Evaluating LDPC Codes for OFDM/QAM Optical Fiber Systems

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Evaluating LDPC Codes for OFDM/QAM Optical Fiber Systems

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ABSTRACT

Optical fiber communications are a critical infrastructure for modern data transmission, providing high throughput and exceptional reliability over long distances. However, the integrity of the transmitted data remains vulnerable to distortion, which increase the bit-error-rate (BER). This effectively arises due to the increased dispersion resulted by the increase in the bit rate. Several correction codes have been developed to overcome this limitation, such as Manchester, Reed-Solomon, and Reed-Muller, however most of them suffer from significant drawbacks including high complexity, power consumption, and suboptimal error correction capabilities. The low density parity check (LDPC) code has been introduced as an effective coding technique to overcome the aforementioned limitation due to its attractive features, such as iterative decoding and parallel processing. This paper aims to verify the effectiveness of the LDPC code by applying it side by side with other codes designed for the same purpose on an OFDM/QAM-based optical communications system and comparing the performance. The performance is examined based on BER and constraints using Optisystem software. The results confirmed the superiority of the LDPC code as it shows lower BER, which contributes to increasing the transmission distance.

***Keywords**: Data Integrity, Error Correction Codes, Reed-Solomon codes, Manchester Codes, LDPC Codes.*

التحقق من فعالية شفرات التحقق من التكافؤ منخفضة الكثافة: دراسة باستخدام نظام اتصالات ضوئي

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الملخص

تعد اتصالات الألياف الضوئية بنية أساسية بالغة الأهمية لنقل البيانات الحديثة، مما يوفر إنتاجية عالية ووثوقية استثنائية للإرسال عبر مسافات طويلة، ومع ذلك، تظل سلامة البيانات المرسلة عرضة للتشويه، مما يزيد من معدل الخطأ في البتات .(BER) ينشأ هذا بشكل فعال بسبب زيادة التشتت الناتج عن الزيادة في معدل البت، وقد تم تطوير العديد من رموز التصحيح للتغلب على هذه المشكلة، مثل مانشستر وريد-سولومون وريد-مولر، ولكن معظمها يعاني من عيوب كبيرة منها التعقيد، واستهلاك الطاقة، وقدرات تصحيح الأخطاء دون المستوى الأمثل. تم تقديم كود التحقق من التكافؤ منخفض الكثافة (LDPC) كتقنية تشفير فعالة للتغلب على المشكلة المذكورة أعلاه نظرًا لميزاته الجذابة، مثل فك التشفير التكراري والمعالجة المتوازية. يهدف هذا البحث إلى التحقق من فعالية كود LDPC من خلال تطبيقه جنباً إلى جنب مع أكواد أخرى مصممة لنفس الغرض على نظام اتصالات ضوئية قائم على OFDM/QAM ومقارنة الأداء. يتم اختبار الأداء بناءً على معدل الخطأ في البتات (BER) باستخدام برنامج .Optisystemوأكدت النتائج تفوق كود LDPC حيث أظهر انخفاض في معدل الخطأ في البتات مما يساهم في زيادة مسافة الإرسال.

الكلمات المفتاحية: سلامة البيانات، شفرات تصحيح الأخطاء، شفرات ريد سولومون، شفرات مانشستر، شفرات التحقق من التكافؤ منخفضة الكثافة

INTRODUCTION

Despite the remarkable development that fiber-optic technology has added to the field of communications, which is the possibility of transmitting at high speeds over long distances, transmission using optical systems is not completely free of errors that may result from some common problems, such as scattering, dispersion, and attenuation (Kao & Hockham, 1966). Considering the literature, several correction codes aimed to reduce errors have been proposed, such as Turbo codes, Reed-Solomon codes, and Reed-Muller codes (Reed & Solomon, 1960), (Berrou et al, 1993). However, these codes have not reached ideality, as some of them suffer from the problem of complexity, and others suffer from deficiencies in the correction capability. For example, although Manchester codes is distinguished by its excellent performance in terms of data encryption and retention, it is not used for error correction purposes (Berrou et al, 1993). Also, even though Solomon codes are characterized by its effective performance in detecting and correcting burst errors, it fails in situations with a more random error pattern. As the demand for faster and more reliable optical communications is growing day by day, the need for efficient error correction codes is becomes urgent. In 1960, Robert Gallager has introduced an alternative solution which is LDPC codes (Gallager, 1992). Later in 1990, LDPC codes became the focus of many researches due to their theoretical closeness to achieving the maximum efficiency of communication channels (MacKay, 1999). What distinguishes LDPC is its sparse matrix, which reflects the ease of the algorithms used in correction process (Richardson, 2001). Integrating LDPC codes into optical communications brings several distinct advantages. For example, compared to Manchester and Reed- Solomon codes, LDPC codes have the ability of iterative decoding due to the sparse matrix construction, which leads to increased efficiency and reduced power consumption. In addition, LDPC codes are characterized by its great ability for adaptation, which makes it suitable for working in a variety of environments. Moreover, LPDC codes show great performance albeit with very noisy channels, especially optical channels. Considering the increasing demand for faster and more reliable optical communication

systems, the potential of LDPC codes cannot be overstated. These features can contribute to creating an optical communication environment capable of including new and advanced services. The research stages related to LDPC codes witnessed multiple steps, starting with laying the foundation for the theoretical concept by Robert Gallager in 1962 (Gallager, 1992) until reaching the stage of implementation as a practical solution.

LITERATURE REVIEW

The research interval of LDPC codes has witnessed many pivotal studies, starting with the foundations mounted by Robert Gallager in 1962 (Gallager, 1992). Fundamentally and effectively, Gallager has contributed to promote to the LDPC codes as an effective error-correcting solution especially in optical communications, as he successfully demonstrated the codes' ability to approach the Shannon limit. In doing so, Gallager has opened the door to more ambitious researches. Researchers in (MacKay, 1997) have practically proven the effectiveness of the LDPC codes in detecting and correcting errors, which effectively contributed to moving it from the theoretical environment to being used as an effective tool that ensures data integrity. In order to reach a fair evaluation, specifically in terms of complexity researchers in (Johnson & Weller, 2010) have confirmed the superiority of the LDPC codes by comparing it with the Manchester code. Further comparison was made with the Reed-solomon, which confirmed the superiority of the LDPC codes especially for random detection capabilities in optical fiber communication (Lee & Park, 2016). The feature of flexible adaptation of LDPC has been exploited by researchers in (Zhang Q et al, 2019). They developed a modified LDPC structure that shows the capability to improve tolerance to phase noise and the nonlinearities in fiber-optic channels. Researchers in (Liu et al, 2020) went to examine the LDPC codes correction capabilities at high-speed optical transmission, specifically at 400 Gpbs. the results showed a significant improvement in the BER, which strongly nominate LDPC codes for future optical fiber communications. Researchers in (Gupta et al, 2021) went to examine the performance of optical systems using LDPC codes with advanced modulation techniques. Although these methods requires coherent detection processes, they led to increase capacity and exhibited a good resistance to channel impairments. In another context, researchers in (Peterson et al, 2022) have developed a hardware-efficient LDPC decoder capable of reducing power consumption and increasing the decoding speed. In a distinguished study (Zhang L, 2022), machine learning techniques were combined to the LDPC codes. The result was a detection system capable of adapting to changes in channel conditions instantly. Researchers in (Norris et al, 2023) have been engaged in the security issues of the optical networks. In this context, they introduced a form of highly secured optical network based on the termed quantum- resistant LDPC codes. This diversity of research somehow confirms the importance of the LDPC codes in the field of optical communications, thus the possibility of its use as an effective tool in the next generations of optical communications networks.

CONTRIBUTION

In this paper, the authors seek to validate the effectiveness of the LDPC code in the field of optical communications by applying it side by side with other codes (Reed-Solomon codes, and Manchester codes) designed for the same purpose, that is to limit the dispersion effect, hence increase data integrity, using an OFDM/QAM-based optical communications system and comparing the performance. The performance is examined based on bit-error-rate constraints.

SIMULATION SETUP

Figure 1 describes the simulation setup. The data stream is first encoded by LDPC code. To be mapped to a sequence of symbols, data is modulated using BPSK or QAM. Data then undergoes OFDM modulation process which includes serial-to-parallel conversion, adding cyclic prefix, applying the Inverse Fast Fourier Transform (IFFT). Data then undergoes parallel-to-serial

conversion before being optically modulated using Mach-Zhender (MZ) modulator. Finally, the data is transmitted over the fiber optic channel. At the receiving side, data is converted from the optical domain to the electrical domain using PIN photo detector. Then it undergoes an OFDM demodulation process including serial-to-parallel conversion, removing cyclic prefix, applying the Fast Fourier Transform (FFT), and performing parallel-to-serial conversion. Finally, data is converted back to its original form after being demodulated and decoded using QAM demodulator and LDPC decoder, respectively. The above mentioned steps are performed using LDPC codes, Reed-Solomon codes, and Manchester codes. Table 1 lists the key parameters used in the simulation.

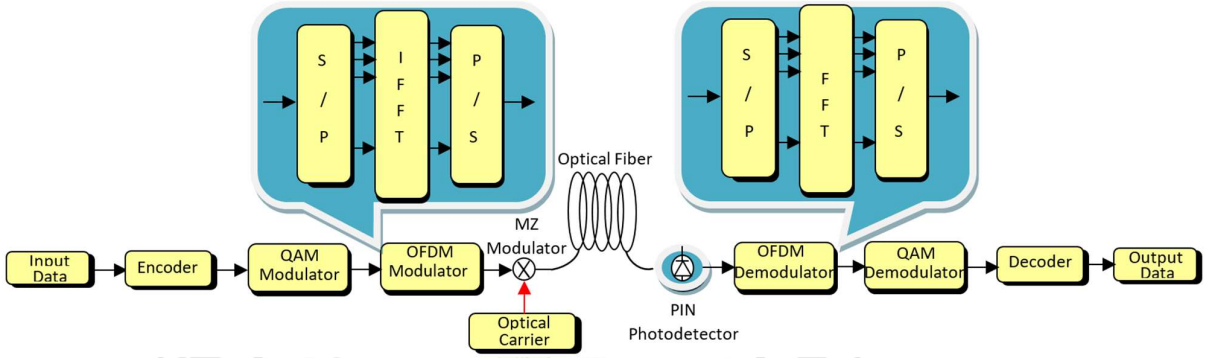


Figure 1. Schematic representation of the simulation setup

Table 1: Parameters used in the simulation.

System parameter	Parameter value
Modulation	QAM
Sample time	$0.05*10^{-6}$ sec
Bandwidth	20 MHZ
Number of pilot subcarrier	4
LDPC rate	1/2, 3/4
Power source	10dBm
Attenuation (SMF)	0.2 dB/km
Dispersion (SMF)	16.75 ps/nm/km
Thermal noise	1.8×10^{-23}
Responsivity	1A/W
Dispersion slop (SMF)	0.075 $ps/nm^2/km$
Dark current	10 Na

Shot noise	Active

RESULTS AND DISCUSSIONS

This section reviews and discusses the obtained results to validate the effectiveness of the LDPC code in optical fiber communications. A comparison will be made with other well-known codes. The comparison will be conducted using the same bit rate (10 Gbps) to come up with a fair judgment. Figure 2 shows the relationship between BER and distance using different codes (LDPC, Reed-Solomon, and Manchester codes). The first and second curves in blue and red representing the LDPC codes using (N = 1024, K = 2048), and (N = 128, K = 256), respectively. The curve in green belongs to the Manchester codes has matched exactly to the green curve. The curve is in purple belongs to the Reed-Solomon codes has matched exactly to the yellow curve that representing performance when no error correction is employed. Both don't reflect any satisfying results.

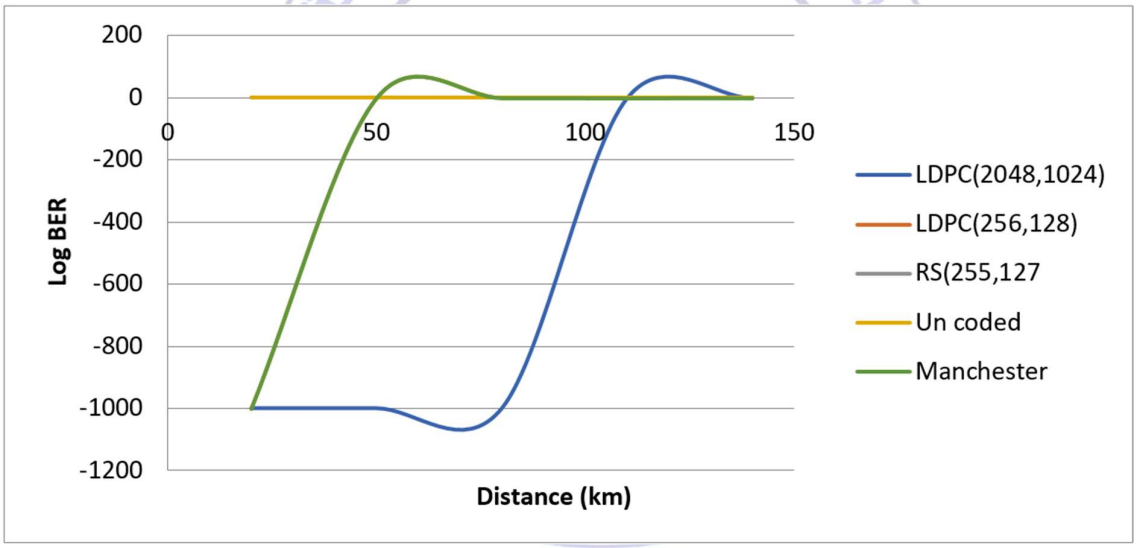


Figure 2. BER versus distance using different codes (LDPC, Reed-Solomon, and Manchester codes)

Looking at the curves, it is clearly evident that the LDPC code is the most superior. The improvement in performance increases with the increase of N and K. This gives an indication that the increase in the amount of processed data leads to improve the detection capabilities, as both N and K represent the number of rows and columns in the parity check matrix, i.e., the information, and the parity check bits that are added to detect and correct errors. However, an increase in the parity check bits would lead to consume a part of the actual bit-rate. In Figure 3, simulation was run using dispersion compensator.

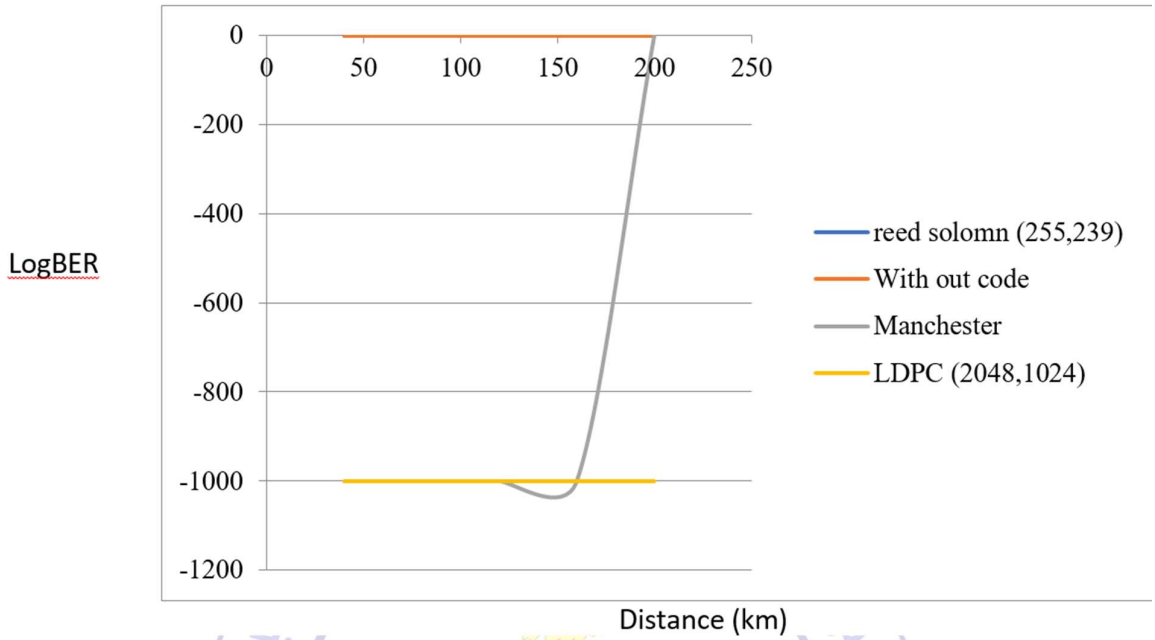


Figure 3. BER versus distance at different codes (LDPC, Reed-Solomon, and Manchester codes) using dispersion compensator and amplifier.

The curve in blue belongs to Reed-Solomon did not give any satisfactory results. It exactly has matched the curve in red which represents performance when no error correction is employed. The curve in purple belongs to Manchester codes shows much better performance compared to the case in Figure 2. By observing all the curves, one can obviously notes the superiority of the LDPC codes. As in Figure 3, in Figure 4 simulation was run using dispersion compensator and amplifier. Looking at Figure 4, it can be concluded that performance can be improved with the use of Reed-Solomon codes if transmission is conducted using 128 carriers and 12 pilots.

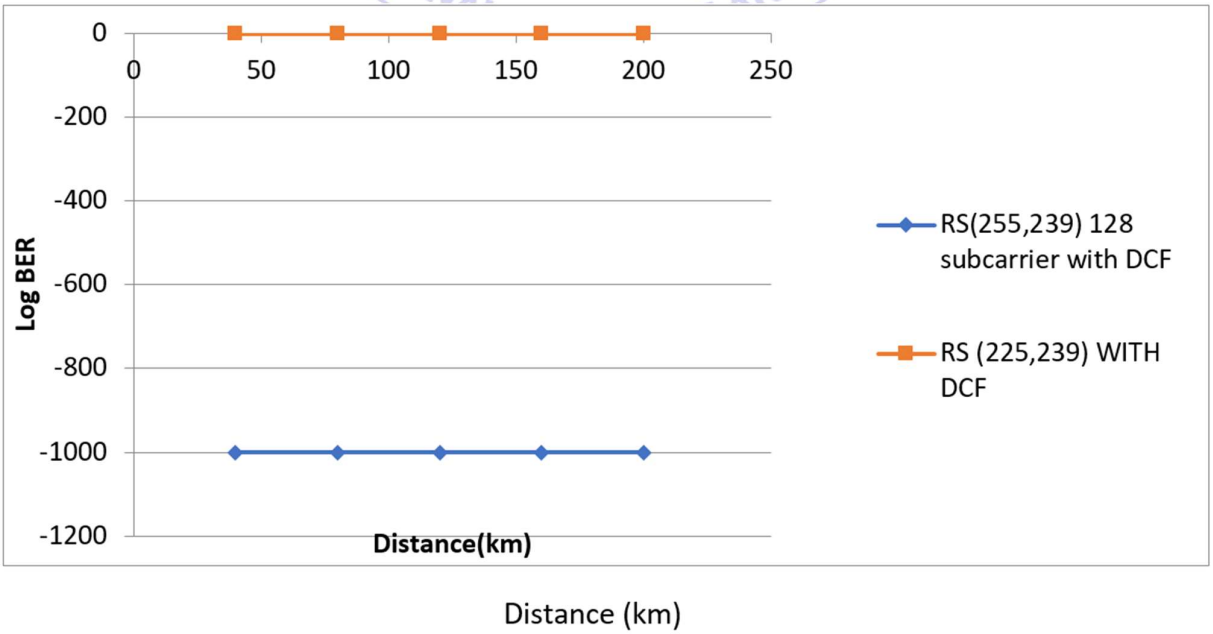


Figure 4. BER versus distance at Reed-Solomon codes using different subcarriers.

CONCLUSIONS

The results showed that the LDPC code gives positive results albeit without using compensators compared to other counterpart codes, which confirms its superiority. The results also showed the poor performance of the Reed-Solomon codes, even with the use of compensation process, compared to the acceptable performance that have been exhibited by the Manchester codes under the same condition. Overall, the results confirmed the superiority of the LDPC code due to the low error rate it shows. A worth-mentioning point is that with the LDPC the increase in the amount of processed data leads to improve the detection capabilities. However, the increase in the processed data would lead to consume a part of the actual bit-rate because the amount of parity check bits also increases.

CONFLECT OF INTEREST

We pronounce that we have no conflict of interest.

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