}\), \(L_k\) are the two times duplication of IEEE802.11a HT-LTF symbols.

3) VHT-SIG field: Very high throughput - Signal 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: \(D_c, 0 \leq k \leq 47, n=0, 1\). VHT-SIG1 field provides data length up to 217 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:

\[
s_{\text{VHT-SIG}}^{(i_{TX})}(t) = s_f \sum_{n=0}^{26} \sum_{i_{STF}=1}^{4} [P_k]_{i_{STF},1} (jD_{k,n} + p_n P_k)
\]

\[
\sum_{k=1}^{96} [Q_{k-96}]_{i_{TX},i_{STF}} e^{j2\pi (k-96)T_{\delta} \tau} + [Q_{k-32}]_{i_{TX},i_{STF}} e^{j2\pi (k-32)T_{\delta} \tau}
\]

\[
+ [Q_{k+32}]_{i_{TX},i_{STF}} e^{j2\pi (k+32)T_{\delta} \tau} - [Q_{k+96}]_{i_{TX},i_{STF}} e^{j2\pi (k+96)T_{\delta} \tau}
\]

where \(\tau = t - nT_{SYM} - T_{GI} - T_{CS}^{\text{VHT-SIG1}} \cdot D_{k,n}\) 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 802.11n one. The preamble efficiency can be approximated by:

\[
\eta = \frac{T_{SYM} N_{SYM}}{T_{PREAMBLE} + T_{SYM} N_{SYM}} 100\%
\]

where \(N_{SYM} = \frac{\text{LENGTH}_{16+6.6N_{ES}}}{N_{ES}}\) 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:

\[
PAPR (dB) = 10 \log_{10} \max \left\{ \frac{\|s_n\|^2}{E[|s_n|^2]} \right\}, \quad n = 0, \ldots, N - 1
\]

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 slightly 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
Two options of Spatial mapper \([Q]\) 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 \(i_{S TS} = 1, 2, 3, 4\) has a different determined pilot pattern denoted as \(p_k^{i_{S TS} = n}, n = 1, 2, \cdots, 8\). 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 increase the data rate when possible. The time domain waveform of the VHT-Data on transmit chain \(i_{TX}\) can be written as:

\[
s^{(i_{TX})}_{Data}(t) = s_f \sum_{n = 0}^{N_{SYM}-1} \sum_{k = -122}^{122} \sum_{i_{S TS} = 1}^{4} [Q_{k,i_{S TS}}] T_k \cdot e^{j2\pi k n T_{SYM}}, (11)
\]

where \(\tau = n T_{SYM} + T_{GI} + T_{S TS}^{CS}\).

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 \(5 \times 4\) 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 [10]. 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.[11]. The ERT will work optimally with system that has bit error rate (BER) lower than 10^-6.

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

The scrambled data is convoluntionally 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 \(N_{CBPS}^{CS}(i_{SS})\), \(i_{SS} = 1, 2, 3, 4\) bits. Each block is interleaved by a three steps permutation interleaver in frequency domain then mapped to QAM symbols.
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:

$$d = \frac{\lambda}{4\pi10^{\frac{\alpha}{10}}} (12)$$

where $\lambda$ is transmitted wave length, $L = L_{d=5} = 10\log_{10}(P,Br)+G_{TX}-G_{RX}-(S\text{SNR}+10\log(kTB)+NF+IM)$ is the path loss for $d \leq 5$ m, and $L = L_{d=5} + 35\log_{10}(d/5)$ for $d > 5$ m. These parameters and their values are included in Table V. $\alpha \leq 1$ is the efficiency 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 $4096 \times 1714$ 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:

$$PSNR = 10\log_{10}\left(\frac{Peak^2}{\frac{1}{3mn}\sum_{c=0}^{2}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}|O(c,i,j) - R(c,i,j)|^2}\right)$$ (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 [12], [13]. 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.

V. CONCLUSION

We have been designing an over 1.2 Gbps Wireless system for next generation WLAN conform with IEEE802.11TGac’s criteria. Simulation results prove that the proposed system...
shall be considered for providing an excellent performance mass digital cinema transmission service.

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