

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

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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} .

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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

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

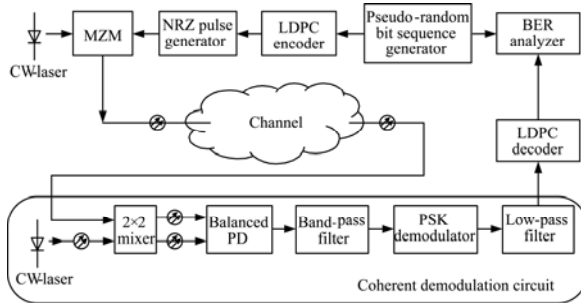


Fig.1 Architecture of LDPC-coded atmospheric optical communication system

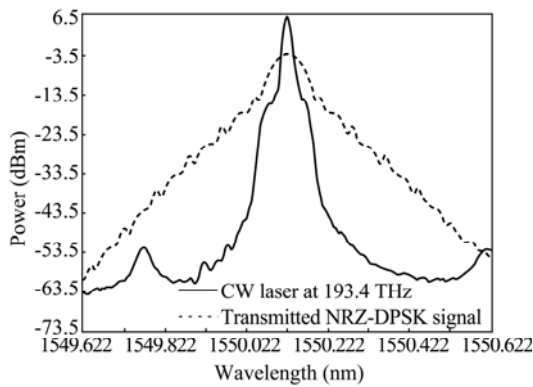


Fig.2 Measured optical spectral for the CW laser tuned at 193.4 THz and the transmitted NRZ-DPSK signal

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 perform-

ance. 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.

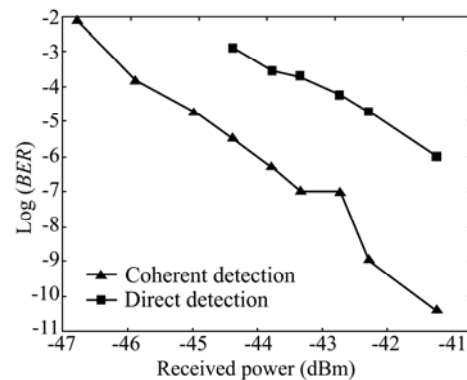


Fig.3 BERs for the atmospheric optical communication systems with coherent detection and direct detection

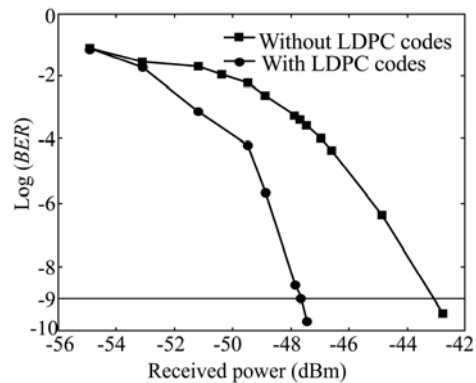


Fig.4 BERs for the atmospheric optical communication system with LDPC codes and the transmission system without LDPC codes

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 re-

ceived 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.

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