Nonlinearity Sensitivity of FBMC and UFMC Modulation System for the 5G Mobile System

Changyoung An, Heung-Gyoon Ryu
Department of Electronics Engineering
Chungbuk National University
Cheongju, Korea 361-763
acy890217@naver.com, ecomm@cbu.ac.kr

Yukinobu Fukushima, Tokumi Yokohira
Graduate School of Natural Science and Technology,
Okayama University
Okayama, Japan 700-8530
fukusima@okayama-u.ac.jp,yokohira@okayama-u.ac.jp

***Abstract*—Recently, many researches on new waveforms have been carried out. UFMC and FBMC technique are famous as a new waveform for 5G. Similar to OFDM system, these techniques use multi-carrier. So, these systems have high PAPR, which can cause nonlinear distortion and OOB power increase because of the nonlinear HPA. In this paper, we have focused on spectrum characteristic analysis and BER performance evaluation of FBMC and UFMC system under the effect of nonlinear HPA. As simulation results, it is confirmed that OOB power of each system increases, and OOB power increase of FBMC system is the biggest. Additionally, we have confirmed that performance of every system is degraded by strength of HPA nonlinearity, and every system needs the PAPR reduction method for the nonlinear distortion compensation and power saving, even though it would be more complicated.**

Keywords*—new waveform; OFDM; FBMC; UFMC; HPA nonlinearity

I. INTRODUCTION

The mobile traffic is being increased dramatically, because various mobile devices and multimedia services are being increased [1]. Also, the growth of mobile traffic is being accelerated. It is difficult for the present mobile communication to support the mobile traffic required in the future [2]. In order to solve the problem, studies for next generation 5G mobile communication has been carried actively [3-4].

Conventional orthogonal frequency division multiplexing (OFDM) based on multi-carrier has high-power out-of-band (OOB) [5]. This characteristic causes adjacent channel interference (ACI). OFDM uses a wide guard band in order to avoid ACI. It decreases spectral efficiency when a number of mobile devices simultaneously access a base station. Next generation mobile communication system requires high-level key performance indicators (KPIs). It is difficult for OFDM to satisfy the KPIs. Universal filtered multi-carrier (UFMC) and filter bank based multi-carrier (FBMC) are known as the candidate waveform for 5G mobile communication. These systems use filtering technique based on multi-carrier. These techniques have characteristic of low OOB power in comparison with conventional OFDM. Therefore, these systems have high spectrum efficiency. FBMC uses a filtering technique in each sub-carrier. UFMC uses a filtering technique in each sub-band [8-9].

However, these systems based on OFDM are vulnerable to non-linearity of high-power amplifier (HPA), like OFDM. OFDM has high peak-to-average power ratio (PAPR) because multi-carrier signals are overlapped. High PAPR causes nonlinear distortion in HPA because it saturates HPA. Similarly, UFMC and FBMC have high PAPR because these systems are based on multi-carrier [10-11]. In UFMC and FBMC system, if nonlinear distortion is caused by high PAPR, OOB power of these systems is increased. That is, advantage of these systems vanishes. Therefore, this drawback should be overcome in the candidate techniques for 5G mobile communication.

In this paper, in order to overcome the drawback, we focus on spectrum characteristic analysis and performance evaluation of FBMC and UFMC system under the effect of nonlinear HPA. Firstly, we describe and explain OFDM, UFMC, FBMC system. And then, we design the systems. Next, under linear environment, we analyze spectrum characteristic of each system and evaluate bit error rate (BER) performance of each system. And then, under the effect of nonlinear HPA, we analyze spectrum characteristic of each system and evaluate bit error rate (BER) performance of each system.

II. SYSTEM MODEL

A. OFDM

Figure 1 shows block diagram of OFDM system. Firstly, in transmitter of OFDM system, the data symbols are transformed into parallel stream from series stream by S/P block. The changed symbols are mapped onto each subcarrier by inverse fast Fourier transform (IFFT) operation. IFFT operation changes frequency-domain signal into time-domain signal. After IFFT operation, the time-domain signals are transformed into series stream from parallel stream by P/S block. And then, cyclic prefix (CP) is added in order to reduce the effect of inter-symbol interference (ISI). And then, the base-band signals are applied to RF chain. Finally, the RF signals are amplified by high-power amplifier (HPA). Receiver of OFDM system consists of reversed structure in comparison with OFDM transmitter. Additionally, in OFDM receiver, an equalizer is used in order to restore desired signal. The equalizer is very simple because of CP. OFDM receiver uses one-tap equalizer. This is a good advantage for OFDM system.

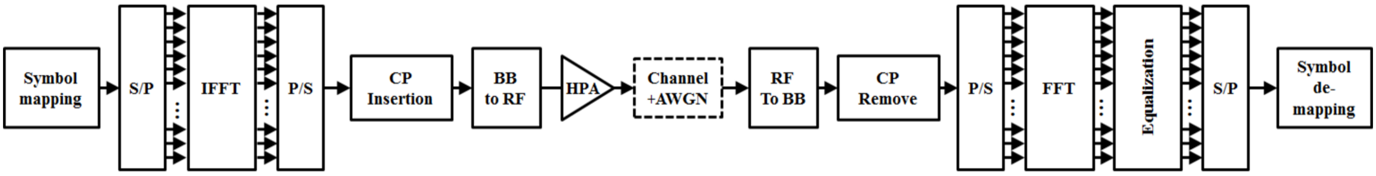

Fig. 1. Block diagram of OFDM system.

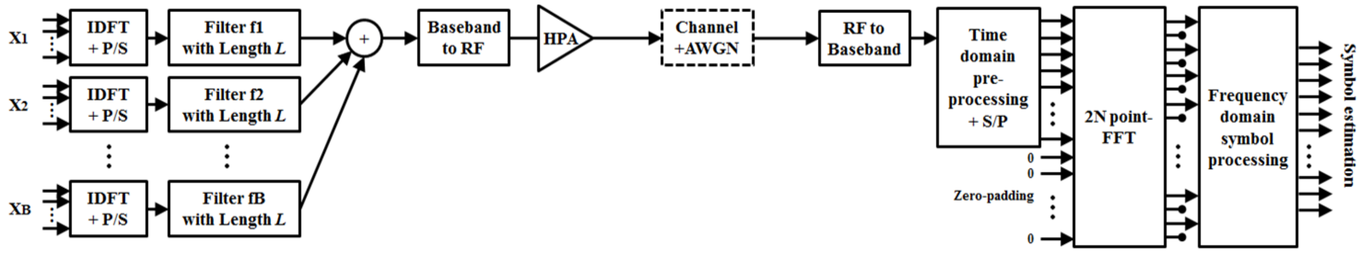

Fig. 2. Block diagram of UFMC system.

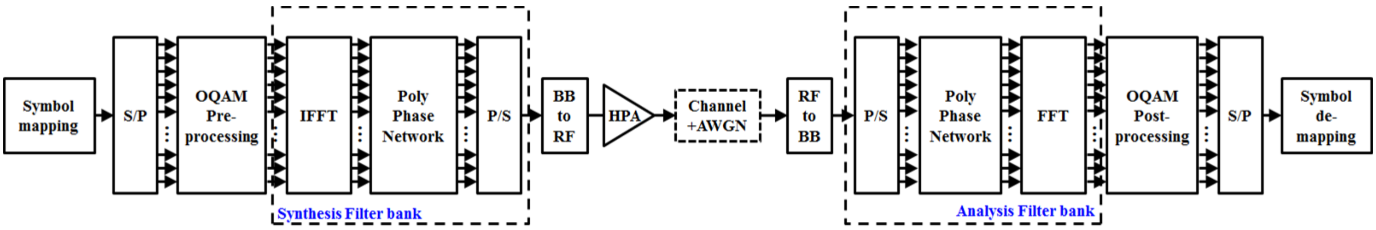

Fig. 3. Block diagram of FBMC system.

OFDM system has advantages of orthogonality between each of subcarriers and robustness against ISI effect by CP. That is, OFDM system requires simple equalizer with one tap [12]. However, each subcarrier of OFDM system has high side-lobe power. As a result, channel capacity is decreased in OFDM system [12]. These drawbacks should be overcome for 5G mobile communication.

B. UFMC

UFMC system uses orthogonal multi-carrier, like OFDM system. UFMC filters each sub-band that consists of orthogonal multi-carrier in order to reduce OOB power [6].

Figure 2 shows block diagram of UFMC system. Each sub-band signal is transformed into series stream by P/S. Secondly, in UFMC receiver, the received signal is applied to RF chain. The received signal is transformed into baseband signal by RF chain. Baseband signal is converted into digital signal by ADC. And then, time-domain pre-processing is processed. After the process, the series data stream is transformed into a parallel data stream by S/P. The time-domain parallel data stream is converted to frequency-domain stream by 2N-FFT operation [6]. After 2N-FFT operation, odd-numbered data symbols are selected and equalized. Spectrum of UFMC system has lower OOB power in comparison with spectrum of OFDM system. This is good advantage. However, because UFMC system uses multi-carriers and multi-carriers are overlapped, UFMC system has high PAPR. High PAPR characteristic can distort signal of UFMC system [6].

C. FBMC

FBMC system uses multi-carrier, like OFDM system. FBMC system filters each sub-carrier in order to reduce OOB power of spectrum [7].

Figure 3 shows block diagram of FBMC system. Firstly, in transmitter of FBMC system, data symbols are transformed into parallel stream from series stream by S/P. The parallel symbols are modulated to offset quadrature amplitude modulation (OQAM) signal [7]. The modulated OQAM signal is transformed into a signal filtered by each sub-carrier by using synthesis filter bank that consists of IFFT and poly phase network (PPN) [7]. Finally, the amplified FBMC signal is transmitted by antenna. Receiver of FBMC system consists of reversed structure in comparison with FBMC transmitter. FBMC system has lower OOB power in comparison with UFMC system and OFDM system. This is a good advantage. However, FBMC system has high system complexity. Additionally, because FBMC system uses multi-carrier, it has high PAPR.

In this paper, purposes are spectrum characteristic analysis and performance evaluation of OFDM, UFMC, and FBMC system under the effect of nonlinear HPA. Therefore, we have designed each system. In Saleh model, characteristics of AM-AM and AM-PM are as follows [13].

$$G[A(t)] = \frac{\alpha_A A(t)}{1+\beta_A A(t)^2} \quad (1)$$

$$\Phi[A(t)] = \frac{\alpha_\Phi A(t)^2}{1+\beta_\Phi A(t)^2} \quad (2)$$

Equation (1) shows AM-AM characteristic of Saleh model, nonlinear HPA model. A is amplitude of input signal. α_A and β_A are coefficients for adjusting amplitude of output signal. Equation (2) shows AM-PM characteristic of Saleh model. α_Φ and β_Φ are coefficients for adjusting phase of output signal.

III. Simulation Results and Analysis

Table 1 shows simulation parameters.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Modulation	QPSK
# of total subcarrier	64
# of used subcarrier	32
# of null subcarrier	32
Filter for FBMC	Phydyas prototype H0 = 1 H1 = 0.97196 H2 = 0.7071 H3 = 0.235147
Filter for UFMC	Chebyshev Attenuation = 60dB,Length = 10
# of sub-band in UFMC	64/8
# of used sub-band in UFMC	4

Table 2 shows the considered HPA nonlinear conditions. Condition 0 is linear. Conditions 1 to 5 are nonlinear condition. Condition 1 is weak nonlinear condition. Condition 5 is strong nonlinear condition.

TABLE II. CONDITION OF HPA NONLINEARITY

Condition	AM-AM	AM-PM
0 (Linear)	α_A= 1	α_Φ= 0
	β_A= 0	β_Φ= 0
Nonlinear 1	α_A= 1	α_Φ= 0.26
	β_A= 0.04	β_Φ= 15.9
Nonlinear 2	α_A= 1	α_Φ= 0.26
	β_A= 0.2	β_Φ= 2.38
Nonlinear 3	α_A= 1	α_Φ= 0.26
	β_A= 0.4	β_Φ= 0.69
Nonlinear 4	α_A= 1	α_Φ= 0.26
	β_A= 0.6	β_Φ= 0.127
Nonlinear 5	α_A= 1	α_Φ= 0.26
	β_A= 0.8	β_Φ= -0.155

TABLE III. COMPARISON OF OOB POWER

Condition	OFDM	UFMC	FBMC
0 (Linear)	-26dB	-80dB	-117dB
Nonlinear 1	-26dB	-45dB	-48dB
Nonlinear 2	-25dB	-32dB	-36dB
Nonlinear 3	-24dB	-27dB	-31dB
Nonlinear 4	-23dB	-24dB	-28dB
Nonlinear 5	-22dB	-23dB	-26dB

Table 3 shows OOB power comparison about each system. In this table, we have confirmed as follows. Under the HPA nonlinearity environment FBMC system shows the biggest change of OOB power, and OFDM system shows the smallest change of OOB power.

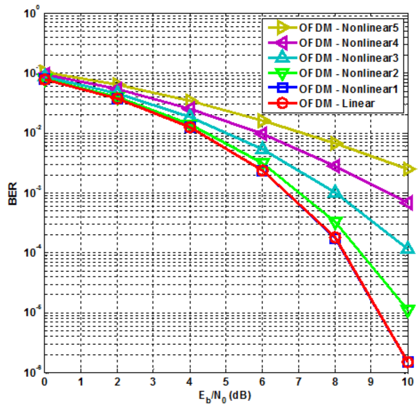

Fig. 4. BER performance of OFDM system according to nonlinear HPA conditions.

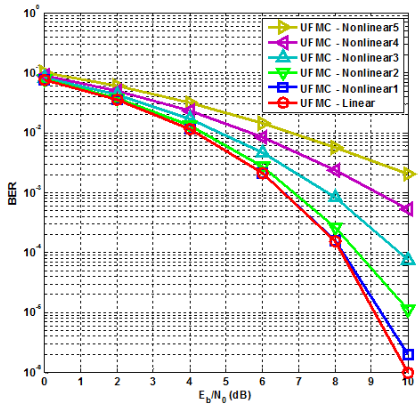

Fig. 5. BER performance of UFMC system according to nonlinear HPA conditions.

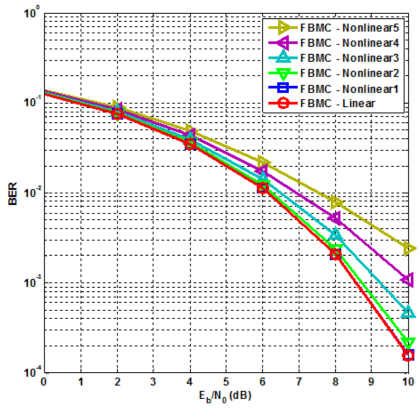

Fig.6. BER performance of FBMC system according to nonlinear HPA conditions.

Figures 4 to 6 show BER performances of each system. Each system has ideal performance under the linear condition or nonlinear condition. Under the nonlinear HPA environment, BER performance of every system is degraded. Additionally, FBMC system shows the smallest degradation of BER performance. However, even though FBMC system is the strongest against HPA nonlinearity, every system needs the PAPR reduction method for the nonlinear distortion compensation and power saving.

IV. Conclusions

FBMC and UFMC systems are strong modulation candidate for 5G mobile communication system. Since these systems are basically multicarrier system, it is important to study the nonlinearity sensitivity. In this paper, we have focused on spectrum characteristic analysis and BER performance evaluation of OFDM, FBMC, and UFMC system under the effect of nonlinear HPA. As simulation results, we have confirmed that if HPA nonlinearity rises in each system, OOB power of each system increases. The OOB power increase of FBMC system is the biggest. Additionally, we have confirmed that performance of every system is degraded by strength of HPA nonlinearity, and every system needs the PAPR reduction method for the nonlinear distortion compensation and power saving, even though it would be more complicated.

Acknowledgment

“This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology(No.2013R1A2A2A01005849)”

References

[1] Shanzhi Chen; Jian Zhao, "The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication," Communications Magazine, IEEE , vol. 52, no. 5, pp. 36-43, May 2014.

[2] Dahlman, E.; Mildh, G.; Parkvall, S.; Peisa, J.; Sachs, J.; Selén, Y.; Sköld, J., "5G wireless access: requirements and realization," Communications Magazine, IEEE, vol. 52, no. 12, pp. 42-47, December 2014.

[3] G. Wunder et al., “5GNOW: non-orthogonal, asynchronous waveforms for future mobile applications”, IEEE Commun. Mag., vol. 52, no. 2, pp. 97-105, Feb. 2014.

[4] P. Banelli et al., “Modulation Formats and Waveforms for the Physical Layer of 5G Wireless Networks: Who Will be the Heir of OFDM?”, in arXiv:1407.5947, July 2014.

[5] Schaich, F.; Wild, T., "Waveform contenders for 5G — OFDM vs. FBMC vs. UFMC," Communications, Control and Signal Processing (ISCCSP), 2014 6th International Symposium on, pp. 457-460, 21-23 May 2014.

[6] Vakilian, V.; Wild, T.; Schaich, F.; ten Brink, S.; Frigon, J.-F., "Universal-filtered multi-carrier technique for wireless systems beyond LTE," in Globecom Workshops (GC Wkshps), 2013 IEEE, pp. 223-228, 9-13 Dec. 2013.

[7] Farhang-Boroujeny, B., "OFDM Versus Filter Bank Multicarrier," in Signal Processing Magazine, IEEE, vol. 28, no. 3, pp. 92-112, May 2011.

[8] Wonsuk Chung; Beomju Kim; Moonchang Choi; Hyungju Nam; Hyunkyu Yu; Sooyoung Choi; Daesik Hong, "Synchronization Error in QAM-Based FBMC System," in Military Communications Conference (MILCOM), 2014 IEEE, pp. 699-705, 6-8 Oct. 2014.

[9] Mukherjee, Mithun; Shu, Lei; Kumar, Vikas; Kumar, Prashant; Matam, Rakesh, "Reduced out-of-band radiation-based filter optimization for UFMC systems in 5G," in Wireless Communications and Mobile Computing Conference (IWCMC), 2015 International, pp. 1150-1155, 24-28 Aug. 2015.

[10] Kollar, Zs.; Varga, L.; Czimer, K., "Clipping-Based Iterative PAPR-Reduction Techniques for FBMC," in OFDM 2012, 17th International OFDM Workshop 2012 (InOWo'12); Proceedings of , pp. 1-7, 29-30 Aug. 2012.

[11] Chafii, M.; Palicot, J.; Gribonval, R., "Closed-form approximations of the PAPR distribution for Multi-Carrier Modulation systems," in Signal Processing Conference (EUSIPCO), 2014 Proceedings of the 22nd European, pp. 1920-1924, 1-5 Sept. 2014.

[12] Elshirkasi, A.M.; Siddiqi, M.U.; Habaebi, M.H., "Generalized Discrete Fourier Transform Based Minimization of PAPR in OFDM Systems," in Computer and Communication Engineering (ICCCE), 2014 International Conference on, pp. 205-208, 23-25 Sept. 2014.

[13] P. Drotar, J. Gazda, D. Kocur, and P. Galajda, “MC-CDMA performance analysis for different spreading codes at HPA Saleh model,” 18th Int. Conf. Radioelektronika, pp. 1-4, Prague, Apr. 2008.