OPTOELECTRONICS LETTERS Vol.9 No.2, 1 March 2013

Application of LDPC codes in atmospheric optical communication with coherent detection*

TAO Jin-jing (陶金晶)******, **ZHANG Yang-an** (张阳安), **HUANG Yong-qing** (黄永清), **ZHANG Jin-nan** (张锦南), **YUAN Xue-guang** (袁学光), **and LI Yu-peng** (李宇鹏)

State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, Beijing 100876, China

(Received 14 November 2012)

A novel scheme employing low-density parity-check (LDPC) codes in atmospheric optical communication system is proposed. We deploy coherent detection at the receiving side in the proposed scheme. To reduce bit error rate (BER) and enhance the system performance, LDPC codes are exploited and coherent receiver is used to improve the receiving sensitivity. Experiments are implemented to evaluate the performance of the transmission system. The atmospheric channel attenuations are set to 20−30 dB/km. The coherent detection with LDPC codes can reduce the received power requirement by ~4 dBm at the BER of 10^{-9}.

Document code: A **Article ID:** 1673-1905(2013)02-0132-3

DOI 10.1007/s11801-013-2402-2

In atmospheric optical communication systems, signals pass through atmospheric channel instead of optical fiber. There has been considerable interest in atmospheric optical communication because it offers many advantages, such as high bandwidth capacity, strong anti-interference ability and low cost. However, the unfavorable weather conditions, such as fog, rain and snow, may lead to serious signal fading and then result in the bit error rate (BER) of system increasing.

Low-density parity-check (LDPC) codes, which are first proposed by Gallager[1] in the 1960's, could improve the system performance[2-4]. As a soft-decision forward error correction (FEC)[5], LDPC code is becoming practical in coherent receivers[6].

In this paper, a scheme which employs LDPC codes in atmospheric optical communication system is proposed and demonstrated. In receiver side, coherent detection is implemented to improve the sensitivity and optimize the system performance. Rain may cause channel attenuations up to 20−30 dB/km at a rain rate of 150 mm/h[7]. The system performance in such a weather condition is discussed. A rate-5/6 (redundancy 20%) π-rotation LDPC code[8] is implemented in our scheme because of its low encoding process complexity and easy hardware implementation. BER performances of the LDPC-coded atmospheric optical communication system with coherent detection and the system which does not employ LDPC codes are studied for contrast. Comparison results show that employing LDPC codes in coherent detection system enhances the system sensitivity, and the received power at the receiver side decreases by about 4 dBm at the BER of 10^{-9}.

To evaluate the performance of the LDPC-coded atmospheric optical communication using coherent detection, a transmission system is set up as illustrated in Fig.1. One 2^{11}-1 pseudo-random bit sequence (PRBS) generated by a PRBS generator is encoded in the LDPC encoder using π-rotation LDPC codes with code rate of r=5/6. A 10 Gbit/s non-return-to-zero (NRZ) electrical pulse train based on the encoded bit stream is produced by the NRZ pulse generator. Light from the laser with central frequency at 193.4 THz is modulated in chirp-free Mach-Zehnder modulator (MZM) driven by the 10 Gbit/s NRZ signal. NRZ differential phase shift keying (DPSK) signal is generated. The optical spectrum for the light source is shown in Fig.2.

The received optical signal is mixed with a local oscillator in the 90° optical hybrid mixer. The central frequency of the local oscillator is set at 193.45 THz. The output from the mixer is fed to the balanced detector circuit. Phase shift keying (PSK) demodulator is introduced to accomplish the PSK demodulation. The low-pass filter suppresses the noise. LDPC decoder first samples and quantizes the received NRZ electrical signal demodulated from the former circuit. The LDPC decoder outputs a binary stream whose length is the same as that of the binary sequence produced by the PRBS generator. BER is calculated by the BER analyzer. Eye pattern is

---

* This work has been supported by the Fundamental Research Funds for the Central Universities (No.2009RC0401), and the Young Scholar Innovation Project (Nos.2011PTB-00-31, 2012RC0407 and 2012RC0406).

** E-mail: taojinjing@bupt.edu.cn

also observed before LDPC decoding. In our scheme, the uniformly most powerful (UMP) belief propagation (BP) based algorithm[9] is implemented in LDPC decoder.

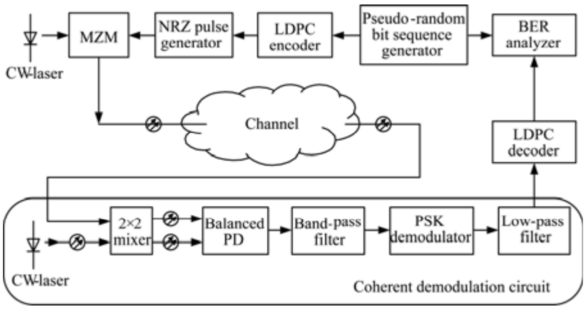

Fig.1 Architecture of LDPC-coded atmospheric optical communication system

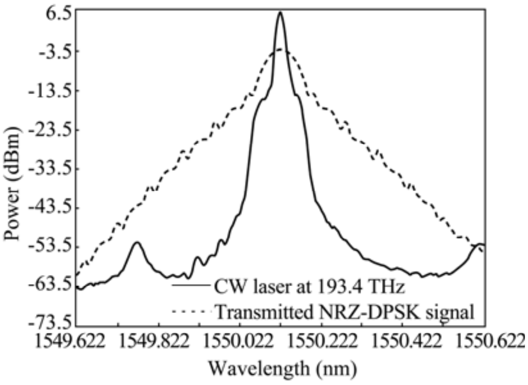

Fig.2 Measured optical spectral for the CW laser tuned at 193.4 THz and the transmitted NRZ-DPSK signal

Limited by the experimental conditions, we assess the proposed scheme by exploiting simulation platform. We simulate the performance of the coherent atmospheric optical transmission system with different atmospheric channel attenuation characteristics. The transmission range is set to 1 km. The aperture diameter of the transmitter telescope is 50 mm, and the aperture diameter of the receiver telescope is 200 mm. The BER curves in Fig.3 reveal the comparison of the LDPC-coded atmospheric optical transmission systems with coherent detection and direct detection. When BER is 10^{-3}, the received powers of the systems are about -44.5 dBm using direct detection and -46.6 dBm using coherent detection, respectively. The received power decreases by about 2 dBm at the BER of 10^{-3}. The receiving sensitivity is improved.

Finally, degradation in performance of the atmospheric optical transmission systems, which is caused by the atmospheric attenuation due to weather effects, is investigated. The atmospheric attenuation factor is adjusted from 20 dB/km to 30 dB/km. It helps us analyze the effect of the atmospheric attenuation on system performance. The BERs are computed by comparing the decision train got from hard decision and the decoded bit stream output from the LDPC decoder with the binary sequence generated by the PRBS generator, as shown in Fig.4. The decision train, the decoded bit stream and the binary sequence have the same length. Fig.4 illustrates that LDPC codes can correct the error bit and improve the BER performance dramatically. When the received power is above -47.4 dBm, the system could achieve the BER of 10^{-12} when LDPC decoding is accomplished. At the BER of 10^{-9}, the received power of the system is decreased by 4 dBm.

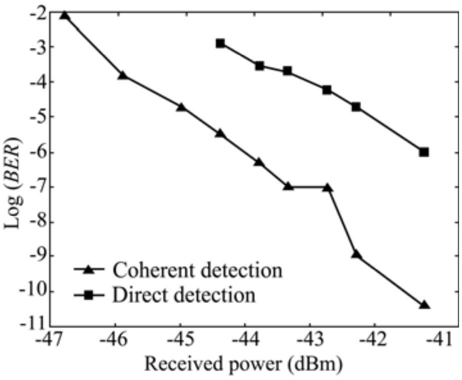

Fig.3 BERs for the atmospheric optical communication systems with coherent detection and direct detection

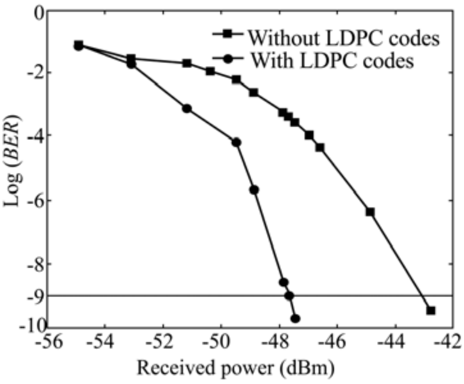

Fig.4 BERs for the atmospheric optical communication system with LDPC codes and the transmission system without LDPC codes

The proposed scheme is feasible and works efficiently. It demonstrates that deploying coherent detection in atmospheric optical communication system, to some extent, can improve the receiving sensitivity. At the BER of 10^{-3}, the received power can decrease by ~2 dBm. Moreover, employing LDPC codes in transmission system reduces the BER to a certain degree. When the atmospheric attenuation because of the unfavorable weather conditions is pretty high (20−30 dB/km), combining the coherent detection and LDPC codes in system can lower the received power and the BER of the system. At the BER of 10^{-9}, the received power requirement for transmission system is reduced by ~4 dBm. The performance of the transmission system is improved remarkably.

References

[1] R. G. Gallager, IRE Transactions on Information Theory **8**, 21 (1962).

[2] Ivan B. Djordjevic, Murat Arabaci and Lyubomir L. Minkov, J. Lightw. Technol. **27**, 3518 (2009).

[3] Jiaojiao Fu, Murat Arabaci, Ivan B. Djordjevic, Yequn Zhang, Lei Xu and Ting Wang, First Experimental Demonstration of Nonbinary LDPC-Coded Modulation Suitable for High-Speed Optical Communications, Optical Fiber Communication Conference **OWF4**, OWF4.1 (2011).

[4] Guo Jian-zhong, Qin Guan-feng and Zeng Lei, Optoelectronics Letters **8**, 306 (2012).

[5] Yuan Jian-guo, Wang Lin, He Qing-ping, Li Hao and Wang Yong, Optoelectronics Letters **8**, 376 (2012).

[6] T. Mizuochi, T. Sugihara, Y. Miyata, K. Kubo, K. Onohara, S. Hirano, H. Yoshida, T. Yoshida and T. Ichikawa, Evolution and Status of Forward Error Correction, Optical Fiber Communication Conference **OTu2A**, OTu2A.6 (2012).

[7] L. Castanet, Influence of the Variability of the Propagation Channel on Mobile, Fixed Multimedia and Optical Satellite Communications, JA2410 SatNEx e-Book, Shaker Verlag, 2007.

[8] Rich Echard and Shih-Chun Chang, The π-Rotation Low-Density Parity Check Codes, Global Telecommunications Conference, 980 (2001).

[9] Jinghu Chen and Marc P. C. Fossorier, Decoding Low-Density Parity Check Codes with Normalized APP-Based Algorithm, Global Telecommunications Conference, 1026 (2001).