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Secure Transmission of 2.5 Gb sec^{-1} 16-QAM OFDM Signal with LDPC Coding in DD-OOFDM Systems

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Abstract: In this study, the authors proposed and experimentally demonstrated an encrypted Direct Detection-optical orthogonal frequency division multiplexing (DD-OOFDM) system based on Low Density Parity Check (LDPC) coding and logistic sequence. The long irregular LDPC code is used to enhance the correction capability of the system. The logistic sequence is adopted for the secure key which is sensitive to the initial condition. It can achieve a secure transmission at physical layer in the DD-OOFDM system for data encrypting. A 2.5 Gb sec^{-1} 16-QAM data with LDPC coding and logistic mapped is transmitted over 40 km SSMF successfully. The experimental results show that the LDPC coding cannot offer good performances of the BER without the correct logistic key.

Key words: DD-OOFDM, LDPC, logistic sequence, 16-QAM

INTRODUCTION

With the continuous growth of high-speed data services, such as Internet Protocol Television (IPTV), High-Definition Television (HDTV) and large interactive network games, the boom in access bandwidth demands will increase dramatically. Recently, the Orthogonal Frequency Division Multiplexing (OFDM) modulation which has been widely used in the wired and wireless wideband communications, is introduced into the optical fiber communication systems due to its excellent resistance to the channel dispersion and the efficient spectrum utilization (Armstrong and Lowery, 2006; Shieh and Athaudage, 2006). Meanwhile, the Direct Detection-optical orthogonal frequency division multiplexing (DD-OOFDM) systems have some advantages such as simple structure, flexible dynamic bandwidth allocation, transparency to heterogeneous services and good compatibility with existing network and a novel architecture with Passive Optical Network (PON) (Fisher, 2009). Therefore, OFDM-PON is proposed as a key optical access network technique in the future.

Considering the huge increase of subscribers and freedom flexibility in the DD-OOFDM systems, security has become a critical issue in the future optical network. However, most of the previous literatures have focused on the encrypted data but have left the control frames and headers without protection. Thanks to the convenient digital processing of OFDM signals, it is easily to encrypt the data without changing any optical module or electrical circuit. Logistic sequence is sensitive to its initial condition. And the transmitted signals can be concealed with logistic carrier or sequence which has a highly unpredictable and random-looking nature (Chen *et al*., 2010). Hence, it can efficiently counteract illegal users in the DD-OOFDM systems. Some works show that Chaos-based OFDM signal has successfully transmitted over 25 km in an OFDM-PON (Zhang *et al*., 2011), while Low Density Parity Check (LDPC) coding has an effective correction capability coupled with the logistic mapping which can enable DD-OOFDM systems to gain a better BER performance.

In this study, the authors have proposed and experimentally demonstrated a logistic-mapping based secure strategy for the LDPC-DD-OOFDM systems. One-dimensional logistic sequence is employed to serve as the secure key. A 2.5 Gb sec^{-1} encrypted 16-QAM LDPC-OFDM signal can be successfully transmitted in the DD-OOFDM systems. The experiment results show high secure key sensitivity and robustness against illegal invader at the receiver, while increasing the transmission distance in SSMF by using Forward Error Correction (FEC) technique.

PRINCIPLE

The block diagram for the principle of OFDM is shown in Fig. 1. The Digital Signal Processing (DSP) which is a part of the baseband OFDM transceiver can be realized off-line. In the OFDM transmitter, the LDPC coding is used as a Forward Error Correction (FEC) technique to improve the correction capability of the system. The long irregular LDPC code acts as the channel error correction coding to resist the impact of the

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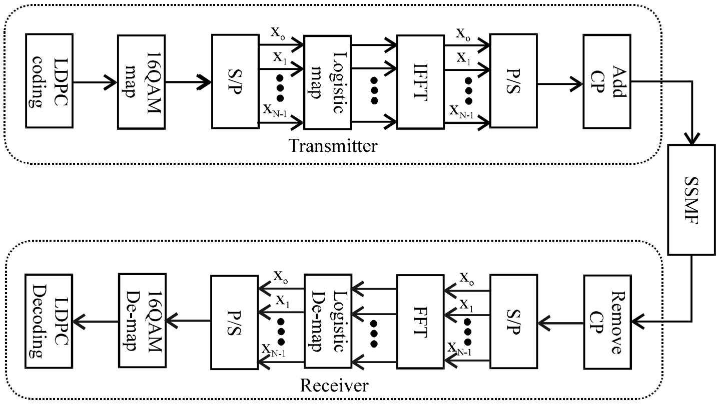

Fig. 1: Block diagram for the principle of OFDM

subcarrier-subcarrier interference. In this study, long irregular LDPC coded OFDM with 0.75 coding rate is used effectively for long-distance single mode fiber transmission. The channel coding can be taken into account according to the quality of transmission system. Then, the bit streams will be mapped into M-QAM or M-PSK symbols. One-dimensional logistic map can be adopted to realize the data encrypt described by the follows. $X_{n+1} = \mu x_n(1-x_n)$, $x\epsilon(0,1)$ and $\mu\epsilon(3.5699,4)$. When μ falls into this domain, the logistic sequence will fall into chaos. A k-order scrambling matrix can be used to encrypt the frequency information of the LDPC-OFDM signals. The time domain sample of the LDPC-OFDM can be represented as:

$$d_k = \text{IFFT } \{D_k \times W\},\ k = 0,\ 1.....,\ K\text{-}1$$

where, W can be defined as:

$$W_n = \{w_n, w_{n+1}, \ldots, w_{n+k-1}\}^T$$

and:

$$\text{cov}\ (w_a,\ w_b) = 0, a \neq b$$

where, K denotes the Nth scrambling matrix with the initial value of W_0 when n = 0. We choose the midpoint of each sub-domain as an initial value which can be defined as:

$$x_{o,n} = \frac{n}{K} - \frac{1}{2K} n = 1,2,\ldots,N$$

where, $X_{o,n}$ is the initial value of k-order sub-domain. In order to obtain W_n, we define a matrix P:

$$p = \begin{pmatrix} \alpha_{11} & \beta_{12} & \cdots & \alpha_{1n} \\ \beta_{21} & \alpha22 & \cdots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{n1} & \alpha_{n2} & \cdots & \beta_{nn} \end{pmatrix} \alpha_{ij} = 0, \beta_{ij} = 1$$

To get W_n, we have $X = W_{n-1}$. P. Due to the chaotic nature of the sequence, it is possible for the same position to get different initial values. After inverse fast Fourier Transforms (IFFT), a certain length of cyclic prefix (CP) can be added to combat inter-symbol interference (ICI). Over 40 km SSMF, at the receiver, the processing of the OFDM signal is reverse to that of the transmitter. As described above, the LDPC-OFDM data is encrypted by the scrambling matrices. It is difficult to extract the data without the knowledge of initial values.

EXPERIMENT AND RESULTS

Figure 2 shows the experiment setup for the 16-QAM OFDM signal with the LDPC coding and security technique in the DD-OOFDM systems. In this experiment, the encrypted LDPC-OFDM signals are generated offline with MATLAB program. The total number of subcarriers is 256, Cyclic Prefix (CP) is 1/8 of the OFDM symbol in each OFDM frame and it is used to mitigate inter-carrier interference (ICI) and inter-symbol interference (ISI). Long irregular LDPC coded OFDM with 0.75 coding rate with 16-QAM is applied for subcarrier modulation scheme. For security strategy, one-dimensional logistic sequence is applied where μ is set as 4. A continuous-wave generated by an external cavity laser (ECL) at 1558.52 nm is fed into a MZM biased at 1.9 V and the OFDM signals generated by a Tektronix Arbitrary Waveform Generator (AWG) are injected into the MZM to generate optical OFDM signals. The sampling rate of the AWG is 2.5 GSa $\sec^{-1}$ The half-wave voltage of the MZM is 3.8 V. The driving amplitude of OFDM signals is 2 V and the output power of the ECL is

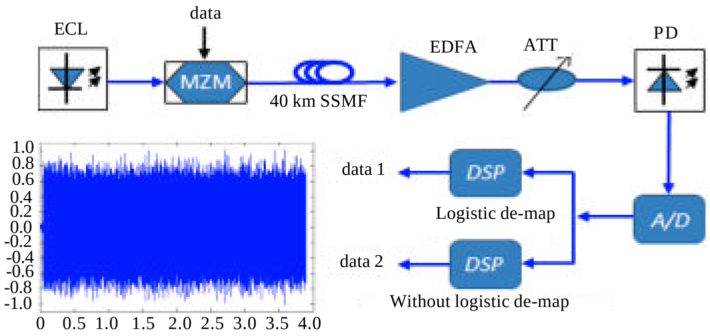

Fig. 2: Experiment setup for the 16-QAM OFDM transmission system

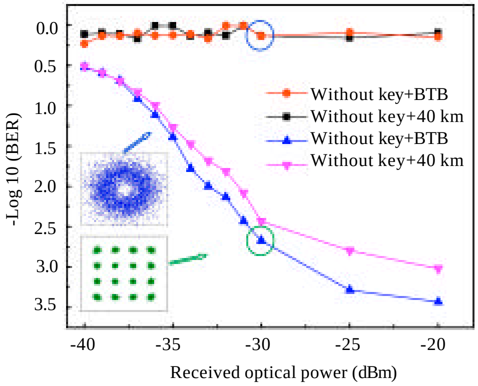

Fig. 3: BER curves for the signals without using LDPC coding

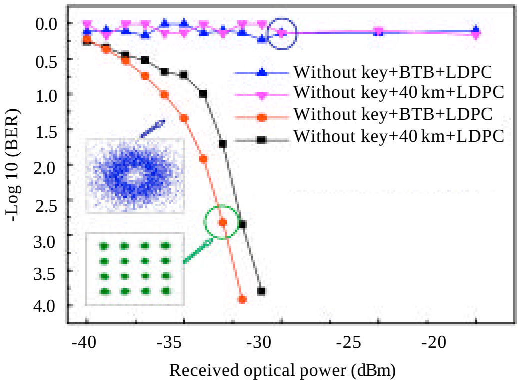

Fig. 4: BER curves for the signals using LDPC coding

12 dBm. The optical launch power into fiber is 3.2 dBm. After the MZM, the optical OFDM signals are then transmitted over a 40 km SSMF. They are amplified by an erbium-doped fiber amplifier (EDFA) to 5.8 dBm. A tunable attention (ATT) is used to change the power of detected optical signal. At the optical receiver, the optical/electrical conversion of the OFDM signals is performed by a commercial optical receiver of PD HP83433 with a 3 dB bandwidth of 10 GHz. The electrical OFDM signals will be captured by a 20 GSa sec^{-1} Tektronix TDS684B real-time oscilloscope and stored for off-line processing by MATLAB program as an OFDM receiver.

For offline DSP processing, an optical network unit can recover its own data through logistic demap with the dedicated secure matrix, while the optical network unit cannot obtain the information delivered without the knowledge of the secure key. In our experiment, we choose N = 256 = 2^8 and the $8^2\times8^2$ matrix to study the performances of the system. Figure 3 shows the measured BER curves and the constellations with/without the secure key before and after the transmission. Figure 4 shows the measured BER curves and the constellations with/without the secure key before and after the transmission based on the LDPC coding. Since there is little difference of initial condition, almost all the constellation symbols are error at the receiver, there is about 5 dB power penalty after 40 km SSMF when the BER is 1×10^{-3} without using FEC technique. The LDPC coding can also improve the performance of the system, there is more than 10 dB power gain when the BER is 1×10^{-3}.

CONCLUSION

We have proposed and experimentally demonstrated a novel security-enhanced transmission strategy for the LDPC-DD-OOFDM system, where one-dimension logistic sequence is used to encrypt the signals. The 16-QAM OFDM data with the logistic encryption and the LDPC coding cannot be obtained at the receiver due to the unknown secure key with the initial value. However, the one-dimensional encryption algorithm is hardly implemented in the CO-OFDM system due to the signal phase-shift. Higher dimensional algorithm is needed to meet the requirements of high-order modulation in the CO-OOFDM systems. Being combined with FEC technique, higher dimensional encryption algorithm can be widely used in different optical networks.

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