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ภาคผนวก

ภาคผนวก ก.

โปรแกรมที่ใช้ในการจำลองการทำงานของระบบโอเอฟดีเอ็ม

โปรแกรมสำหรับค่าพีเอพีอาร์

```
clear all;
clc;


%%% Defined parameters %%%%


BW=5;                       % Total Bandwidth = 5 MHz
NMess=16;                   % Range of Signals
DSI=16;                     % Total number of dummy sub-carriers
M=64;                       % Total number of sub-carriers
Nov=3;                      % Number of Over sampling
N=M+(M*Nov);                % Total number of IFFT/FFT point
L=20;                       % Total number of OFDM symbol per frame
CNst=10;                    % Staating CNR (dB)
CNx=20;                     % Stop CNR (dB)
Stcn=5;                     % Step of CNR (dB)
TgRatio=0.1;                % Ratio of Guard Interval
Num_count=20;               % Number of loop.
Ets=round(M/BW);            % Effective Symbol Duration
Dg=Ets*TgRatio;             % Duration of Guard Interval
Ts=Ets+Dg;                  % Symbol Duration  Ts %%%
DeltraF=round(BW/M);
DeltraT=Ets/N;
Zerop=round((N-M)/2);
Ng=round(Dg/(Ets/(N)));


Mess=(M-DSI)*L;
Nt=N+Ng;
NNt=Nt*L;
L1=Zerop+1;
L2=Zerop+M;


for count=1:Num_count;      % Loop
count
Zero1=zeros(1,Zerop);


RandSignal(1,1:Mess)=randint(1,Mess,NMess);
StoP=serial2parallel(RandSignal,(M-DSI));
```

```
LengthSt=length(StoP(:,1));

SubSt=length(StoP(1,:));

Signal=StoP;

%========================================================

%%%%%%%%%%%%%%%%%   Modulation   %%%%%%%%%%%%%%%%%%%%%

%========================================================

Y=Signal;

for k=1:LengthSt;

   ComplexSignal(k,1:(M-DSI))=f_EnMQAM(Y(k,1:(M-DSI)),NMess);

end


LoopMax=20;

for ii=1:LoopMax;

Stx=Xt1;

InputS=Stx;

[RowStx ColStx]=size(InputS);

Sref=mean(abs(parallel2serial(Stx)))*1.5;

for rr=1:RowStx

   for cc=1:ColStx

      if abs(InputS(rr,cc))>Sref,

         Er(rr,cc)=abs(InputS(rr,cc))*exp(j*angle(InputS(rr,cc)));

      else

         Er(rr,cc)=0;

      end

   end

   ERR(rr,1:N)=reshape(fft(reshape(Er(rr,1:N),N,1)),1,N)./sqrt(N);

   PH_ERR(rr,1:M)=angle(ComplexSignal(rr,1:M)-ERR(rr,L1:L2));

   DiffPH(rr,1:M)=(f_posangle(angle(ComplexSignal(rr,1:M)))-f_posangle(PH_ERR(rr,1:M)));

end


for cc=1:M;

   MeanERR(1,cc)=mean(DiffPH(:,cc));

end

WFph=angle(MeanERR);

for mm=1:M;

   for k=1:LengthSt;

      PARref1(1,k)=f_par_dB(Xt1(k,:));

   end
```

```
        PARref=mean(PARref1);
     for k=1:LengthSt;
        ComplexSignal(k,mm)=ComplexSignal(k,mm).*exp(-j*WFph(1,mm));
        NewTxf(k,1:N)=[Zero1 ComplexSignal(k,1:M) Zero1];
        Xt1(k,1:N)=reshape(ifft(reshape(NewTxf(k,1:N),N,1)),1,N).*sqrt(N);
        PARnew1(1,k)=f_par_dB(Xt1(k,:));
     end
     PARnew=mean(PARnew1);
     if PARnew>PARref,
        for k=1:LengthSt;
           ComplexSignal(k,mm)=ComplexSignal(k,mm).*exp(j*WFph(1,mm));
           NewTxf(k,1:N)=[Zero1 ComplexSignal(k,1:M) Zero1];
           Xt1(k,1:N)=reshape(ifft(reshape(NewTxf(k,1:N),N,1)),1,N).*sqrt(N);
        end
     else
     end


end
for k=1:LengthSt;
        PAPRloop(k,ii+1)=f_par_dB(Xt1(k,:));
end
end
for k=1:LengthSt;
  Xt2(k,1:Nt)=[Xt1(k,N-Ng+1:N) Xt1(k,1:N)];          % Assume we have a frame delay.
end


Stx=Xt2;
Stx_Bypass=Stx;


%+++++++++++++++++++++++++++++++++++++++
for k=1:LengthSt;
PAPR(count,k)=f_par_dB(Stx(k,:));                     % PAPR Output of IFFT
end
%+++++++++++++++++++++++++++++++++++++++
pause(0.1);
```

```
%################################################################
%=====  Solid-State Power Amplifiers (SSPA) ====================
%################################################################
[Row_amp Col_amp]=size(Stx);
IN_amp=parallel2serial(Stx);


N_amp=length(IN_amp);
%!!!!!!!!!!!!!!!!!!!!!!
IBO=-6;                                % IBO (dB)
Pamp=2;                                % P-parameter of SSPA
%!!!!!!!!!!!!!!!!!!!!!!
Pamp1=2*Pamp;
Pamp2=1/Pamp1;


AMPmean_power=mean(IN_amp(1:N_amp).*conj(IN_amp(1:N_amp)));
AMP_nor(1:N_amp)=IN_amp(1:N_amp)./sqrt(AMPmean_power);
AMP_nor1(1:N_amp)=sqrt(10^(IBO/10)).*AMP_nor(1:N_amp);


AMPabs(1:N_amp)=abs(AMP_nor1(1:N_amp));
AMP_ph(1:N_amp)=angle(AMP_nor1(1:N_amp));


for k=1:N_amp;
        AMPout(1,k)=AMPabs(1,k)/((1+(AMPabs(1,k))^(Pamp1))^(Pamp2));
end


AMPout_aver=mean(AMPout(1:N_amp).^2);
AMPout1(1:N_amp)=AMPout(1:N_amp).*sqrt(AMPmean_power/AMPout_aver);        %Input      power      is
keeped equal output power.
OUT_amp(1:N_amp)=AMPout1(1:N_amp).*exp(j*AMP_ph(1:N_amp));
Stx=serial2parallel(OUT_amp,Col_amp);


%++++++++++++++++++++++++++++++++++++++++++
for k=1:LengthSt;
PAPR4(count,k)=f_par_dB(Stx(k,:));                        %PAPR output of SSPA
end
%++++++++++++++++++++++++++++++++++++++++++
MeanLoop(count,1)=mean(CountLoop');
```

```
end                        %Loop

AllMeanLoop=mean(MeanLoop')
Max_papr=13;                   %Maximum values of PAPR measurement
Min_papr=0;                    %Miniumu values of PAPR measurement
St_papr=0.1;                   %Step size of PAPR measurement

Prob_papr=hist(PAPR(:)',Min_papr:St_papr:Max_papr);
cdf_length=length(Min_papr:St_papr:Max_papr);
for cdf=1:cdf_length;
  CDF(1,cdf)=sum(Prob_papr(1,cdf:cdf_length));
end                            %Loop for 1st-CCDF function
figure;
semilogy(Min_papr:St_papr:Max_papr,(CDF(1,:))/(Num_count*L),'bx-')

hold on
Prob_papr=hist(PAPR4(:)',Min_papr:St_papr:Max_papr);
cdf_length=length(Min_papr:St_papr:Max_papr);
for cdf=1:cdf_length;
  CDF(1,cdf)=sum(Prob_papr(1,cdf:cdf_length));
end                                            %Loop for 2nd-CCDF function
semilogy(Min_papr:St_papr:Max_papr,(CDF(1,:))/(Num_count*L),'gx-')
grid on

xlabel('PAPR (dB)')
ylabel('CCDF')
StrNMess=int2str(NMess);
StrM=int2str(M);
legend('Conventional','Proposed Method');
```

ภาคผนวก ข.
ผลงานวิจัยที่ได้รับการตีพิมพ์เผยแพร่

1. **Pornpawit Boonsrimuang,** Pisit Boonsrimuang, Kazuo Mori, Tawil Paungma and Hideo Kobayashi, **"Proposal of PAPR Reduction Method for OFDM Signal without Side Information,"** 4th ECTI Annual Conference (ECTI-CON 2007), pp745-748, 9-12 May 2007, Mea Fah Luang University, Chiang Rai, Thailand.

2. Pisit Boonsrimuang, **Pornpawit Boonsrimuang,** Kazuo Mori, Tawil Paungma and Hideo Kobayashi, **"Mitigation of Non-linear Distortion using PTS and IDAR Method for Multi-Level QAM-OFDM system,"** ECTI Transactions on Computer and Information Technology, Vol.1, No.2, pp 84-90, Nov 2005.

3. Pisit Boonsrimuang, **Pornpawit Boonsrimuang**, Kazuo Mori, Tawil Paungma and Hideo Kobayashi, **"Mitigation of Non-linear Distortion using PTS and IDAR Method for Multi-Level QAM-OFDM system,"** 2nd ECTI Annual Conference (ECTI-CON 2005), pp303-306, 12-13 May 2005, Pattaya, Thailand.

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Proposal of PAPR Reduction Method for OFDM Signal without Side Information

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Abstract— The major drawback of orthogonal frequency division multiplexing (OFDM) is large Peak-to-Average Power Ratio (PAPR) of its time domain signal. To overcome the PAPR problem on OFDM signal, various PAPR reduction methods have been proposed up to today. The most of PAPR reduction methods such as PTS and SLM methods require the side information which causes the degradation of transmission efficiency and complexity of transmitter and receiver. In this paper, we propose a novel PAPR reduction method which can improve the PAPR performance without side information. The feature of proposed method is to use the common weighting factor over a frame including preamble and data symbols in which the common weighting factor is multiplied to the frequency domain signal over a frame so as to reduce the PAPR performance. The data symbols in one frame can be demodulated at the receiver by using the estimated common weighting factor. The common weighting factor can be estimated together with the channel frequency response by using the preamble symbol located at the start of every frame. This paper presents various computer simulation results to verify the effectiveness of proposed method in the multi-path fading channel.

I. INTRODUCTION

Recently the OFDM technique has been received a lot of attentions especially in the field of wireless communications because of its efficient usage of frequency bandwidth and robustness to the multi-path fading. From these advantages, the OFDM has already been adopted as the standard transmission techniques in the wireless LAN systems and the terrestrial digital broadcasting system [1-2]. The OFDM technique is also considering as one of the candidate transmission techniques for the next generation of wireless communications systems. One of the limitations of using OFDM technique is the larger peak to averaged power ratio (PAPR) of its time domain signal as compared with the conventional single carrier transmission techniques [3]. The larger PAPR signal would cause the severe degradation of bit error rate (BER) performance due to the inter-modulation noise occurring in the non-linear amplifier.

From the above background, the PAPR reduction method is recognized as one of the essential research topics for the OFDM method employed in the wireless communications sytems. Up to today, various kinds of PAPR reduction methods were proposed including the selected mapping method (SLM) [4] and partial transmit sequence method (PTS) [5-6]. Although both methods can achieve the better PAPR performance by controlling the phase of data sub-carriers, these two methods are required to inform the phase information controlled for the data sub-carriers to the

receiver as the side information (SI). Since the side information is required to inform the receiver symbol by symbol by using the data or control channels with the higher signal quality for the correct demodulation of data information at the receiver, the transmission efficiency would be degraded relatively and the system complexity would be increased. The size of side information depends on the number of clusters and discrete phases employed in the SLM or PTS methods. To improve the PAPR performance, the larger number of clusters and discrete phases are required which lead the proportional increasing of side information size.

To overcome the problem for the conventional PAPR reduction methods with using the side information, we propose a novel PAPR reduction method which is required no side information. The feature of proposed method is that the PAPR performance can be improved by multiplication of common weighting factor over one frame including preamble and data symbols. The original data can be recovered by multiplying the inverse of common weighting factor employed at the transmitter. In the proposed method, the inverse of weighting factor can be estimated by using the preamble symbols which are usually used in the conventional OFDM system to establish the synchronization of received signal and to estimate the channel frequency response of fading channel.

In the following of this paper, Section II presents the system model to be used in the following evaluations. Section III presents the proposed PAPR reduction method. Section IV presents the various computer simulation results to verify the effectiveness of the proposed method, and we draw some conclusions in Section V.

II. SYSTEM MODEL

In the OFDM system, the modulated signal in the frequency domain is converted to the time domain signal by using *IFFT*. The time domain signal for *l-th* symbol at *k-th* sample is given by the following equation.

$$y_{(l,k)} = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_{(l,n)} e^{j\frac{2\pi kn}{N}} \tag{1}$$

where N is the number of *IFFT* points and $X_{(l,n)}$ is the modulated data for *l-th* symbol at *n-th* sub-carrier. Here the PAPR performance for the sampled time domain signal can be given by,

where L is the frame length including preamble and data symbols. By using (10), the transmission time domain signal at the *(i+1)-th* iteration can be given by,

$$\overline{y}_{(l,k)}^{(i+1)} = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \left\{ X_{(l,n)}^{(i)} \cdot e^{j\theta_n^{(i+1)}} \right\} \cdot e^{j\frac{2\pi kn}{N}}$$

$$= \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_{(l,n)}^{(i+1)} \cdot e^{j\frac{2\pi kn}{N}} \qquad (11)$$

In the proposed method, the procedures from (5) to (11) are repeated up to reach either the predetermined target PAPR performance or predetermined number of iterations.

B. Receiver

Figure 3 (b) shows the structure of receiver for the proposed method. The received signal $r_{(l,k)}$ for *l-th* symbol at *k-th* sample after down converter (D/C) and Analog to Digital converter (A/D) as shown in Fig.3 (b) can be given by the following equation.

$$r_{(l,k)} = \overline{y}_{(l,k)}^{(P)} \otimes h_{(l,k)} + n_{(l,k)} \qquad (12)$$

where $s_{(l,k)}$, $h_{(l,k)}$ and $n_{(l,k)}$ show the transmitted OFDM signal, impulse response of multi-path fading channel and Additive White Gaussian Noise (AWGN) for *l-th* symbol at *k-th* sample, respectively. In (12), P is the number of iterations which provides the best PAPR performance at the transmitter. The received signal as given in (12) is converted to the frequency domain signal by using *FFT* which is expressed by the following equation.

$$R_{(l,n)} = X_{(l,n)}^{(P)} \cdot H_{(l,n)} + N_{(l,n)} \qquad (13)$$

where, $R_{(l,n)}$, $X_{(l,n)}^{(P)}$, $H_{(l,n)}$ and $N_{(l,n)}$ show the received signal, transmitted signal, channel frequency response and noise component in the frequency domain, respectively.

When assuming the operation environments such as the radio LAN system, the time variance of channel frequency response can be assumed as sufficiently slow because of very lower terminal moving speed. From this fact, the channel frequency response over one frame can be considered as static. Accordingly, the channel frequency response estimated by using two known preamble symbols inserted at the start of every frame can be used in the equalization of data symbols over one frame. The channel frequency response which is improved the estimation accuracy by taking the ensemble average over two preamble symbols, can be obtained by the following equation.

$$\hat{H}_n = \frac{1}{2} \sum_{l=1}^{2} \left\{ X_{(l,n)}^{P} \cdot H_n + N_{(l,n)} \right\} / X_{(l,n)} \qquad (14)$$

$$= H_n \cdot e^{j\psi_n} + N_{(l,n)} / X_{(l,n)}$$

where $\hat{H}_n$ is the estimated channel frequency response affected by the common weighting factor and noise component. Here, $e^{j\psi_n}$ can be given by following equation.

$$\psi_n = \sum_{i=1}^{P} \theta_n^{(i)} \qquad (15)$$

From (14), it can be observed that the common weighting factor can be estimated in the frequency domain by using preamble symbols. By using (14), the original data signal

can be demodulated by employing the same manner as the conventional frequency domain equalization method in which the common weighting factor multiplied at the transmitter and the multi-path fading multiplied in the channel can be removed from the received signal.
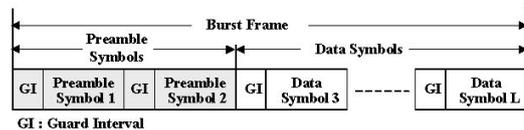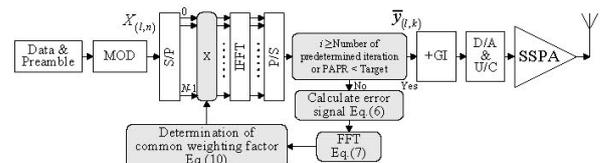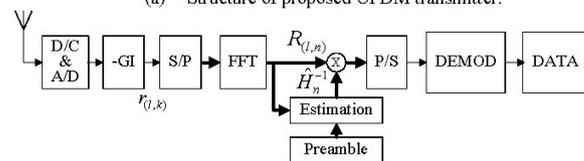

Figure. 2. Structure of burst frame format.

(a) Structure of proposed OFDM transmitter.

(b) Structure of proposed OFDM receiver.

Figure. 3. System model of proposed method.

IV. PERFORMANCE EVALUATION

This section presents the various computer simulation results to verify the performance of proposed method. The modulation method is assumed by 64QAM with coherent detection method. The multi-path fading is modeled by 16 delay paths having the exponential power delay profile with -1 dB decay constant. In the following simulations, the synchronizations both for the symbol timing and frequency offset are assumed to be established ideally by using two preamble symbols. The simulation parameters to be used in the following evaluations are shown in Table 1. In the simulations, the number of *FFT* points (N=256) is taken by 4 times larger than the number of sub-carriers (M=64) to evaluate the PAPR performance with higher accuracy.

TABLE I
SIMULATION PARAMETERS

Modulation	64QAM
Demodulation	Coherent
Allocated bandwidth	5MHz
Number of *FFT* points	256
Number of sub-carriers	64
Symbol duration	12.8us
Guard interval	1.28us
Non-linear amplifier	SSPA
Non-linear parameter of SSPA	r=2
Number of data symbols in one frame	12
Number of preamble symbols in one frame	2
Multi-path fading model	
Power delay profile	Exponential
Number of delay paths	16
Decay constant	-1 dB

Figure 4 shows the averaged PAPR performance both for the conventional OFDM and proposed methods when changing the number of iterations. The frame length is 12 symbols including 2 preamble symbols. From the figure, it can be seen that the proposed method can achieve the best PAPR performance when the number of iterations is larger than 8. The proposed method shows the better averaged PAPR performance than the conventional OFDM by 1.4 dB. From the results, the number of iterations is assumed by 8 in the following evaluations.

Figure 5 shows the PAPR performance for the conventional OFDM and proposed methods when the frame length is 12 symbols. The PAPR performance is evaluated by using the Complementally Cumulative Distribution Function (CCDF). From the figure, it can be observed that the proposed method can achieve the better PAPR performance than conventional OFDM about 1.9 dB at 10^{-1}. Here it should be noted that the degradation of BER performance of OFDM signal in the non-linear channel would be dominated by the PAPR performance at the CCDF larger than 10^{-1}.

Figure 6 shows the BER performances for the proposed and conventional OFDM methods in the multi-path fading channel when the input back-off (IBO) of non-linear amplifier is taken by -6 dB and -8 dB. From the figure, it can be observed that the proposed method can achieve much better BER performance than conventional OFDM method in the channel including the non-linear amplifier and multi-path fading.
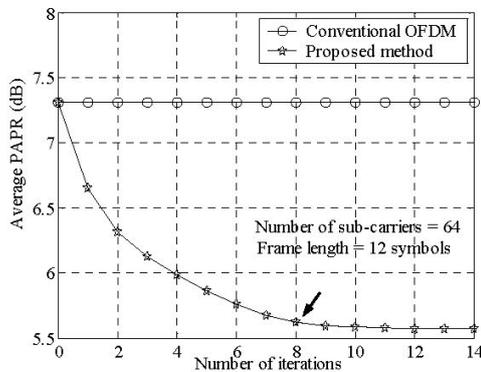

Figure. 6. BER performance of proposed method.

V. CONCLUSIONS

This paper proposed the PAPR reduction method for the OFDM signal without degradation of transmission efficiency. The feature of proposed method is to use the common weighting factor over one frame including the preamble symbols so as to improve the PAPR performance. In the proposed method, the time-frequency domain swapping algorithm is employed in the determination of common weighting factor. The common weighting factor can be removed from the received data symbols by using the frequency domain equalization. In the proposed method, the common weighting factor can be estimated together with the channel frequency response by using preamble symbols. Form this fact, the proposed method can achieve the better PAPR performance without loss of transmission efficiency. From the various computer simulation results, we confirmed that the proposed method can achieve the better PAPR performance and better BER performance than the conventional OFDM in the channel including non-linear amplifier and multi-path fading.

Figure. 4. Averaged PAPR performance versus number of iterations.

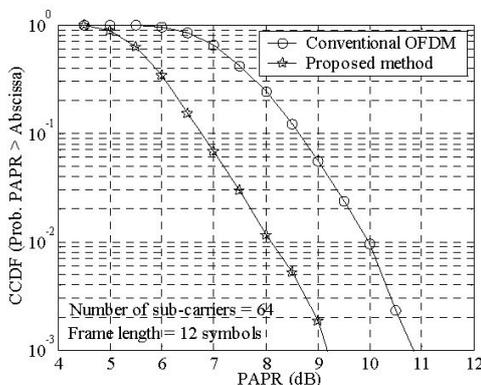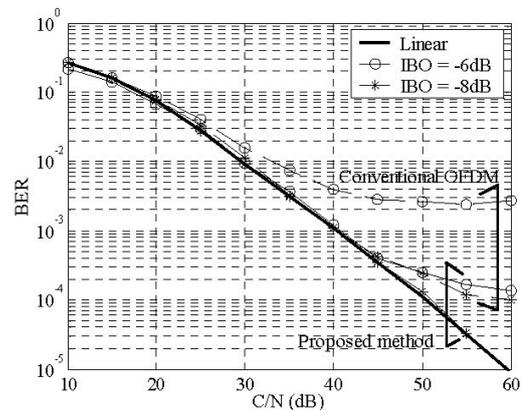Figure. 5. PAPR performance for proposed method.

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Mitigation of Non-linear Distortion Using PTS and IDAR Method for Multi-Level QAM-OFDM System

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ABSTRACT

The future satellite communication systems are required to support the higher transmission data rate for providing the multimedia services by employing the efficient modulation method such as multi-level QAM. The employment of single carrier transmission with multi-level QAM would cause the fatal degradation of signal quality due to the non-linear amplifiers located at the earth station and satellite. To overcome this problem, we have proposed the multi-level QAM-OFDM technique with IDAR (Improved Decision Aided Reconstruction) method designed for non-linear satellite channel. However, the proposed method could not mitigate the non-linear distortion sufficiently when modulation level becomes higher such as 64QAM. This paper proposes the combined scheme of partial transmission sequence (PTS) and OFDM-IDAR methods so as to enable the usage of higher multi-level QAM method, which can achieve the higher transmission data rate with keeping the better bit error rate performance in the non-linear satellite channel. The various computer simulations are conducted in this paper to verify the effectiveness of proposed method in the non-linear satellite channel.

Keywords: PAPR, Satellite channel, PTS, IDAR, QAM.

1. INTRODUCTION

The future satellite communications including the fixed, mobile and broadcasting systems are required to support the higher transmission data rate for providing the multimedia services, which are already available in the terrestrial network. To realize the higher data rate transmission in the satellite channel, it is required to employ the efficient modulation method such as multi-level QAM [1]. However, the employment of conventional single carrier transmission with multi-level QAM would cause the fatal degradation of signal quality due to the inter-modulation noise incurred at the non-linear amplifiers located at the earth station and satellite. From this reason, the current satellite communications are usually limited by low transmission data rate with employing QPSK method, which has the robustness to the non-linear distortion because of its better PAPR (Peak to averaged power ratio) performance as compared with the multi-level QAM.

On the other hand, the Orthogonal Frequency Division Multiplexing (OFDM) technique has been received a lot of attentions especially in the field of terrestrial wireless communications because of its efficient usage of frequency bandwidth, robustness to the multi-path fading and enabling the employment of multi-level QAM with less complexity of transmitter and receiver. One of the disadvantages of using the OFDM is that its time domain signal has the larger PAPR, which causes the degradation of BER performance in the non-linear amplifier [2]. From this reason, the OFDM has been also considered as unsuitable transmission technique for the satellite channel, although it has a potential capability to improve the transmission data rate by employing the multi-level QAM with less complexity of transmitter and receiver. To solve PAPR problem in the OFDM scheme, we proposed the OFDM-IDAR (Improved Decision Aided Reconstruction) method, which can mitigate the non-linear distortion and achieve the higher transmission data rate with keeping the better BER performance even in the satellite channel [3][4]. The feature of proposed OFDM-IDAR method is to reconstruct the non-linear distortion by using the decision data at the receiver. However, the proposed OFDM-IDAR method has some limitation on the usage of higher level of modulation method such as 64QAM because its higher level of modulation method causes a lot of decision error due to the non-linear amplifier and IDAR method could no more mitigate the non-linear distortion sufficiently. To reduce the non-linear distortion, it is required to improve the PAPR performance as much as possible for the OFDM signal at the transmission side. If the PAPR performance of the transmitting OFDM signal can be improved somehow at the transmission side, the non-

linear distortion can be reduced and IDAR method could achieve the better BER performance even when the higher level of modulation method is employed in the satellite channel. In this paper we propose the OFDM-IDAR method in conjunction with the PAPR reduction method, which allows the employment of higher level of modulation method in the non-linear satellite channel.

In this paper, Section 2 firstly presents the satellite system model including the non-linear amplifiers at the earth station and satellite. Section 3 presents the partial transmission sequence (PTS) method as the PAPR reduction method at the transmit earth station and presents the IDAR method as the mitigation method of non-linear distortion at the receive earth station. Section 4 presents the various computer simulation results to verify the effectiveness of proposed OFDM-IDAR with PTS method in the non-linear satellite channel, and Section 5 draws some conclusions.

2. SATELLITE SYSTEM MODEL

Figure 1 shows the typical satellite system model assumed in the following evaluations. In this paper, the non-linear amplifier for the earth station is assumed to use the Solid State Power Amplifier (SSPA), which is modelled by Rapp [5]. The AM-AM and AM-PM conversions characteristics of SSPA modelled by Rapp are given by the following equations, respectively.

$$F_E\left(\rho\right) = \frac{\nu\rho}{\left[1 + \left(\nu\rho/A_0\right)^{2p}\right]^{1/2p}} \qquad (1)$$

$$\Phi_E\left(\rho\right) = \alpha_\phi\left(\frac{\nu\rho}{A_0}\right)^4 \qquad (2)$$

where, $F_E\left(\rho\right)$ and $\Phi_E\left(\rho\right)$ show the AM-AM and AM-PM conversion characteristics of SSPA, respectively, and ρ is the amplitude of input signal, ν is the gain factor, A_0 is the saturated output level, p is the parameter to decide the non-linear level and α_ϕ is phase displacement. In the following evaluations, the values for these parameters are assumed by $A_0 = 1$, $\nu = 1$, $p = 6$ and $\alpha_\phi = 0.025$, which can approximate the standard characteristics of SSPA employed at the transmit earth station [3]. The non-linear amplifier assumed for the satellite station is assumed to use the TWTA, which is modelled by Saleh [6]. The AM-AM and AM-PM characteristics of TWTA modelled by Saleh are given by the following equations, respectively.

$$F_S\left(\gamma\right) = \frac{\alpha_a\gamma}{(1 + \beta_a\gamma^2)} \qquad (3)$$

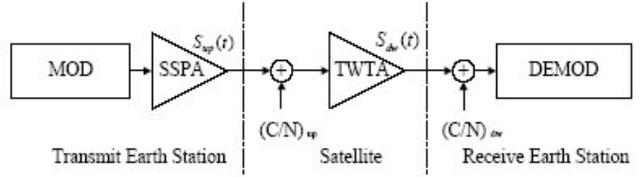$$\Phi_S\left(\gamma\right) = \frac{\alpha_\theta\gamma}{(1 + \beta_\theta\gamma^2)} \qquad (4)$$
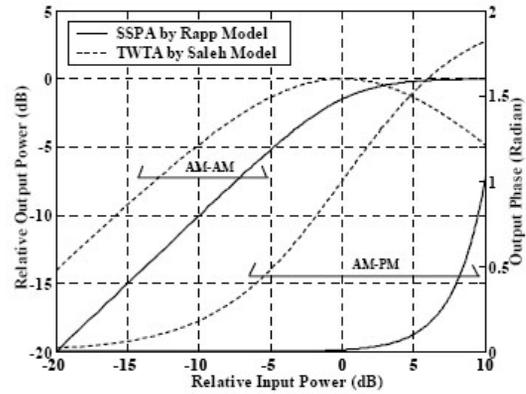

Fig.1: *Satellite system model*

Fig.2: *Input and output relationships for SSPA and TWTA.*

where, γ is the amplitude of input signal, α_a and β_a are the parameters to decide the non-linear level, and α_θ and β_θ are phase displacements. The values for these parameters are assumed by $\alpha_a = 2$, $\beta_a = 1$, $\alpha_\theta = 2$ and $\beta_\theta = 1$, which can approximate the standard TWTA employed at the satellite station [3].

Figure 2 shows the input and output relationships of AM-AM and AM-PM conversions characteristics both for SSPA and TWTA when the parameters are given by the above values. In this paper, we assume the higher non-linearity for the satellite amplifier (TWTA) than that for the earth station amplifier (SSPA) as shown in Fig. 2.

3. PROPOSAL OF OFDM-IDAR WITH PTS METHOD FOR SATELLITE CHANNEL

3.1 PAPR Reduction Method at Transmit Earth Station

Up to today, various kinds of PAPR reduction methods for OFDM signal were proposed such as the selected mapping method (SLM) [7] and the partial transmit sequence method (PTS) [7] [8]. Both methods can achieve the better PAPR performance by controlling the phase values of data sub-carriers at the transmitter, although these two methods are required to inform the phase information used for controlling the data sub-carriers to the receiver as the side information. In this paper, we employ the PTS method as the PAPR reduction method at the transmit earth station because the PTS method can achieve the bet-

ter PAPR performance with less complexity of required processing as compared with the SLM method [7]. The following presents the PTS method briefly.

Figure 3 shows the structure of OFDM transmitter with PTS method. In the PTS method, the data information in the frequency domain X_n is partitioned into V clusters as $X_n^{(\nu)}(1 \leq \nu \leq V)$. All sub-carriers including each cluster are multiplied by the same phase of $c_n^{(\nu)} = e^{j\varphi_n^{\nu}}$ so as to reduce the PAPR performance. Here, the phase value considered in each cluster is given by the following equation.

$$\varphi_n^{(\nu)} = [0, 2\pi) \, (1 \leq \nu \leq V) \qquad (5)$$

After multiplying the phase value for each cluster, the sub-carrier vector is given by the following equation.

$$Y_n = \sum_{\nu=1}^{V} c_n^{(\nu)} \cdot X_n^{(\nu)} \qquad (6)$$

where, the controlling phases $c_n^{(\nu)}$ used for all clusters are required to inform the receiver as the side information. The set of phase values for all clusters are optimized in the time domain so as to achieve the better PAPR performance, by using the following equation.

$$
\begin{aligned}
y_k &= \sum_{\nu=1}^{V} c_n^{(\nu)} \cdot IFFT\left\{X_n^{(\nu)}\right\} \\
&= \sum_{\nu=1}^{V} c_n^{(\nu)} \cdot x_k^{(\nu)} \qquad (7)
\end{aligned}
$$

From (6) and (7), it can be seen that the controlling phase values can be multiplied either in the frequency or time domains and the results on optimized PAPR performance are the same. Figure 3 shows the case of (7) where the optimization of phase value is performed in the time domain. In the PTS method, the better PAPR performance could be achieved, if phase value of $c_n^{(\nu)}$ is chosen with continuous phase as given in (5), although the size of side information to be transmitted to the receiver would be increased. Since the side information is required to inform the receiver by using the data channel with the high signal quality, the larger size of side information would cause the degradation of system efficiency relatively. To solve this problem, the fixed number of discrete phase value is employed in this paper to reduce the size of side information, although the PAPR performance would be degraded slightly [7] as compared with that for using the continuous phase values. In this paper, we assume four discrete phase values as given by the following equation.
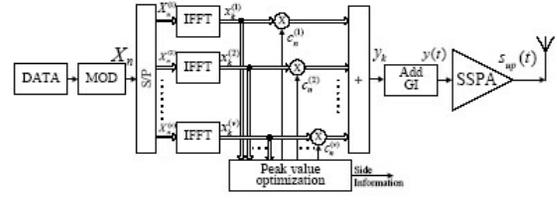

Fig.3: *Structure of OFDM transmitter with PTS method.*

$$\varphi_n^{(\nu)} \in \{0, \pi/2, \pi, 3\pi/2\} \, (1 \leq \nu \leq V) \qquad (8)$$

After optimization of phase value for each cluster, the time domain signal after adding the guard interval (GI) is converted to the uplink radio frequency and input to non-linear amplifier of SSPA. The output signal of SSPA, which corresponds to the uplink signal in the radio frequency, can be given by the following equation.

$$s_{up}(t) = F_E\left[|y(t)|\right] \cdot e^{j[arg\{y(t)\} + \Phi_E\{|y(t)|\}]} \qquad (9)$$

where, $y(t)$ is the OFDM signal at the input of SSPA, $F_E[\,]$ and $\Phi_E[\,]$ represent the AM-AM and AM-PM conversions characteristics of non-linear amplifier given by (1) and (2), respectively. The output signal of SSPA given by (9) is transmitted to the satellite and then input to the satellite TWTA after converting from the uplink to downlink radio frequency. The output signal of TWTA, which corresponds to the downlink signal in the radio frequency, is given by the following equation.

$$s_{dw}(t) = F_S\left[|s_{up}(t)|\right] \cdot e^{j[arg\{s_{up}(t)\} + \Phi_s\{|s_{up}(t)|\}]} \qquad (10)$$

The receive earth station demodulates the data information from (10) by using the IDAR method, which is presented in the next section.

3.2 OFDM-IDAR Method for Satellite Channel

Figure 4 shows the structure of proposed OFDM-IDAR receiver with PTS method. In Fig.4, the received RF signal r_t is first down converted to the base band signal and digitized by A/D converter. The received time domain sampled signal after removing the guard interval (GI) is given by the following equation.

$$
\begin{aligned}
r_k &= s_{dw,k} + w_k \\
&= y_k + i_k + w_k \qquad (11)
\end{aligned}
$$

where, $s_{dw,k}$, w_k and i_k represent the output signal of TWTA, additive noise in the downlink, and inter-modulation noise on the k-th time domain sampled

signal, respectively. In (11), y_k is the desired signal in the time domain of which phase is optimized by PTS method at the transmit earth station. Here, the inter-modulation noise is assumed to add the desired signal y_k linearly. It should be noted that inter-modulation noise at the output of non-linear amplifier is unable to express separately as given in (11), because it is strongly related to the desired signal y_k. However, the inter-modulation noise is reconstructed separately in the IDAR method by using the decision data at the receiver. Although it is inappropriate to express the inter-modulation noise separately, (11) is given here just as the assumption so as to explain the following IDAR algorithm clearly. The received time domain sampled signal given (11) is converted to the frequency domain signal by FFT, which is given by the following equation.

$$R_n = Y_n + I_n + W_n \qquad (12)$$

where, the capital letter represents the frequency domain signal, which corresponds to its small letter given by (11) in the time domain. The decision for (12) can be made by using the following equation.

$$\widehat{Y}_n = \underset{n}{min} \, |R_n - X_n| \qquad (13)$$

where $\widehat{Y}_n$ is the decision data at the n-th sub-carrier. Here, it should be noted that the decision data $\widehat{Y}_n$ is not the transmitted information data X_n, because it includes the controlled phase value optimized by the PTS method as in (6). Since all the discrete phase values used in the PTS method are the factor of $\pi/2$, the decision can be made on the basis of (13), although the decision data is not directly correspondent to X_n.

The decision data in the frequency domain is converted to the time domain signal $\widehat{y}_k$ by IFFT, which corresponds to the reconstructed transmitted time domain signal. In the IDAR method, the time domain signal $\widehat{y}_k$ is used for the reconstruction of inter-modulation noise. This is based on the fact that the OFDM time domain signal converted from the decision data in the frequency domain, which includes even some decision errors, would be almost the same as the original time domain signal without error [4]. From this reason, the inter-modulation noise can be reconstructed by using the decision data in the time domain.

By using the time domain signal $\widehat{y}_k$, the output time domain signal of SSPA and TWTA can be reconstructed by using the same manner as processed at the earth station and satellite. In the IDAR method, the operations of non-linear amplifiers both for the SSPA and TWTA are conducted on the digital sampled data by assuming the same AM-AM and AM-PM conversion characteristics as that operated in the
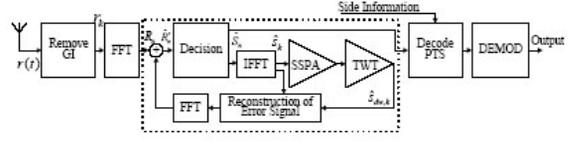
radio frequency. The time domain signal at the output of SSPA and TWTA as shown in Fig.4 is given by the following equation.

Fig.4: *Structure of receiver with proposed OFDM-IDAR with PTS method.*

$$\widehat{s}_{dw,k} = F_P\left[|\widehat{y}_k|\right] \cdot e^{j\{arg(\widehat{y}_k) + \Phi_P(|\widehat{y}_k|)\}} \qquad (14)$$

where, $\widehat{y}_k$ is the time domain signal converted from the frequency domain decision data given in (13), F_P and Φ_P are the AM-AM and AM-PM conversions characteristics which is the composite characteristics of SSPA and TWTA. This paper assumes that the composite characteristics of SSPA and TWTA are known at the receiver. By using (14), the inter-modulation noises incurred at the SSPA and TWTA can be estimated by the following equation.

$$\begin{aligned}
\widehat{e}_k &= \widehat{s}_{dw,k} - \widehat{y}_k \\
&\approx \widehat{y}_k + \widehat{i}_k - \widehat{y}_k \\
&\approx \widehat{i}_k \qquad (15)
\end{aligned}$$

The inter-modulation noise given by (15) is then converted to the frequency domain signal $\widehat{E}_n$ by FFT. By subtracting the reconstructed inter-modulation noise $\widehat{E}_n$ from (12), the frequency domain signal coped with the inter-modulation noise can be obtained by the following equation.

$$\begin{aligned}
\widehat{R}'_n &= R_n - \widehat{E}_n \\
&= Y_n + \left\{ I_n - \widehat{I}_n \right\} + W_n \\
&\approx Y_n + W_n \qquad (16)
\end{aligned}$$

The above procedures are repeated until the better performance can be achieved in the IDAR method. Finally, the data information for each sub-carrier can be obtained by decoding the PTS, which is given by the following equation.

$$X_n = \sum_{\nu=1}^{V} \left\{ c_n^{(\nu)} \right\}^* \cdot \widehat{Y}_n^{(\nu)} \qquad (17)$$

where, * is the complex conjugate and $c_n^{(\nu)}$ is the controlled phase by PTS at the transmitter. These phase values are known at the receiver, because they are informed to the receiver as the side information.

Table 1: *Simulation parameters*

Allocated bandwidth	26MHz
Modulation method	64QAM
Detection method	Coherent
Number of FFT points	512
Number of sub-carriers	128
Symbol duration	4.92us
Guard interval	0.5us
Transmission data rate	141.6 Mbit/s
Non-linear amplifier	
Earth station	SSPA
Satellite station	TWTA

4. PERFORMANCE EVALUATIONS

This section presents the various computer simulation results to demonstrate the performance of OFDM-IDAR with PTS method in non-linear satellite channel. Table 1 shows the list of simulation parameters used in the following computer simulations. In the following simulations, the side information for PTS is assumed to be informed to the receiver ideally. The modulation method is 64QAM and its demodulation method is the coherent detection.

In the following evaluation, the up-link C/N is assumed to be the noise free condition and only the downlink noise is added to the received signal. The IBO for the earth station amplifier of SSPA is fixed by -3dB. The downlink C/N is defined by using the desired signal power at the output of satellite non-linear amplifier of TWTA at IBO=0dB. In this definition of C/N, the actual C/N for the signal at the receive earth station would be changed from the given C/N according to the IBO of TWTA. In other words, the power of inter-modulation noise could be reduced as decreasing IBO while the desired signal power at the output of amplifier would be reduced.

Figure 5 shows the PAPR performance when changing the number of clusters for the PTS method at the transmit earth station. The number of discrete phase values is assumed by four kinds of phases 0, and 3 /2, which requires 2 bits for each cluster as the side information. In the figure, the PAPR performance is evaluated by using the Cumulative Distribution Function (CDF). From the figure, it can be seen that the PAPR performance for the PTS method can be improved relatively as compared with the conventional OFDM signal, especially when increasing the number of clusters.

Figure 6 shows the BER performances when changing the number of iteration in the IDAR method. The IBOs for satellite TWTA are taken by -4, -6 and -8dB respectively. The number of clusters for the PTS method is 4 and the downlink C/N is 25dB. From the figure, it can be observed that the proposed OFDM-IDAR with PTS method can

achieve the bestter BER perforamnce than that for the conventional IDAR method when comparing at the same iteration number.

Figure 7 shows the BER performances when changing the number of iteration for the IDAR method. In the simulation, the IBOs for earth station SSPA and satellite TWTA are taken by -3dB and -6dB, respectively and the downlink C/N is 28dB. From the figure, it can be observed that the proposed OFDM-IDAR with PTS method can achieve much better BER performance than that for the OFDM-IDAR method. It can be also observed that the BER performance of proposed method is converged when the number of iterations is taken larger than 8. From these results, the following evaluations for proposed OFDM-IDAR with PTS method are assumed to use 8 as the IDAR iteration number.

Figure 8 shows the BER performances when changing the IBO for satellite TWTA. In the simulations, the IBO for the earth station SSPA is fixed by -3dB. The downlink C/N is defined by using the desired signal power at the output of satellite non-linear amplifier of TWTA at IBO=0dB. In this definition of C/N, the power of inter-modulation noise could be reduced as decreasing IBO of TWTA while the desired signal power at the output of TWTA would be reduced. In other words, there is the trade-off between the inter-modulation noise power and the desired signal power according to the value of TWTA IBO. Therefore, the best BER performance could be achieved at the optimum value of IBO, which is compromised of them. The definition of C/N assumed here is based on the actual satellite communications systems, which is taken into account the desired signal power at the output of non-linear amplifier, and can evaluate the usage of power efficiency of non-linear amplifier. From Fig. 8, it can be observed that the OFDM-IDAR with PTS method has the optimum IBO at -6dB, which can achieve the best BER performance, while the optimum IBO for the conventional OFDM-IDAR method is around -8dB. It can be also seen that the proposed method at the optimum IBO shows much better BER performance than that for the conventional method. In other words, the proposed OFDM-IDAR with PTS method can operate at the higher IBO with keeping the better BER performance than the conventional method. From these results, it can be concluded that the proposed OFDM-IDAR with PTS method can achieve the higher efficient usage of non-linear amplifier with keeping the better BER performance.

Figure 9 shows the BER performances for the conventional OFDM-PTS, OFDM-IDAR and the proposed OFDM-IDAR with PTS methods when changing the IBO of TWTA and the downlink C/N. From the figure, it can be observed that the proposed method can achieve much better BER performance than that for the conventional PTS and IDAR meth-
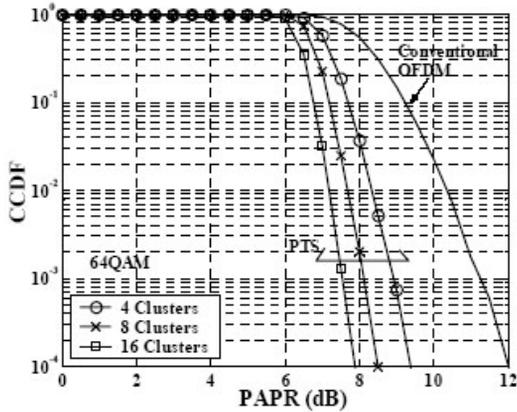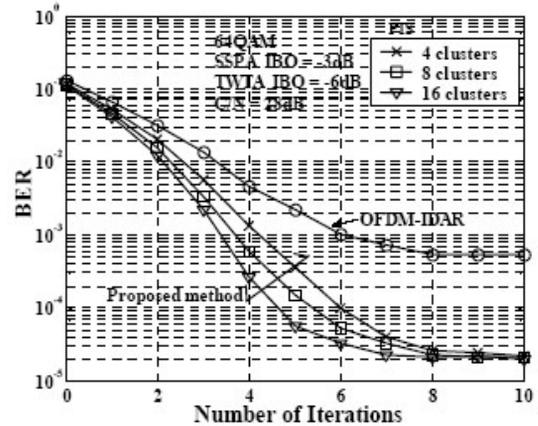
Fig.5: *PAPR performance.*

Fig.7: *BER vs. number of iterations for IDAR.*
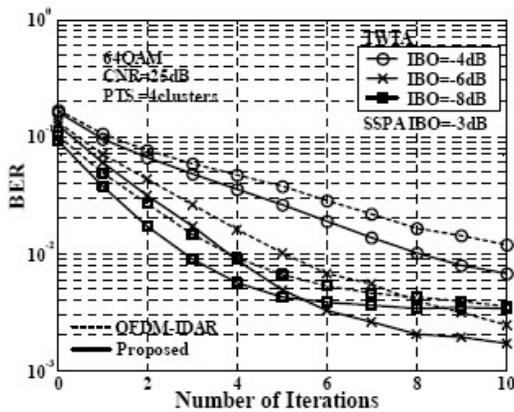

Fig.6: *BER performance vs. number of iterations for IDAR.*
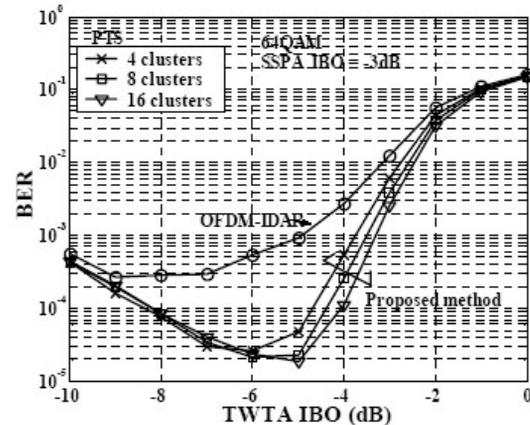

Fig.8: *BER performance vs. IBO of TWTA.*

ods of which BER performances have error floor at the higher C/N. From the figure, it can be also observed that the OFDM-IDAR with PTS method shows much better BER performance than that for others conventional methods. From these results, it can be concluded that the proposed OFDM-IDAR with PTS method could achieve the higher transmission data rate with keeping the better BER performance in the non-linear satellite channel.

This paper proposed the OFDM-IDAR with PTS method, which can reduce the PAPR performance at the transmitter by PTS and can mitigate the non-linear distortion at the receiver by IDAR, respectively. This paper presented various computer simulation results to verify the effectiveness of proposed method. From the computer simulation results, we confirmed that the proposed method could achieve the higher transmission data rate with keeping the better BER performance in the non-linear satellite channel.
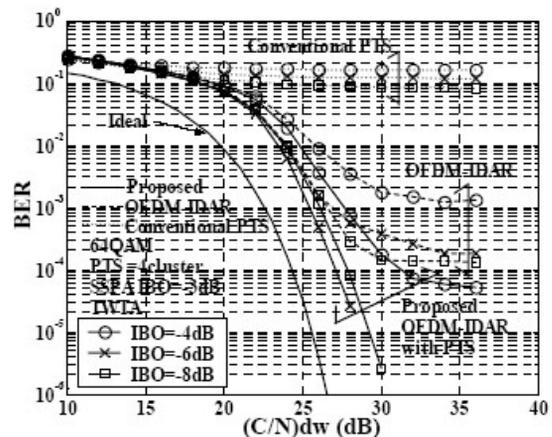

Fig.9: *BER performance vs. C/N.*

5. CONCLUSIONS

This paper proposed the OFDM-IDAR with PTS method, which can reduce the PAPR performance at the transmitter by PTS and can mitigate the nonlinear distortion at the receiver by IDAR, respectively. This paper presented various computer simulation results to verify the effectiveness of proposed method. From the computer simulation results, we confirmed that the proposed method could achieve the higher transmission data rate with keeping the better BER performance in the non-linear satellite channel.

Acknowledgment

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Mitigation of Non-linear Distortion using PTS and IDAR Method for Multi-Level QAM-OFDM system

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ABSTRACT

The future satellite communications system is required to support the higher transmission data rate for providing the multimedia services by employing the efficient modulation method such as multi-level QAM. However, the employment of multi-level QAM in the satellite channel would cause the fatal degradation of signal quality due to the non-linear amplifiers located at the earth station and satellite. To overcome this problem, we have proposed the multi-level QAM-OFDM technique with IDAR (Improved Decision Aided Reconstruction) method for satellite channel. However, the proposed method could not mitigate the non-linear distortion sufficiently when modulation level becomes higher such as 64QAM. This paper proposes the combined method of partial transmission sequence (PTS) and IDAR so as to enable the usage of higher multi-level QAM method, which can achieve the higher transmission data rate with keeping the better bit error rate performance in the non-linear channel. This paper presents various computer simulation results to verify the effectiveness of proposed method in the non-linear satellite channel.

Keywords: PAPR, Satellite channel, PTS, IDAR.

1. INTRODUCTIONS

To realize the higher data rate transmission in the satellite channel, it is required to employ the efficient modulation method such as multi-level QAM. However, the employment of multi-level QAM with single carrier transmission would cause the fatal degradation of signal quality due to the non-linear distortion incurred at the non-linear amplifiers located at the earth station and satellite [1]. From this reason, the modulation method used in the current satellite communications is usually limited by low data rate QPSK method, which has the robustness to the non-linear distortion because of its better PAPR (Peak to averaged power ratio) performance as compared with the multi-level QAM.

The Orthogonal Frequency Division Multiplexing (OFDM) technique has been received a lot of attentions especially in the field of terrestrial wireless communications because of its efficient usage of frequency bandwidth and robustness to the multi-path fading. One of the disadvantages of using the OFDM signal is that its time domain signal has the larger PAPR, which causes the degradation of BER performance in the non-linear amplifier [2]. From this reason, the OFDM has been also considered as unsuitable transmission technique for the satellite channel, although it has a potential capability to improve the transmission data rate by employing the multi-level QAM with less complexity of transmitter and receiver. To solve this problem, we proposed the QAM-OFDM technique with IDAR (Improved Decision Aided Reconstruction) method (OFDM-IDAR), which can mitigate the non-linear distortion and achieve the higher data rate with keeping the better BER performance even in the satellite channel [3][4]. The feature of proposed OFDM-IDAR method is to reconstruct the non-linear distortion by using the decision data at the receiver. However, the proposed OFDM-IDAR method has some limitation of usage for higher level of modulation method such 64QAM because its decision data includes a lot of error due to the non-linear distortion. To reduce the non-linear distortion, it is required to improve the PAPR performance as much as possible for the transmission OFDM signal. If the PAPR performance can be improved somehow for the transmission signal, the non-linear distortion can be also reduced and IDAR method could work well even for the higher level of modulation method such as 64QAM and the BER performance can be improved accordingly. In this paper we propose the OFDM-IDAR method in conjunction with the PAPR reduction method, which allows the employment of higher level of modulation method in the non-linear satellite channel.

Up to today, various kinds of PAPR reduction methods were proposed such as the selected mapping method (SLM) [4] and the partial transmit sequence method (PTS) [5]. Both of these methods can achieve the better PAPR performance by controlling the phase of data sub-carriers at the transmitter, although these two methods are required to inform the phase information controlled for the data sub-carriers to the receiver as the side information (SI). In this paper, we employ the PTS

method as the reduction method of the PAPR at the transmit earth station because PTS method can achieve the better PAPR performance with less complexity of required processing as compared with the SLM method [6].

In this paper, Section 2 presents the proposed OFDM system with the PTS and IDAR methods for satellite channel. Section 3 presents the various computer simulation results to verify the performance of proposed method, and we draw some conclusions in Section 4.

2. PROPOSAL OF OFDM-IDAR WITH PTS METHOD

2.1 Satellite System Model

Fig. 1 shows the typical satellite system model assumed in the following evaluations. The non-linear amplifier assumed for the earth station is the Solid State Power Amplifier (SSPA), which is modelled by Rapp [2]. The AM-AM and AM-PM conversions characteristics of SSPA modelled by Rapp are given by the following equations, respectively.

$$F_E(\rho) = \frac{\nu\rho}{\left[1 + \left(\nu\rho / A_o\right)^{2p}\right]^{1/2p}}$$ (1)

$$\Phi_E(\rho) = \alpha_\phi \left(\frac{\nu\rho}{A_o}\right)^4$$ (2)

where, ρ is the amplitude of input signal, ν is the gain factor, A_0 is the saturated output level, p is the parameter to decide the non-linear level and α_ϕ is phase displacement. In the following evaluations, the values for these parameters are assumed by $A_0 = 1$, $\nu = 1$, $p = 6$ and $\alpha_\phi = 0.025$. The non-linear amplifier assumed for the satellite station is the TWTA, which is modelled by Saleh [2]. The AM-AM and AM-PM conversions characteristics of TWTA modelled by Saleh are given by the following equations, respectively.

$$F_S(\gamma) = \frac{\alpha_a\gamma}{(1 + \beta_a\gamma^2)}$$ (3)

$$\Phi_S(\gamma) = \frac{\alpha_\theta\gamma^2}{(1 + \beta_\theta\gamma^2)}$$ (4)

where, γ is the amplitude of input signal, α_a and β_a are the parameters to decide the non-linear level, α_θ and β_θ are phase displacements. The values for these parameters are assumed by $\alpha_a = 2$, $\beta_a = 1$, $\alpha_\theta = 2$ and $\beta_\theta = 1$. The characteristics of both SSPA and TWTA are shown in Fig 2.
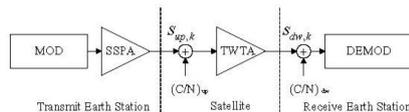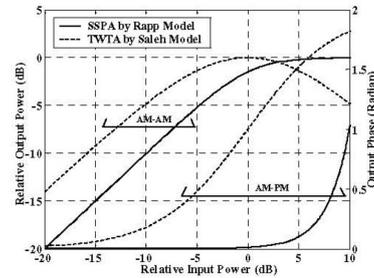

Fig. 1 Satellite system model.

Fig. 2. Input and output relationships for SSPA and TWTA.

2.2 PTS Method at the Transmitter

This subsection presents the PTS method briefly. Figure 3 shows the structure of PTS method. In the PTS [6], the sub-carrier vector X_n is partitioned into V clusters $X_n^{(v)} (1 \leq v \leq V)$. All sub-carriers including V cluster are multiplied by constant phase $c_n^{(v)} = e^{+j\phi_n^{(v)}}$ so as to reduce the PAPR performance. Here, the phase value is given by the following equation.

$$\varphi_n^{(v)} \in [0, 2\pi) \ (1 \leq v \leq V)$$ (5)

After multiplying the phase, the sub-carrier vector is given by the following equation.

$$\tilde{X}_n = \sum_{v=1}^{V} c_n^{(v)} \cdot X_n^{(v)}$$ (6)

where, the set of controlled phase $\left\{c_n^{(v)}, 1 \leq v \leq V\right\}$ are required to inform the receiver as side information. The set of phase values for all clusters are optimized in the time domain so as to achieve the better PAPR performance, by using the following equation.

$$\tilde{x}_k = \sum_{v=1}^{V} c_n^{(v)} \cdot IFFT\left\{X_n^{(v)}\right\} = \sum_{v=1}^{V} c_n^{(v)} \cdot x_k^{(v)}$$ (7)

The better PAPR performance could be achieved, if $c_n^{(v)}$ is chosen with continuous phase, although the size of side information to be transmitted to the receiver would increase. Since the side information is required to inform the receiver by using the data channel with the high signal quality, the large size of side information would cause the degradation of system efficiency relatively. To solve this problem, the discrete phase value is employed to reduce the size of side information although the PAPR performance would be degraded slightly [6] as compared with that for using the continuous phase values.

After optimization of phase value for each cluster, the time domain signal with guard interval (GI) is input to the non-linear amplifier (SSPA) at the earth station. The non-linear operation of amplifier can be expressed by the following equation.

$$s(t) = F\left[|y_k|\right]e^{j\left(\arg(y_k) + \Phi(|y_k|)\right)}$$ (8)

where, y_k is OFDM signal in the time domain, F[ ] and Φ[ ] represent the AM/AM and AM/PM conversion characteristics of non-linear amplifier given by (1) and (2).
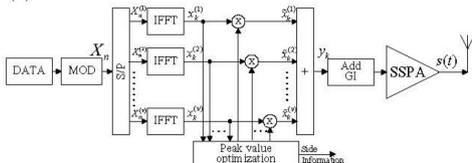

Fig. 3 Structure of OFDM transmitter with PTS method

2.3 IDAR Method at the Receiver

Figure 4 shows the structure of proposed OFDM-IDAR receiver with PTS method. In Fig.4, the received RF signal r(t) is first down converted (D/C) to the base band signal and digitized by A/D converter. The received time domain sampled signal after removing the guard interval (GI) is given by the following equation.

$$r_k = s_{dw,k} + w_k = s_k + i_k + w_k \tag{9}$$

where, $s_{dw,k}$, w_k, s_k and i_k represent the output signal of TWTA, additive noise, original signal and non-linear distortion in the time domain, respectively. Equation (9) is converted to the frequency domain signal by FFT and given by,

$$R_n = S_n + I_n + W_n \tag{10}$$

The decision for the information data can be made for each sub-carrier on the basis of the following equation.

$$\hat{S}_n = \min_S \left| R_n - S_n \right| \tag{11}$$

where $\hat{S}_n$ is the decision data at the n-th sub-carrier. The decision data in the frequency domain is converted to the time domain signal $\hat{s}_k$ by IFFT, which corresponds to the reconstructed transmitted time domain signal.

By using the time domain signal $\hat{s}_k$, the output time domain signal of SSPA and TWTA can be reconstructed by using the same manner as processed at the earth station and satellite. Here, the operations of non-linear amplifiers both for the SSPA and TWTA are conducted on the digital sampled data by assuming the relative AM-AM and AM-PM conversion characteristics as that operated in the radio frequency. The time domain signal consisting of non-linear distortion incurred at the SSPA and TWTA can be estimated by the following equation.

$$\hat{e}_k = \hat{s}_{dw,k} - \hat{s}_k = \hat{i}_k \tag{12}$$

where, $\hat{s}_{dw,k}$ and $\hat{i}_k$ represent the time domain reconstructed signal at the output of TWTA and estimated non-linear distortion, respectively. By subtracting (12) in the frequency domain from (10), the frequency domain signal coped with non-linear distortion of SSPA and TWTA can be obtained by the following equation.

$$\hat{R}_n = R_n - \hat{E}_n = S_n + \left(I_n - \hat{I}_n \right) + W_n \approx S_n + W_n \tag{13}$$

In the IDAR method, the processing from (11) to (13) is repeated up to achieving the better BER performance. After the IDAR processing, the phase rotation controlled by PTS at the transmitter is recovered by using the side information as shown in Fig. 4. The proposed IDAR method on the basis of above procedures could provide the better BER performance, even when the non-linear amplifier is operated at the near saturation region.
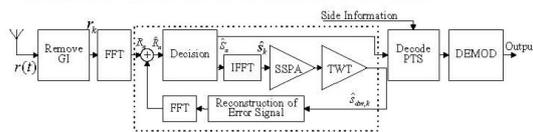

Fig.4: Structure of receiver with proposed OFDM-IDAR with PTS method

3. PERFORMANCE EVALUATIONS

This section presents the various computer simulation results to demonstrate the performance of OFDM-IDAR method with PTS method in satellite channel. In the following simulations, the side information can be informed to the receiver perfectly. Table 1 shows the list of simulation parameters used in the following computer simulations. The modulation method is 64QAM and its demodulation method is the coherent detection.

Table 1: *Simulation parameters*

Allocated bandwidth	26MHz
Modulation method	64QAM
Number of FFT points	512
Number of sub-carriers	128
Symbol duration	4.92us
Guard interval	0.5us
Non-linear amplifier	SSPA, TWTA
Transmission data rate	141.6 Mbit/s

In the following evaluation, the up-link C/N is assumed to be the noise free condition and only the downlink noise is added to the received signal. The IBO for the earth station amplifier of SSPA is fixed by –3dB. The downlink C/N is defined by using the desired signal power at the output of satellite non-linear amplifier of TWTA at IBO=0dB. In this definition of C/N, the actual C/N for the received signal would be changed from the given C/N according to the IBO of TWTA. The power of inter-modulation noise could be reduced as decreasing IBO while the desired signal power at the output of amplifier would be reduced.

Figure 5 shows the PAPR performance when changing the number of clusters for the PTS method. The number of discrete phase values is assumed by four kinds of phases 0, $\pi/2$, π and $3\pi/2$, which requires 2 bits for each cluster as the side information. In the figure, the PAPR performance is evaluated by using the Cumulative Distribution Function (CDF). From the figure, it can be seen that the PAPR performance for the PTS method can be improved relatively as compared with the conventional

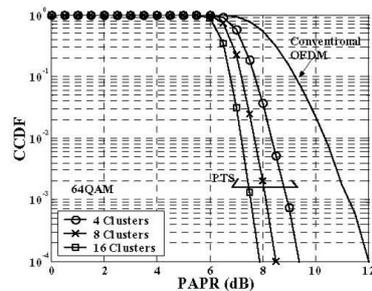OFDM signal, especially when increasing the number of clusters.

Fig.5: PAPR performance

Figure 6 shows the BER performances when changing the number of iteration in the IDAR method. The IBO for satellite TWTA is taken by -4, -6 and -8dB. The number of clusters for the PTS method is 4 and the downlink C/N is 25dB. From the figure, it can be observed that the proposed OFDM-IDAR with PTS method can achieve the bestter BER perforamnce than that for the conventional IDAR method when comparing at the same iteration number.
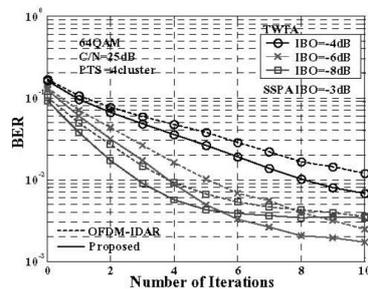

Fig.6: BER performance vs. number of iterations for IDAR.

Figure 7 shows the BER performances for the conventional PTS, IDAR and the proposed PTS-IDAR methods when changing the IBO of TWTA and the downlink C/N. From the figure, it can be observed that the proposed PTS-IDAR method can achieve much better BER performance than that for the conventional PTS and IDAR methods of which BER performances have error floor at the higher C/N. From these results, it can be concluded that the proposed OFDM-IDAR with PTS method can provide the higher transmission data rate with keeping the better BER performance in the non-linear satellite channel.

4. CONCLUSIONS

This paper proposed the OFDM-IDAR method in conjunction with the PTS method, which can reduce the

PAPR performance at the transmitter and can mitigate the non-linear distortion at the receiver by using PTS and IDAR methods, respectively. This paper presented various computer simulation results to verify the effectiveness of proposed method. From the computer simulation results, we confirmed that the proposed method can employ the higher level of modulation method and can provide the higher transmissiondata rate with keeping the better BER performance in the non-linear satellite channel.
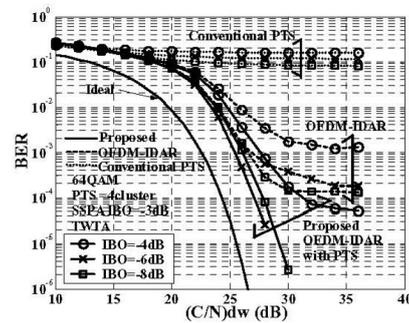

Fig.7: BER performance vs. C/N

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ประวัติผู้เขียน

นาย พรภวิษย์ บุญศรีเมือง เกิดเมื่อวันที่ 8 พฤศจิกายน พ.ศ. 2522 ที่จังหวัด ราชบุรี สำเร็จ การศึกษาปริญญาตรีวิศวกรรมศาสตรบัณฑิต สาขาวิศวกรรมโทรคมนาคม คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง ปี พ.ศ. 2546 และเข้าปฏิบัติงานใน ตำแหน่งผู้ช่วยนักวิจัยสังกัดโครงการ สำนักวิจัยการสื่อสารและเทคโนโลยีสารสนเทศ (ReCCIT) ณ ห้องปฏิบัติการวิจัยการสื่อสารเคลื่อนที่ (Mobile Communication Laboratory) สถาบัน เทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบังในปี 2546 ถึง 2547

ในปีการศึกษา 2547 ได้เข้าศึกษาต่อในระดับบัณฑิตวิทยาลัย หลักสูตร วิศวกรรมศาสตร มหาบัณฑิต สาขาวิชา วิศวกรรมโทรคมนาคม สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหาร ลาดกระบังและในปีการศึกษา 2549 ได้เข้าร่วมโครงการนักศึกษาวิจัยแรกเปลี่ยนกับมหาวิทยาลัย มิเอะ (Mie University) ณ คณะวิศวกรรมศาสตร์ สาขาวิชาวิศวกรรมไฟฟ้าและอิเล็กทรอนิกส์ (Electrical and Electronic Engineering) ห้องปฏิบัติการวิจัยการโทรคมนาคม (Communication Laboratory) ประเทศญี่ปุ่นในปี 2549- 2550