PAPR reduction based on improved Nyquist pulse shaping technology in OFDM-RoF systems*

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(Received 1 September 2012)

High peak-to-average power ratio (PAPR) is the main disadvantage in orthogonal frequency-division multiplexing (OFDM) communication systems, which also exists in OFDM-radio over fiber (RoF) systems. In this paper, we firstly analyze the impact of high PAPR on a 40 GHz OFDM-RoF system, and then describe the theory of Nyquist pulse shaping technology for reducing PAPR. To suppress PAPR further, an improved Nyquist pulse shaping technology is proposed, in which the distribution of original-data amplitude is changed by properly selecting the time-limited waveforms of the different subcarriers. We firstly apply the improved Nyquist pulse shaping technology to an OFDM-RoF system. The simulation results show that PAPR is effectively reduced by more than 2 dB with the bit error rate (BER) declining by about 0.125%.

Document code: A **Article ID:** 1673-1905(2013)01-0057-4

DOI 10.1007/s11801-013-2324-z

With the world interoperability for microwave access (WiMAX) and long term evolution (LTE) trial network construction, wireless communications have entered the era of high-speed data communication, but the spectrum resources and transmission distance of wireless communication limit the development. However, radio over fiber (RoF) technology which combines the wireless and the optical networks was presented. In order to solve the problem of nervous spectrum resources, some scholars put forward the orthogonal frequency-division multiplexing (OFDM) RoF system[1-4]. The high peak-to-average power ratio (PAPR) is the main disadvantage in OFDM communication system, which also exists in OFDM-RoF systems.

To achieve the above objective, several proposals have been suggested and studied, such as clipping with filtering, companding, coding scheme, selective mapping (SLM) and partial transmit sequence (PTS). Clipping is a simple and effective method to reduce PAPR[5,6] which can be reduced by about 4 dB. However, clipping is a nonlinear process which brings unrecoverable nonlinear distortion. By companding method[7,8], PAPR can be reduced by about 5 dB at most, but de-spreading can increase the channel noise and the BER of system. SLM and PTS[8] can bring about 2 dB PAPR reduction, but the computational complexity of SLM and PTS is unacceptable because of sideband information. Improved Nyquist pulse shaping was proposed as a potential method for reducing the PAPR without affecting the bandwidth efficiency in OFDM system[9,10]. In the previous research works, improved Nyquist pulse shaping technology was used in the traditional OFDM communication systems[10]. In this paper, we firstly demonstrate that this technology can successfully reduce PAPR in OFDM-RoF system, meanwhile, the performance of BER of system is improved.

Fig.1 shows the schematic diagram of OFDM-RoF system model. As shown in Fig.1, the central frequency of the continuous wave (CW) generated by a laser diode (LD) is 193.1 THz. To generate radio frequency (RF) optical carrier, the lightwave is modulated by 20 GHz RF signal in optical-carrier-suppression double-sideband (OCS-DSB) mode in a $LiNbO_3$ Mach-Zehnder modulator (LN-MZM). The two sidebands of the RF optical carrier are separated by an interleaver (IL). The OFDM signal based on 16 quadrature amplitude modulation (16QAM) 2.5 GHz intermediate frequency (IF) in-phase/quadrature (I/Q) modulation scheme is generated by an off-line program in MATLAB. Then 2.5 GHz OFDM signal from the low pass filter (LPF) is modulated on one of the two separeted sidebands. The sideband carried OFDM IF signal is coupled with another sideband to generate OFDM-

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* This work has been supported by the Natural Science Foundation of Hebei Province (No.F2008000116).

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RoF signal. After transmission over 20 km single-mode fiber, the OFDM-RoF signal is detected by a photodetector (PD) in base station. The photodetector outputs 40 GHz OFDM RF signal which is mixed with 40 GHz local signal. Then the mixed signal passes a band-pass filter (BPF). The BPF outputs 2.5 GHz OFDM signal which is demodulated in MATLAB to recover the baseband OFDM signal[11,12].

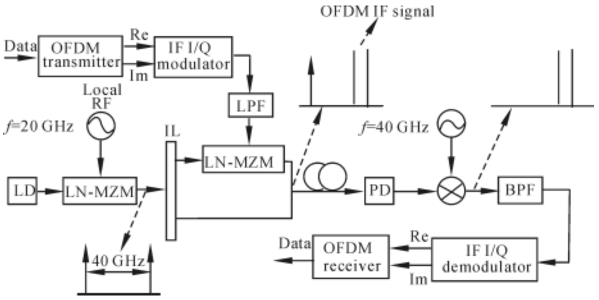


Fig.1 Schematic diagram of OFDM-RoF system model

In OFDM modulation, the incoming data is firstly modulated in baseband using a bandwidth efficient modulation (QAM modulation). The modulated baseband stream is then split into N parallel streams. Each stream is shaped by a pulse $p_k(t)$ and transmitted over a given subcarrier. The OFDM signal with pulse shaping can be expressed by[13]

$$x(t)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}p_k(t)s(k)\exp(\mathrm{j}2\pi kt/T),\qquad 0\le t\le T\ , \quad (1)$$

where $s(k)$ is the modulated data symbol of the k-th subcarrier, T is the duration of the OFDM block, and $p_k(t)$ is a pulse shape with duration of T and a bandwidth less or equal to the bandwidth of the OFDM signal $x(t)$, which is used at the k-th subcarrier.

In order to guarantee the orthogonality between subcarriers, the shaping pulse must meet four conditions[13]: (1) Equienergy: $\int_0^T|p_k(t)|^2\,\mathrm{d}t=T$; (2) Time limit: $p_k(t)$=0, $t>T$ or $t<0$; (3) Band limit: $P_k(f)\approx 0$, $|f-B|>B(1+\beta)$, where $P_k(f)$ is frequency of $p_k(f)$, and $B=1/2T_s$ is the coefficient related with the subcarrier number and sending filter; (4) Orthogonal: $\int_0^T p_m(t)p_n^*(t)\exp[\mathrm{j}2\pi(f_m-f_n)t]\,\mathrm{d}t=\begin{cases}T, m=n\\0, m\ne n\end{cases}$.

The cross-correlation between sampling values of OFDM signal can be expressed by

$$R_{1,2}(t_1,t_2)=\sum_{k=0}^{N-1}\sum_{l=0}^{N-1}E[s(k)s^*(l)]p_k(t_1)p_l^*(t_2)\times \exp[\mathrm{j}2\pi(kt_1-lt_2)/T]\ . \quad (2)$$

By analyzing Eqs.(1) and (2), we know that pulse shaping makes subcarriers have certain correlation. As a result, the probability of the subcarrier peaks appearing at the same time is reduced. Using the same shaping pulse to shape each subcarrier can not affect the mutual-correlation of each subcarrier, but it only increases or keeps signal peak, and makes PAPR increase or remain the same. On the contrary, using different shaping pulses to shape each subcarrier can reduce the signal peak, and makes the PAPR reduced. Therefore, we should select different shaping pulses to achieve the purpose of reducing PAPR.

As we know, Nyquist pulse is the most commonly used shaping pulse, so we construct an effective Nyquist pulse set. First, the pulse set must satisfy the four conditions mentioned above. Second, the shaping pulse set is formed by cycle shifting of a master pulse. It makes the peaks of the subcarrier waveforms not occur at the same time instantly. After analyzing the characteristics of Nyquist pulse, we can define the Nyquist pulse set as

$$p_k(t)\exp(\mathrm{j}2\pi kt/T)=p_l(t-\tau_{k-l})\exp[\mathrm{j}2\pi l(t-\tau_{k-l})/T]\ ,(3)$$

where τ_{k-l}=[(k-l)mod$N$]T_s, and T_s is the sampling period. The PAPR can be expressed by

$$PAPR=\frac{1}{N}\max\left[\sum_{k=0}^{N-1}|p_k(t)|\right]^2\le\frac{1}{N}\left[\sum_{k=0}^{N-1}\max|p_k(t)|\right]^2=N,$$
$$0\le t\le T\ . \quad (4)$$

Eq.(4) shows that using Nquist pulse to shape subcarriers of OFDM signal can reduce PAPR. Commonly used Nyquist pulse is the raised cosine pulse, and its frequency spectrum can be expressed by

$$P_1(f)=\begin{cases}1, & |f|\le B(1-\alpha)\\ \frac{1}{2}\left\{1+\cos\left[\frac{\pi}{2\alpha B}(|f|-B(1-\alpha))\right]\right\}, & B(1-\alpha)<|f|<B(1+\alpha)\\ 0, & |f|\ge B(1+\alpha)\end{cases}\ , \quad (5)$$

where α is the roll-off factor, B is the bandwidth corresponding to symbol repetition rate of T=1/2B, and its corresponding time function can be expressed by

$$p_1(t)=\sin c(t/T)\frac{\cos(\pi\alpha t/T)}{1-(2\alpha t/T)^2}\quad . \quad (6)$$

The amplitude of the main sidelobes for the raised cosine pulse is not small enough[13]. The smaller the amplitude of the main sidelobes, the better the performance of interference (ISI) resistance.

To improve the performance of the Nyquist pulse shaping, a new pulse has been proposed in Ref.[13]. In this paper, we apply this new pulse to suppress the PAPR of the signal in OFDM-RoF system. Its frequency spectrum and corresponding time function can be expressed by

$$P_2(f)=\begin{cases}1, & |f|\le B(1-\alpha)\\ \exp\{\lambda[B(1-\alpha)-|f|]\}, & B(1-\alpha)<|f|\le B\\ 1-\exp\{\lambda[|f|-B(1+\alpha)]\}, & B<|f|<B(1+\alpha)\\ 0, & |f|\ge B(1+\alpha)\end{cases}\quad , \tag{7}$$

$$p_2(t)=\frac{1}{T}\operatorname{sinc}(t/T)\frac{4\lambda\pi t\sin(\pi\alpha t/T)+2\lambda^2\cos(\pi\alpha t/T)-\lambda^2}{(2\pi t)^2+\lambda^2}. \tag{8}$$

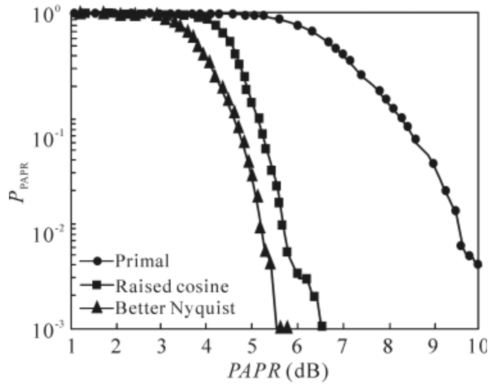
It can be proved in Ref.[14] that $p_1(t)$ asymptotically decays as t^{-3}, while $p_2(t)$ as t^{-2}. The amplitude of the main sidelobes for the pulse with t^{-2} decay is smaller than that for the pulse with t^{-3} decay. For all different values of roll-off factor and sampling time errors, the t^{-2} pulse beats the t^{-3} pulse[14].

According to the theory analysis above, we perform the simulation by MATLAB and optical communication simulation software.

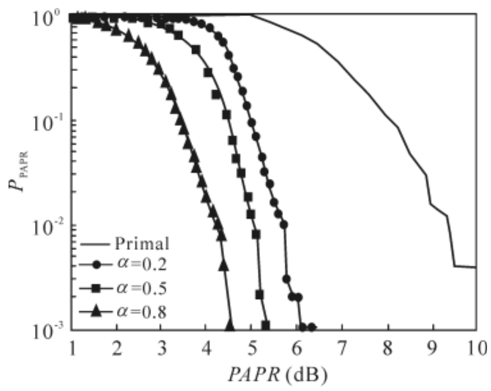
Fig.2(a) is the performance comparison of primal OFDM signal, OFDM signal with raised cosine pulse shaping and OFDM signal with improved Nyquist pulse shaping. A better measure of the PAPR of communication signals is to use the complementary cumulative distribution function (CCDF)[15] defined as:

$$P_{\mathrm{PAPR}}=P(PAPR\ge PAPR_{\mathrm{t}})\quad , \tag{9}$$

where $PAPR_{\mathrm{t}}$ is the PAPR threshold. It can be seen in Fig.2(a) that the improved Nyquist pulse shaping technology is better than raised cosine pulse for reducing PAPR. Fig.2(b) is the PAPR performance comparison of OFDM signals with different roll-off factors. It can be seen that the bigger the roll-off factor, the more notable the efficiency of reducing PAPR.



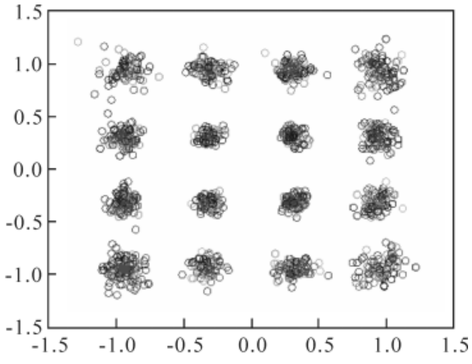
(a) OFDM signals with different shaping pulses



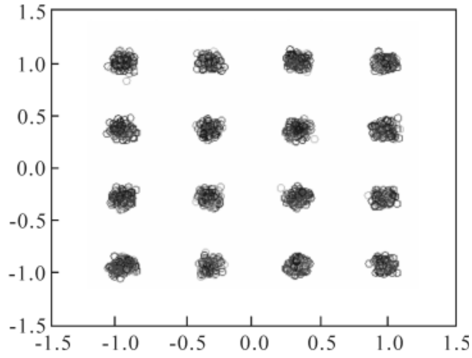
(b) OFDM signals with different roll-off factors

Fig.2 PAPR performance comparison

Fig.3 shows the constellation of receipt signal in PAPR suppression system is more concentrated than that without PAPR suppression. It shows that the system with PAPR suppression improves the BER performance.



(a) Without pulse shaping



(b) With improved pulse shaping

Fig.3 Constellation of receipt signal

Fig.4 shows that after being processed by improved Nyquist pulse shaping, the PAPR of the sender OFDM signal declines by more than 2 dB. Fig.5 is the BER characteristic curve of the system under different fiber lengths. It shows that the BER of OFDM-RoF system with PAPR suppression

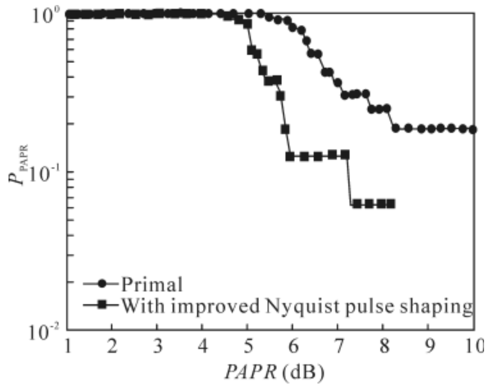


Fig.4 PAPR performance of the sender OFDM signal in OFDM-RoF system

has declined by about 0.125% under the same fiber length.

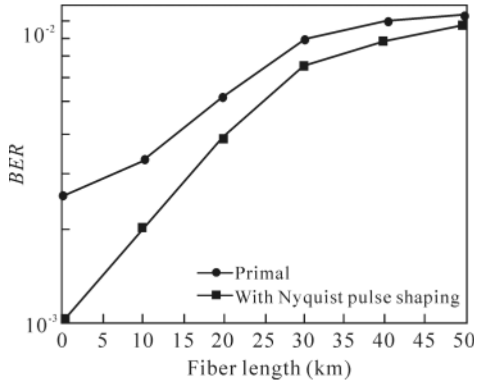


Fig.5 BER performance

Theoretical analysis and simulation show that using improved Nyquist pulse shaping technology can significantly reduce the PAPR of the 16QAM OFDM signal and the BER of OFDM-RoF system. As a result, the performance of the communication system is improved. Pulse shaping technology brings less information redundancy and less computational complexity. It changes the linear transformation of input data without causing signal distortion. Therefore, it has a certain value to OFDM-RoF communication system.

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