A Novel Precoding Based Hybrid MC/SC Radio Access System for PAPR Reduction in Layered OFDMA of LTE-Advanced

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***Abstract*—This paper presents a novel precoding based hybrid multi-carrier/single-carrier (MC/SC) uplink radio access system for layered orthogonal frequency division multiple access (Layered-OFDMA) of long-term-evolution advanced (LTE-Advanced). Generalized-Chirp-like (GCL) precoder is implemented before subcarrier mapping and IFFT to reduce the high peak-to-average power ratio (PAPR) of MC uplink system. Conventional localized single carrier frequency division multiple access (LFDMA) is also implemented to support all the functionalities provided in release 8 LTE. Extensive computer simulations have been performed to analyze the PAPR of precoding based MC/SC uplink system. The computer simulations show that the PAPR of GCL precoded MC signals approaches in the order of SC signals. Additionally, GCL precoded MC system also take the advantage of the frequency variations of the communication channel and can also offer substantial performance gain in fading multipath channels.**

***Index Terms*—Multi-carrier/single-carrier (MC/SC), Long term evolution advanced (LTE-Advanced), Layered-OFDMA, Generalized-Chirp-like (GCL), Localized single carrier frequency division multiple access (LFDMA)**

I. Introduction

LAYERED orthogonal frequency division multiple access (Layered-OFDMA) radio access scheme has been proposed recently to achieve the higher level requirements of long term evolution advanced (LTE-Advanced). The Layered-OFDMA will support all the functionalities provided in release 8 LTE including its enhancements. In the Layered OFDMA, layered transmission bandwidth is assigned according to the required data rate. Layered OFDMA has its own layered control signaling structure and layered environments in which hybrid multi-carrier/single-carrier (MC/SC) radio access scheme is proposed to be used [1]. Single carrier frequency division multiple access (SC-FDMA) was adopted for the uplink communications in release 8 LTE. SC-FDMA utilizes single carrier modulation with frequency domain equalization at the receiver.

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The main advantage of using SC-FDMA over the OFDMA is its low peak to average power ratio (PAPR). On the other hand, OFDMA was also selected for down link communications in the release 8 LTE [2]. In [3] LTE-Advanced requirements were agreed but radio interface schemes are still debatable.

OFDMA thwarts inter symbol interference (ISI) by inserting a guard interval using a cyclic prefix (CP) and moderates the frequency selectivity of the multi path channel with a simple equalizer. This leads to cheap hardware implementation and makes simpler the design of the receiver [4], [5], [6]. OFDMA is widely adopted in various communication standards like worldwide interoperability for microwave access (WiMAX), mobile broadband wireless access (MBWA), evolved UMTS terrestrial radio access (E-UTRA) and ultra mobile broadband (UMB). OFDMA is also a strong candidate for the wireless regional area networks (WRAN) and LTE-Advanced. However OFDMA has some drawbacks, among others, the PAPR is still one of the major drawbacks in the transmitted OFDMA signals [7]. Therefore, for zero distortion of the OFDMA signal, the HPA must not only operate in its linear region but also with sufficient back-off. Thus, high power amplifiers (HPA) with a large dynamic range are required for OFDMA systems. These amplifiers are very expensive and are major cost component of the OFDMA system.

Thus, if we reduce the PAPR it not only means that we are reducing the cost of OFDMA system and reducing the complexity of analog-to-digital (A/D) and digital-to-analog (D/A) converters, but also increasing the transmit power, thus, for same range improving received signal-to-noise (SNR), or for the same SNR improving range. A large number of PAPR reduction techniques have been proposed in the literature. Among them, schemes like constellation shaping [8], clipping and filtering [9], partial transmit sequence (PTS) [10], selective mapping (SLM) [11], precoding based selecting mapping (PSLM) [12],[13] and precoding based techniques [14],[15] are popular.

In [16] H. G. Myung et.al presented PAPR analysis of the SC-FDMA signals with pulse shaping. They showed through computer simulations that, that pulse shaping increases the PAPR of SC signals. They compared their results with the OFDMA conventional and found that SC-FDMA has low PAPR because of its single carrier structure than OFDMA conventional. They also compare the PAPR of interleaved FDMA (IFDMA) and localized FDMA (LFDMA) with and without pulse shaping. At the end, they conclude that IFDMA has lower PAPR then LFDMA.

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This paper presents a novel precoding based hybrid MC/SC radio access system with improved PAPR for the Layered-OFDMA of LTE-Advanced. We implement the Generalized Chirp like (GCL) precoding matrix to lower the correlation relationship of the localized OFDMA (LOFDMA) input sequence. The Inverse-Fast-Fourier transform (IFFT) function can be viewed as: multiplying sinusoidal functions to the input sequence, summing and sampling the results. So, if correlation property of the input sequence is high, then the sinusoidal functions will be arranged in in-phase form. After the summation of these in-phase functions, the output might have large amplitude. Therefore, if we lower the autocorrelation of input sequence of IFFT by implementing GCL precoding matrix, the PAPR can be significantly reduced.

This paper is organized as follows: Section II describes the basics of the MC (LOFDMA) systems, SC (LFDMA) systems and PAPR, In Section III we present our proposed hybrid (MC/SC) radio access system with improved PAPR, Section IV presents the computer simulation results and section V concludes the paper.

II. MC SYSTEM AND SC SYSTEM

A. *Multi Carrier System (LOFDMA)*

Fig. 1 shows the block diagram of an OFDMA uplink system. The OFDMA system splits the high speed data stream into a number of parallel low data rate streams and these low rates data streams are transmitted simultaneously over a number of orthogonal subcarriers.

There are two different approaches to do subcarrier mapping in OFDMA systems, localized subcarrier mapping of OFDMA also known as LOFDMA where the subcarrier mapping is done in adjacent and distributed subcarrier mapping of OFDMA. Distributed subcarrier mapping can be further divided in to two modes, interleaved OFDMA also known as IOFDMA, where the subcarrier are mapped equidistant to each other's and random interleaved or distributed OFDMA called DOFDMA, where subcarriers are distributed randomly.

In LOFDMA system, the baseband modulated symbols are passed through serial-to-parallel (S/P) converter which generates complex vector of size M. We can write the complex vector of size M as $X = [X_0, X_1, \dots X_{M-1}]^T$.

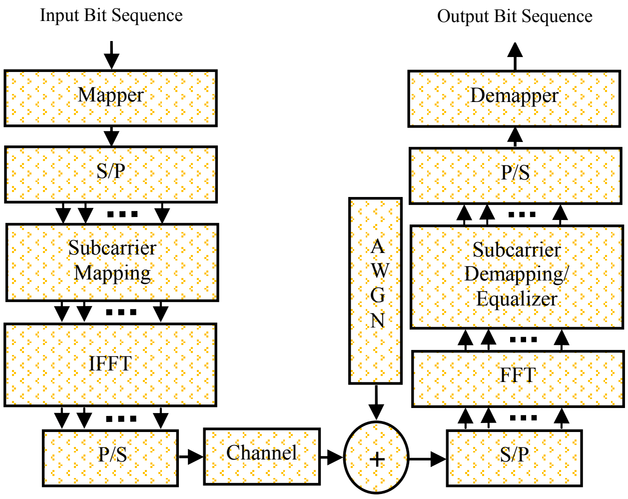

Fig. 1. General Block diagram of MC (OFDMA) system

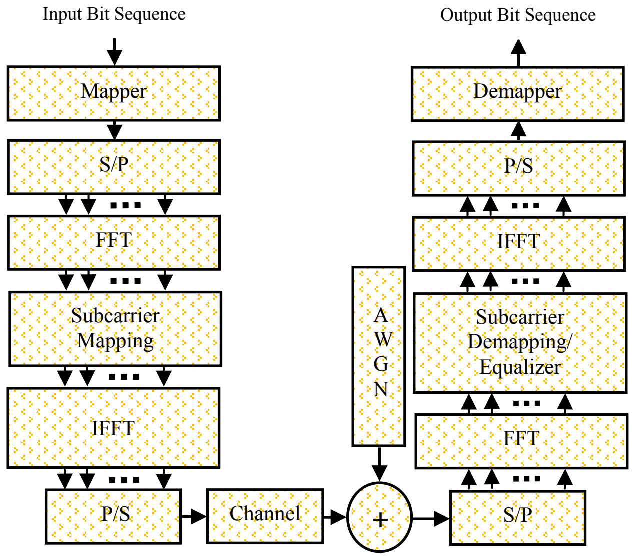

Fig. 2. General Block diagram of Single Carrier System

After N subcarrier mapping to the X in the localized mode, we get $\hat{X}_m = [\hat{X}_0, \hat{X}_1, \dots \hat{X}_{N-1}]^T$. The localized subcarrier mapping can be done mathematically as:-

$$\hat{X}_m = \begin{cases} X_m & 0 \le m \le M-1 \\ 0 & M \le m \le N-1 \end{cases} \qquad (1)$$

The complex baseband LOFDMA uplink signal with N system subcarriers and M user subcarriers can be written as:-

$$x_n^{(k)} = \frac{1}{\sqrt{N}} \sum_{m=0}^{M-1} (\hat{X}_m{}^{(k)} . e^{j2\pi \frac{(kM+m)}{N} n}), n = 0, 1 \dots N-1 \quad (2)$$

where $\hat{X}_l$ we get after subcarrier mapping, $j = \sqrt{-1}$, n = 0,1,2...N-1, $\hat{X}_l{}^{(k)}$ is modulated signal on subcarrier m for k^{th} user and users index $k = 1, 2, \dots, Q-1$.

B. *Single Carrier System (LFDMA)*

Fig. 2 shows the block diagram of LFDMA system. In LFDMA system, baseband modulated data is passed through S/P converter which generates a complex vector of size M that can be written as $X = [X_0, X_1, \dots X_{M-1}]^T$. Then DFT precoding is applied to this complex vector. The DFT precoded signal can be written as:-

$$x_n = \frac{1}{\sqrt{M}} \sum_{l=0}^{M-1} X_l \, . e^{-j2\pi \frac{n}{M} l} \, , n = 0, 1, 2, \dots, M-1 \qquad (3)$$

This DFT precoded signal is then mapped on to the N subcarriers and we get $\hat{Y}_k = \left[\hat{Y}_0, \hat{Y}_1, \dots \hat{Y}_{N-1}\right]^T$. The IDFT precoded signal with N subcarriers can be written as:-

$$\hat{x}_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \hat{Y}_k \, . e^{j2\pi \frac{n}{N} k} \, , n=0,1,2,\dots,N-1 \qquad (4)$$

$\hat{Y}_k$, we get after subcarrier mapping. Using equations (3) and (4) we get complex baseband SC signal with N subcarrier and can be written as:-

$$\hat{x}_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left(\frac{1}{\sqrt{M}} \sum_{l=0}^{M-1} X_l \, . e^{-j2\pi \frac{n}{M} l} \right) . e^{j2\pi \frac{n}{N} k} \qquad (5)$$

III. Proposed Model

A. Generalized Chirp Like (GCL) Sequences

Zadoff-chu sequences are class of poly phase sequence of length M and can be defined as:-

$$a_k = \begin{cases} W_M^{k^2/2+qk} & For\ M\ even \\ W_M^{k(k+1)/2+qk} & For\ M\ odd \end{cases} \tag{6}$$

where $k = 0,1,\ldots M-1$, q is any integer and W_M^r represents a primitive M^{th} root of unity. It is a complex number given by $W_M^r = e^{\frac{-j2\pi r}{M}}$, where r is any integer relatively prime to M and $j = \sqrt{-1}$. GCL sequences are derived from zadoff-chu sequences. Let $\{a_k\}$, $k = 0,1,2\ldots M-1$, be a zadoff-chu sequence of length $M = sm^2$, where m and s are any positive integers. Let $\{b_i\}$, $i = 0,1\ 2\ldots\ m-1$, be any sequence of m complex numbers having the absolute values equal to 1. The GCL sequence $\{s_k\}$ according to [17] can be defined as:-

$$s_k = a_k b_{(k) mod\ m}\ , \quad k = 0,1,2,\ldots,M-1 \tag{7}$$

where $(\ k\ )\ mod\ m$ means that index k is reduced modulo m. The GCL precoding matrix P of size $L \times L$ can be created by using the column-wise sequence reshaping as given in equation (8).

$$k = m + lL \tag{8}$$

Using equation (7) the kernel of GCL precoding matrix P with column-wise reshaping can be written as:-

$$P = \begin{bmatrix} s_{00} & s_{10} & \cdots & s_{(L-1)0} \\ s_{01} & s_{11} & \cdots & s_{(L-1)1} \\ \vdots & \vdots & \ddots & \vdots \\ s_{0(L-1)} & s_{1(L-1)} & \cdots & s_{(L-1)(L-1)} \end{bmatrix} \tag{9}$$

In other words, the L^2 point long GCL sequence fills the precoding matrix column-wise. The GCL sequences are perfect sequences. Both sequences a_k and s_k of length L have ideal periodic autocorrelation function $R(p)$ and is given by:-

$$R(P) = \sum_{k=0}^{L-1} s_k s^*_{(k+p) mod\ L} \tag{10}$$
$$= \begin{cases} L, & P = 0(mod\ L) \\ O, & P \neq 0(mod\ L) \end{cases}$$

where (*) represent the complex conjugate and the index $(k+p)$ is computed modulo L. This ideal property makes the GCL sequences, the proper contenders for the precoding based PAPR reduction in OFDMA systems.

B. Hybrid MC/SC Radio Access System

Fig. 3 shows the hybrid MC/SC (LOFDMA/LFDMA) radio access system designed for uplink communications of LTE-Advanced with improved PAPR. In MC part of the proposed model, the GCL precoder is implemented before the subcarrier mapping and IFFT. This GCL precoder precodes the constellation symbols to reduce the PAPR. On the other hand, the DFT precoding is done before subcarrier mapping and IFFT to make system SC-FDMA.

In the GCL precoding based LOFDMA uplink system, baseband modulated data is passed through S/P convertor which generates a complex vector of size M that can be written as $X = [X_0, X_1, \ldots X_{M-1}]^T$. Then GCL precoding is applied to this complex vector which transforms this complex vector into new vector of length L that can be written as $Y = PX = [Y_0, Y_1, \ldots Y_{L-1}]^T$, where P is a GCL precoding matrix. The value of P can be used from equation (9). With the use of column-wise sequence reshaping in equation (8), precoding X gives rise to Y as follows:-

$$Y = PX \tag{11}$$

$$Y_{pm} = \sum_{l=0}^{N-1} p_{m,l} X_m \qquad m = 0,1,\ldots L-1 \tag{12}$$

$p_{m,l}$ means m^{th} row and l^{th} column of precoder matrix. After that, The N subcarrier mapping is done in the localized mode. After subcarrier mapping, we get $\hat{Y}_m = [\hat{Y}_0, \hat{Y}_1, \ldots \hat{Y}_{N-1}]^T$. The complex baseband GCL precoded LOFDMA uplink signal for k^{th}user can be written as:-

$$x_n^{(k)} = \frac{1}{\sqrt{N}} \sum_{l=0}^{L-1} (\hat{Y}_m{}^{(k)} . e^{j2\pi \frac{(kL+l)}{N} n}),\ n = 0,1\ldots N-1 \tag{13}$$

where, users index $k = 0,1\ldots Q-1$ and $\hat{Y}_m{}^{(k)}$ is modulated signal on subcarrier m for k^{th} user. The complex passband transmit signal, $x(t)$ of the GCL precoded OFDMA uplink system for k^{th} user after the root-raised-cosine (RRC) pulse shaping and digital-to-analog (D/A) of $x_n^{(k)}$ can be written as:-

$$x(t) = e^{j\omega_c t} \sum_{n=0}^{L-1} x_n^{(k)} . r(t - n\breve{T}) \tag{14}$$

where ω_c is carrier frequency, $r(t)$ is baseband pulse, $\breve{T} = \left(\frac{M}{N}\right) . T$ is compressed symbol duration in seconds after the IFFT operation. According to [18] RRC pulse shaping filter can be defined as:-

$$r(t) = \frac{sin\left(\frac{\pi t}{\breve{T}}(1-\alpha)\right) + 4\alpha \frac{t}{\breve{T}} . cos\left(\frac{\pi t}{\breve{T}}(1+\alpha)\right)}{\frac{\pi t}{\breve{T}} . \left(1 - \frac{16\alpha^2 t^2}{\breve{T}^2}\right)} \tag{15}$$

$0 \leq \propto \leq 1$, where $\propto$ is rolloff factor. The PAPR of the signals in equation (14) with pulse shaping can be written as follows:-

$$PAPR(dB) = 10 log_{10} \frac{\max(|x(t)|^2)}{E\{\max(|x(t)|^2)\}} \tag{16}$$

$E\{.\}$, denote expected value. If the amplitude of all subcarriers are normalized, $E\{\max(|x(t)|^2)\} = N$, and the equation (16) reduced to:-

$$PAPR(dB) = 10 log_{10} \frac{\max(|x(t)|^2)}{N} \tag{17}$$

The instantaneous power of $x(t)$ can be defined as follows:-

$$p(t) = |x(t)|^2 = x(t) * x^*(t) \tag{18}$$
$$= \frac{1}{N} \sum_m^{N-1} \sum_k^{N-1} x_{pm} x^*_{pk} e^{\{j2\pi(p-k)t\}}$$
$$= \frac{1}{N} [N + 2Re\{\sum_m^{N-2} \sum_{k=m+1}^{N-1} x_{pm} x^*_{pk} e^{\{j2\pi(p-k)t\}}\}]$$
$$= 1 + \frac{2}{N} Re\{\sum_{i=1}^{N-1} e^{(j2\pi t)} \sum_{m=0}^{N-1-i} x_{pm} x^*_{p(m+i)}\} \tag{19}$$

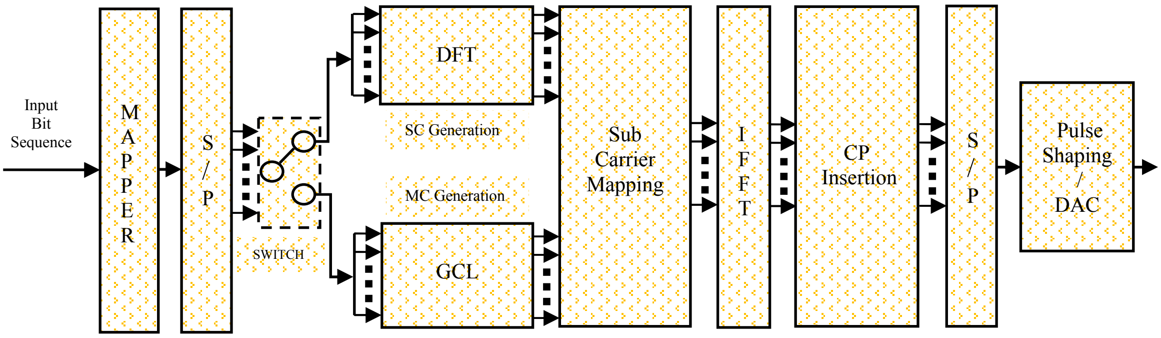

Fig. 3. Block diagram of hybrid MC/SC Radio Access System

For any complex c, $Re(c) \leq |c|$, $|\sum c_n| \leq |\sum c_n|$. That's why,

$$p(t) \leq 1 + \frac{2}{N}\sum_{i=1}^{N-1}|\rho(i)| \qquad (20)$$

where, $\rho(i) = \sum_{m=0}^{N-1-i} x_{pm} x^*_{p(m+i)}$, $i = 0,1,2, \ldots, N-1$ is the aperiodic autocorrelation function. It is concluded from equation (21) that if the aperiodic autocorrelation mold of the IFFT input sequence x_P is small (i.e. small $\rho(i)$ for $i \geq 1$) then, the peak-power factor of the signal obtained by passing through the multi-carrier combination also can be small.

The peak value of the autocorrelation is the average power of input sequence. Then if the number of subcarriers is not changed, this peak value depends on the input sequence. This means that if the sidelobe of an autocorrelation function of an input sequence has larger value than other input sequences, the former has high correlation property. The IFFT operation can be viewed as multiplying sinusoidal functions to the input sequence, summing and sampling the results. Thus the high correlation property of IFFT input causes the sinusoidal functions to be arranged with in-phase form. After summing these in-phase functions, the output might have large amplitude.

B.a. The effect of GCL Kernel

To verify the contribution of GCL matrix, we consider OFDMA system for QPSK modulation. Fig. 4 shows that the aperiodic autocorrelation function of randomly generated QPSK sequence with the length 64 is given, which are normalized by the length. Thus the maximum value is 1 which is the average power of the sequence.

It is obvious from the Fig. 4 that two autocorrelation functions have different sidelobe value. If the sidelobes of autocorrelation have higher values, then the input sequence is highly correlated and its PAPR is high. The high correlation in the input to IFFT causes the subcarriers to align in-phase. After summing these in-phase functions, the output might have high amplitude resulting in higher PAPR. The sidelobe value of the proposed GCL precoded sequence is much smaller than the without precoded sequence. Therefore, it is concluded that if we apply GCL precoder to the IFFT input sequence, it lower the correlation relationship of the LOFDMA input sequence, thus PAPR can be reduced.

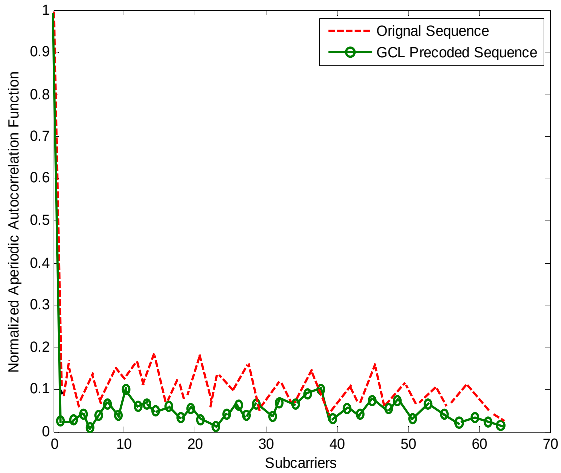

Fig.4. The normalized autocorrelation function

IV. SIMULATION RESULTS

Extensive simulations in MATLAB(R) have been performed to analyse the PAPR of the proposed hybrid MC/SC radio access system for uplink communication of LTE-Advanced. We evaluate the PAPR statistically by using complementary cumulative distribution function (CCDF). The CCDF of PAPR, for MC/SC signal, is used to express the probability of exceeding a given threshold $PAPR_0$ ($i.e.\ CCDF = Pr\,(PAPR > PAPR_0)$) simulation parameters used are; 8-times oversampling, 20MHz transmission bandwidth, user subcarriers $M = 16$, and system subcarriers $N = 512$ using QPSK, 16-QAM, and 64-QAM modulation techniques. All the simulations have been performed are based on 10^5 random data blocks. Simulation parameters that we have used are given in the following Table. I as:-

TABLE I
SYSTEM PARAMETERS

Channel Bandwidth	20MHz
Over-sampling Factor	8
User Subcarriers	16
System Subcarriers	512
Precoding	WHT and GCL
Modulation	QPSK, 16-QAM, 64-QAM
Pulse Shaping	Root Raised Cosine (RRC)
RRC roll-off Factor	$\alpha = 0.22$
Subcarrier Mapping	Localized
CCDF Clip Rate	10^{-3}

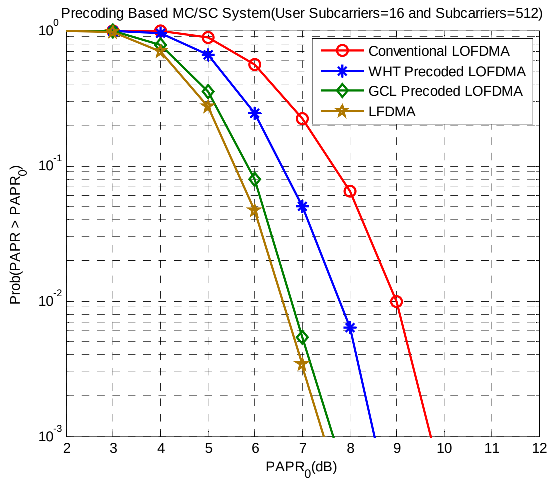

Fig. 5. CCDF Comparisons of PAPR of GCL Precoded LOFDMA Uplink System, LFDMA, WHT Precoded LOFDMA Uplink System and Conventional LOFDMA Uplink System using QPSK.

Fig. 5 shows the CCDF comparison of the PAPR of the GCL precoding based LOFDMA system with the LFDMA uplink system, the WHT precoding based LOFDMA uplink systems and the conventional LOFDMA uplink systems respectively, for the user subcarriers (M=16) and the system subcarriers (N=512). At clip rate of 10^{-3}, the PAPR is reduced to 9.8 dB, 8.5 dB, 7.45 dB and 7.55 dB respectively for conventional LOFDMA uplink system, WHT precoded LOFDMA uplink system, LFDMA uplink system and GCL precoded LOFDMA uplink system using the QPSK modulation.

Fig. 6 shows the CCDF comparison of the PAPR of the GCL precoding based LOFDMA system with the LFDMA uplink system, the WHT precoding based LOFDMA uplink systems and the conventional LOFDMA uplink systems respectively, for the user subcarriers (M=16) and the system subcarriers (N=512). At clip rate of 10^{-3}, the PAPR is reduced to 9.8 dB, 8.8 dB, 8.35 dB and 8.4 dB respectively for conventional LOFDMA uplink system, WHT precoded LOFDMA uplink system, LFDMA uplink system and GCL precoded LOFDMA uplink system using the 16-QAM modulation.

Fig. 7 shows the CCDF comparison of the PAPR of the GCL precoding based LOFDMA system with the LFDMA uplink system, the WHT precoding based LOFDMA uplink systems and the conventional LOFDMA uplink systems respectively, for the user subcarriers (M=16) and the system subcarriers (N=512). At clip rate of 10^{-3}, the PAPR is reduced to 10 dB, 8.8 dB, 8.4 dB and 8.45 dB respectively for conventional LOFDMA uplink system, WHT precoded LOFDMA uplink system, LFDMA uplink system and GCL precoded LOFDMA uplink system using the 64-QAM modulation.

Fig. 8 illustrates the location of sub-bands considered in the localized subcarrier mapping. Fig. 9 shows the SER performance of the GCL precoded LOFDMA uplink system and the conventional LOFDMA uplink system over the ITU pedestrian A outdoor channel with additive-white-gaussian-noise (AWGN) using MMSE equalization. Fig. 9 shows that the GCL precoded LOFDMA uplink system has better SER performance improvement over the conventional LOFDMA uplink systems for both sub-band 0 and sub-band 15 using QPSK modulation. SER performance varies, depending on which part of the spectrum it occupies.

According to Fig. 8, in localized subband 0, the channel gain is higher than the average and therefore, the SER performance is much better. On the other hand, in localized subband 15, the channel gain is lower; hence the performance is poor as a result. Therefore, localized subcarrier mapping needs frequency diversity and it should either use subband hopping or channel dependent scheduling to overcome this drawback.

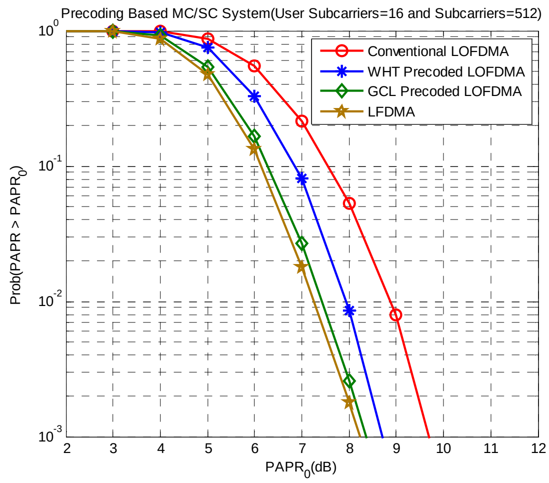

Fig. 6. CCDF Comparisons of PAPR of GCL Precoded LOFDMA Uplink System, LFDMA, WHT Precoded LOFDMA Uplink System and Conventional LOFDMA Uplink System using 16-QAM.

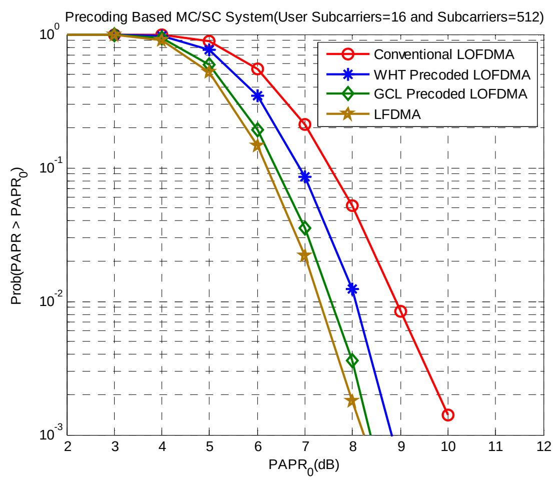

Fig. 7. CCDF Comparisons of PAPR of GCL Precoded LOFDMA Uplink System, LFDMA, WHT Precoded LOFDMA Uplink System and Conventional LOFDMA Uplink System using 64-QAM.

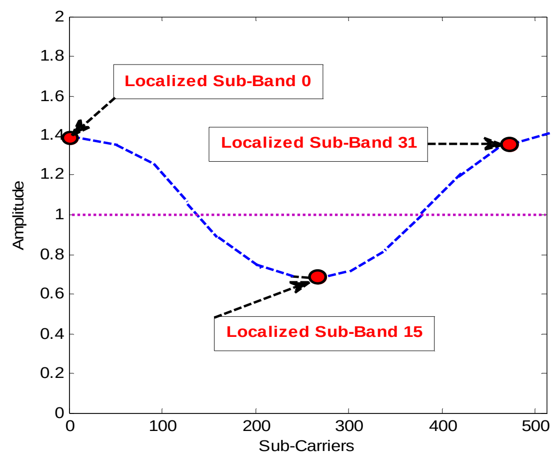

Fig. 8. Localized Sub-Carrier Illustration (ITU Pedestrian A channel)

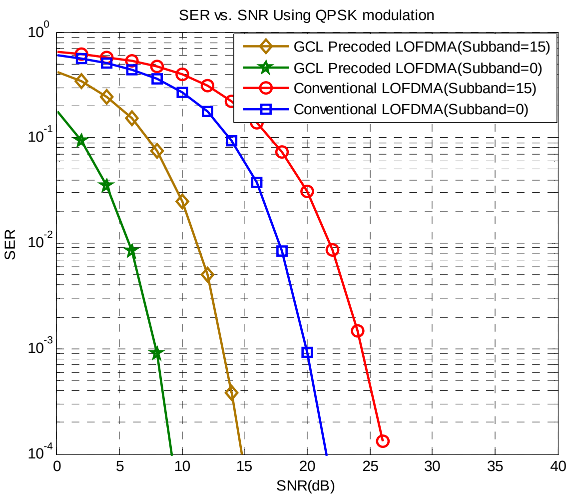

Fig. 9. SER vs. SNR Comparison of the GCL precoded LOFDMA uplink system with the Conventional LOFDMA uplink system for ITU Pedestrian A channel with MMSE equalization using QPSK modulation.

At the end it is concluded that, the PAPR of the GCL precoded LOFDMA uplink signals approaches almost equal the PAPR of the LFDMA uplink signals. Hence, it is concluded from the above discussions and simulation results that the GCL precoded LOFDMA uplink system may be one of the best choices for MC part of the Layered OFDMA of LTE-Advanced standard.

V. Conclusion

In this paper, a novel hybrid MC/SC radio access system is presented for high PAPR reduction in the Layered OFDMA of LTE-Advanced. Both PAPR and SER of the proposed system are analyzed through computer simulations. It is concluded from the computer simulation results that, the PAPR of GCL precoded LOFDMA (MC system) signals have almost equal to the LFDMA (SC system) signals. Simulation results also show that the SER performance of the proposed system is better than the conventional LOFDMA uplink systems. GCL precoded MC system is efficient, signal independent, distortionless and do not require any complex optimizations. Hence, it is concluded that the GCL precoded LOFDMA uplink system may be the one of best choice for Layered OFDMA MC part.

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