Performance Analysis of MCDD in an OBP Satellite Communications System

Sanggoo Kim and Dongweon Yoon

Abstract: **Multi-carrier demultiplexer/demodulator (MCDD) in an on-board processing (OBP) satellite used for digital multimedia services has two typical architectures according to the channel demultiplexing procedure: Multistage multi-carrier demultiplexer (M-MCD) or poly-phase fast Fourier transform (PPF). During the channel demultiplexing, phase and quantization errors influence the performance of MCDD; those errors affect the bit error rate (BER) performance of M-MCD and PPF differently. In this paper, we derive the phase error variances that satisfy the condition that M-MCD and PPF have the same signal to noise ratio according to quantization bits, and then, with these results, analyze the BER performances of M-MCD and PPF. The results provided here may be a useful reference for the selection of M-MCD or PPF in designing the MCDD in an OBP satellite communications system.**

Index Terms: **Bit error rate (BER), multi-carrier demultiplexer/demodulator (MCDD), multistage multicarrier demultiplexer (M-MCD), poly-phase fast Fourier transform (PPF).**

I. INTRODUCTION

For effective multimedia services, for example high-speed internet, mobile communication and digital multimedia broadcasting (DMB) via satellite, on-board processing (OBP) is essential in satellites [1], [2]. In an OBP satellite, a multi-carrier demultiplexer/demodulator (MCDD) demultiplexes and demodulates multi-carrier signals for signal processing such as switching, channel decoding and remodulation. MCDD has two typical architectures: Multistage multi-carrier demultiplexer (M-MCD) and poly-phase fast Fourier transform (PPF). Because M-MCD and PPF use different demultiplexing procedures, the characteristics of MCDD depend on which architecture is applied to an OBP satellite. Two main factors affect the performance of MCDD: Phase errors and quantization errors. PPF is more sensitive to quantization errors than M-MCD, whereas M-MCD is more sensitive to phase errors than PPF [3], [4]. For example, when the phase variance is not trivial, PPF has a better bit error rate (BER) performance than M-MCD [5].

In this paper, we extend the results of [4] to present a reference for the selection of M-MCD or PPF in designing the MCDD. In order to obtain the reference, we investigate the relation between phase errors and quantization errors, derive the phase error variances that satisfy the condition that M-MCD and PPF have the same signal to noise ratio (SNR) according to quantization bits, and analyze the effects on the BER performances of M-MCD and PPF. Finally, we present a reference to select M-MCD or PPF in designing the MCDD in an OBP satellite communications system.

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II. SNR ANALYSIS OF M-MCD AND PPF

In previous works [3]–[5], the BER performances of M-MCD and PPF were analyzed for the SNR of M-MCD, SNR_{M-MCD} and SNR of PPF, SNR_{PPF}. For more detailed comparisons, in this paper, we examine the variance of phase errors σ_φ^2 and the number of quantization bits b that satisfy $SNR_{M-MCD} = SNR_{PPF}$, and analyze the variations of SNR_{M-MCD} and SNR_{PPF} according to σ_φ^2 and b. We then use the results to analyze the BER performances of M-MCD and PPF according to both variations of phase errors and quantization errors, and present a reference for the selection of M-MCD or PPF in designing the MCDD.

When considering the influences of phase errors and quantization errors on the SNR of M-MCD, we can express SNR_{M-MCD} as [4]

$$SNR_{M-MCD} = \frac{P_{M-MCD}}{N_{narrow} + I_{M,\varphi} + I_{M,Q}} \quad (1)$$

where

$$I_{M,\varphi} = \frac{\sigma_\varphi^2}{2} E_k \int_{(k-1)\pi P/Q}^{k\pi P/Q} \mathrm{sinc}^2 \left[\frac{P(\omega - \omega_k) T_k}{2^{2+\log_2 N} Q \pi T_s} \right] d\omega \quad (2)$$

and

$$I_{M,Q} = 4^{\log_2 N} 2\pi P T_s \left[N_Q^2 + \left(Q + \sum_{l=1}^{1+\log_2 N} N^l \right) \times \frac{\left(N_{Q_2}^{HBF} + N_{Q_3}^{HBF} + \gamma^2 S \right)}{Q N^{(1+\log_2 N)}} \right]. \quad (3)$$

Here, P_{M-MCD} is the power of an input signal, N_{narrow} is the narrow-band additive white Gaussian noise (AWGN), $I_{M,\varphi}$ is the power related to phase error, $I_{M,Q}$ is the power related to quantization error, $\omega_k = 2\pi f_k$ is the desired carrier frequency, P and Q are up-sampling and down-sampling factors of the rate conversion filter, respectively, N is the total number of channels, T_s is the sampling interval of the analog to digital converter (ADC), E_k is the unwanted symbol energy not removed from the fast Fourier transform (FFT) processor, σ_φ^2 is the variance of phase errors, $N_Q^2 = 2^{-2b}/3$ is the quantization noise introduced at the ADC, $N_{Q_2}^{HBF} = (C+1)2^{-2b}/3$ is the coefficient quantization effects introduced by the finite impulse response

(FIR) filter, $N_{Q_3}^{HBF} = (C+1)2^{-2b}/6$ is the quantization noise of arithmetic operations in the internal memory, l is the number of M-MCD stages, γ is the decimation processing factor, C is the number of filter taps, S is the power of input signal, and $b = \log_2 M$ is the number of quantization bits [4].

Similarly, when considering the influences of phase errors and quantization errors on the SNR of PPF, we can express as [4]

$$SNR_{PPF} = \frac{P_{PPF}}{N_{narrow} + I_{P,\varphi} + I_{P,Q}} \tag{4}$$

where

$$I_{P,\varphi} = \frac{\sigma_\varphi^2}{2N} \sum_{p=1}^{N} E_p \int_{(k-1)\pi P/Q}^{k\pi P/Q} \text{sinc}^2 \left[\frac{P(\omega - \omega_k)T_k}{4NQ\pi T_s} \right] d\omega \tag{5}$$

and

$$I_{P,Q} = 8\pi P T_s N \Bigg[N_Q^A + S_k\gamma^2 N + N(1-a^2) \times \frac{(N_{Q_2}^{APF} + N_{Q_3}^{APF} + N_{Q_2}^{FFT} + N_{Q_3}^{FFT} + S_k\gamma^2 Q)}{QN(1-a^2)} \Bigg]. \tag{6}$$

Here, P_{PPF} is the power of an input signal, $I_{P,\varphi}$ is the power related to phase error, $I_{P,Q}$ is the power related to quantization error, E_p is the unwanted symbol energy not removed from the FFT processor, $N_Q^A = \{N_Q^2 + N(N_{Q_2}^{HBF} + N_{Q_2}^{HBF} + \gamma^2 S)\}/N$ is the sum of quantization noises introduced at ADC and DAF, $N_{Q_2}^{APF} = N_Q^2/(1-a^2)$ is the coefficient quantization effects of the All-Pass Filter (APF), $N_{Q_3}^{APF} = N_Q^2/(1-a^2)$ is the quantization noise of arithmetic operations at the APF, $N_{Q_2}^{FFT} = 3 \cdot 2^{-2b}N/4$ is the quantization noise obtained from FFT algorithms, $N_{Q_3}^{FFT} = 2(N \cdot \log_2 N) N_2^Q$ is the coefficient quantization error of FFT processor, S_k is the power of the kth channel signal, and a is the coefficient of APF [4].

By letting $SNR_{M-MCD} = SNR_{PPF}$, i.e.,

$$\frac{P_{M-MCD}}{N_{narrow} + I_{M,\varphi} + I_{M,Q}} = \frac{P_{PPF}}{N_{narrow} + I_{P,\varphi} + I_{P,Q}} \tag{7}$$

we can obtain the conditions of phase error variances and quantization bits that the PPF and MMCD have the same SNR. Assuming that P_{M-MCD} and P_{PPF} are equal, we can rewrite (7) as

$$I_{M,\varphi} - I_{P,\varphi} = I_{P,Q} - I_{M,Q}. \tag{8}$$

Finally, substituting the powers related to phase errors and quantization errors, (2), (3), (5) and (6), into (8), we obtain the phase error variance as (9) at the top of the next page.

III. NUMERICAL RESULTS

In this section, we analyze the BER performances of M-MCD and PPF according to the phase error variances and quantization bits, and tabulate the values of phase error variances and quantization bits for $SNR_{M-MCD} = SNR_{PPF}$, in order to serve as a reference in selecting M-MCD or PPF.

Table 1. Simulation parameters for BER analysis.

Parameter	Value
Modulation type	QPSK
B_k	5.5 MHz
N	6
P	4
Q	3
C	9
γ	1.0258
a	0.99

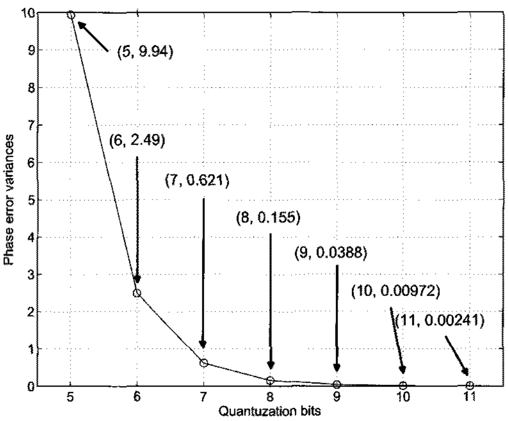

Fig. 1. The values of phase error variances and quantization bits for $SNR_{M-MCD} = SNR_{PPF}$.

Assume that quadrature phase-shift keying (QPSK) is used in the digital video broadcasting satellite (DVB-S) [6], and an MCDD simulation model is based on the SKYPLEX MCDD processor used in the Hot Bird 6 Satellite [7]. Table 1 shows the parameters for the simulation. Using (9) to (12), we summarize the values of phase error variances and quantization bits for $SNR_{M-MCD} = SNR_{PPF}$ in Fig. 1.

Because the SNR of the input signal at the demodulator SNR_{demod} establishes the BER performance, to analyze the BER performance, we express SNR_{demod} influenced by phase errors and quantization errors as

$$SNR_{demod} = SNR_{signal} - 10 \left\{ \log_{10} \frac{(N_{narrow} + I_\varphi)(N_{narrow} + I_Q)}{N_{narrow}^2} \right\} [dB] \tag{13}$$

where SNR_{signal} is the SNR of the received signal, I_φ is the power related to phase errors, and I_Q is the power related to the quantization errors.

Fig. 2 shows the BER performances of M-MCD and PPF by phase errors when the number of quantization bits is 9. When $\sigma_\varphi^2 = 0.04$, M-MCD and PPF have almost the same BER performances. When $\sigma_\varphi^2 = 0$, the BER performance of M-MCD is better than that of PPF because M-MCD has the advantage

$$\sigma_\varphi^2 = \frac{B(C,N,P,Q,T_s)}{3A(N,P,Q,T_s,T_k)} 2^{-2b} + \frac{D(a,\gamma,N,P,Q,T_s,S,S_k)}{A(N,P,Q,T_s,T_k)} \quad (9)$$

where

$$A(N,P,Q,T_s,T_k) = \left(E_k - \sum_{m=1}^{N} E_m\right) \int_{(k-1)\pi P/Q}^{k\pi P/Q} \operatorname{sinc}^2\left[\frac{P(\omega-\omega_k)T_k}{4NQ\pi T_s}\right] d\omega, \quad (10)$$

$$B(C,N,P,Q,T_s) = 8\pi P T_s \left[\frac{\left\{\frac{1}{N} + \frac{3}{2}(C+1) + 2N + \left(4N^2 + 2N^2\log_2 N\right)\left(1-a^2\right)\right\}}{Q(1-a^2)} - \frac{N + \frac{3}{2}N\left(Q + \sum_{l=1}^{1+\log_2 N} N^l\right)}{N^{\log_2 N}}\right], \quad (11)$$

and

$$D(a,\gamma,N,P,Q,T_s,S,S_k) = 8\pi P T_s \left[\frac{\gamma^2\left(S + S_k N + S_k Q\left(1-a^2\right)\right)}{Q(1-a^2)} - \frac{N\left(Q + \sum_{l=1}^{1+\log_2 N} N^l\right)\gamma^2 S}{N^{\log_2 N}}\right]. \quad (12)$$

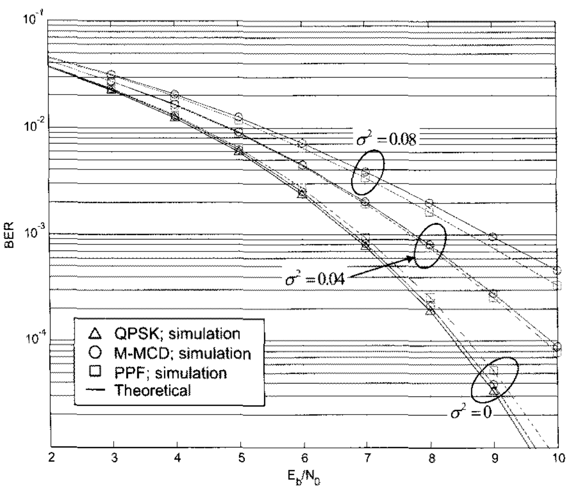

Fig. 2. BER performances by phase errors when the number of quantization bits is 9.

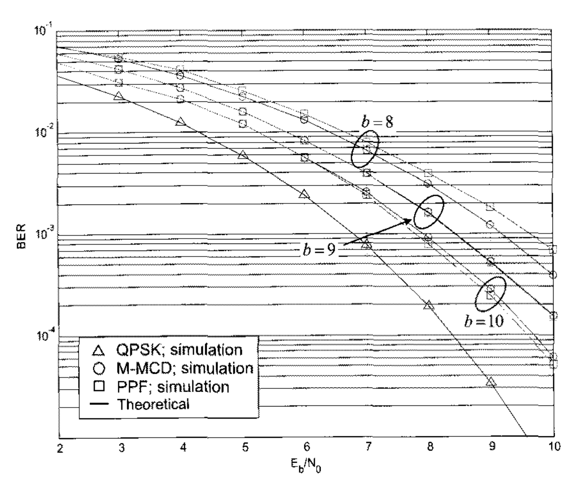

Fig. 3. BER performances by quantization errors when phase error variance is 0.04.

of being affected only by quantization errors, whereas, when $\sigma_\varphi^2 = 0.08$, we can see that the BER performance of PPF is better than that of M-MCD.

From the results, we see that when the number of quantization bits b is 9 (the value of quantization bits corresponding to the phase variance 3.88×10^{-2} (≈ 0.04) in Fig. 1), if σ_φ^2 is higher than 3.88×10^{-2} , we can confirm that PPF performs better than M-MCD, and if σ_φ^2 is lower than 3.88×10^{-2}, M-MCD performs better than PPF.

Fig. 3 shows the BER performances of M-MCD and PPF by quantization errors when the phase error variance is 0.04. From the Figs. 2 and 3, we can see excellent agreement between the results from the analytical expressions and simulations. When $b = 9$, the BER performance of M-MCD and PPF are almost same. When the number of quantization bits b is 10, PPF has better BER performance than M-MCD, whereas when $b = 8$, M-MCD has better BER performance than PPF.

That is, when the phase error variance σ_φ^2 is given as 0.04 ($\approx 3.88 \times 10^{-2}$) which is the phase error variance corresponding to 9 quantization bits in Fig 1, if b is larger than 9 the BER performance of PPF is better than that of M-MCD, otherwise, the BER performance of M-MCD is better than that of PPF.

The results inform us which MCDD architecture performs better in designing an OBP satellite communications system.

IV. CONCLUSIONS

In this paper, we derived the phase error variances that satisfy the condition that M-MCD and PPF have the same SNR according to quantization bits, and analyzed the effects on the BER performances of M-MCD and PPF. For a given number of quantization bits, if a phase error variance is higher than the value of phase error variance corresponding to the number of given quantization bits in Fig. 1, the BER performance of PPF is better than that of M-MCD. Otherwise, M-MCD has better BER performance than PPF. Similarly, for a given phase error variance, if the number of quantization bits is higher than the value of quantization bits corresponding to the given phase error variance in Fig. 1, the BER performance of PPF is better than that of M-MCD. Otherwise, M-MCD has better BER performance than PPF. Our results should aid in the selection of M-MCD or PPF when designing an OBP satellite communications system.

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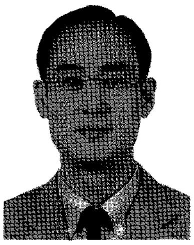

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