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Performance of LDPC Codes in Multipath OFDM System

Kinerja Kode LDPC Pada Sistem OFDM Dengan Kanal Multipath

Reni Dyah Wahyuningrum[1*], Lia Hafiza[2], Khoirun Ni'amah [3], Solichah Larasati[4], Ida Udlhiya[5]
[1,5]*Faculty of Electrical Engineering,* Politeknik Negeri Semarang
Semarang, Indonesia
[2]*School of Electrical Engineering,* Telkom University
Jakarta, Indonesia
[3,4]*Department of Telecommunication Engineering,* Telkom University
Purwokerto, Indonesia
[1*]reni.dyahwahyuningrum@polines.ac.id

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Abstract

In fifth-generation wireless networks (5G), a significant challenge arises: delivering high-speed data transmission and extensive networking services while maintaining a low bit error rate (BER). To meet the demands of 5G services, Orthogonal Frequency Division Multiplexing (OFDM) emerges as a promising technique for ensuring high-quality communication and an FFT size of 256. Moreover, several channel coding methods have been employed to enhance BER performance. Among these methods, Quasi Cyclic- Low-Density Parity Check (QC-LDPC) has become the established standard for high-speed data transmission in 5G networks. However, implementing these coding methods in conjunction with 5G standard specifications presents various complexities and challenges. In this research, we analyze QC-LDPC in multipath fading using OFDM. The performance of QC-LDPC codes at a BER of 10-3 can be achieved with an SNR of 15 dB for OFDM with QC-LDPC codes and an SNR of 20 dB for OFDM. The inclusion of QC-LDPC coding in the OFDM system significantly improves performance by reducing the required SNR for a BER of 10-3 from 20 dB (uncoded) to 15 dB (coded), a 5 dB reduction. Channel coding with QC-LDPC also enhances system efficiency by consistently decreasing the BER across various SNR values. These results confirm that QC-LDPC coding provides better reliability and performance than the uncoded OFDM system.

Keywords: 5G, Channel Coding, Multipath, OFDM, QC-LDPC

Abstrak

Jaringan nirkabel Generasi Kelima (5G) menghadirkan tantangan besar, yaitu menyediakan transmisi data berkecepatan tinggi dan layanan jaringan yang luas sambil mempertahankan tingkat kesalahan bit (BER) yang rendah. Untuk memenuhi kebutuhan layanan 5G, *Orthogonal Frequency Division Multiplexing* (OFDM) muncul sebagai teknik yang menjanjikan untuk memastikan komunikasi berkualitas tinggi dengan ukuran FFT 256. Selain itu, berbagai metode pengkodean saluran telah diterapkan untuk meningkatkan kinerja BER. Di antara metode-metode ini, *Quasi Cyclic-Low Density Parity Check* (QC-LDPC) telah menjadi standar yang mapan untuk transmisi data berkecepatan tinggi di jaringan 5G. Namun, penerapan metode pengkodean ini bersamaan dengan spesifikasi standar 5G menghadirkan berbagai kompleksitas dan tantangan. Dalam penelitian ini, kami melakukan analisis terhadap QC-LDPC dalam kondisi fading jalur ganda menggunakan OFDM. Kinerja kode QC-LDPC pada BER sebesar 10^{-3} dapat dicapai dengan SNR 15 dB untuk OFDM dengan kode QC-LDPC dan SNR 20 dB untuk OFDM tanpa kode. Penambahan pengkodean QC-LDPC pada sistem OFDM secara signifikan meningkatkan kinerja dengan mengurangi SNR yang dibutuhkan untuk mencapai BER sebesar 10^{-3} dari 20 dB (uncoded) menjadi 15 dB (dengan QC-LDPC), yaitu pengurangan sebesar 5 dB. Pengkodean saluran dengan QC-LDPC juga meningkatkan efisiensi sistem dengan secara konsisten mengurangi BER pada berbagai nilai SNR. Hasil ini mengkonfirmasi bahwa pengkodean QC-LDPC memberikan keandalan dan kinerja yang lebih baik dibandingkan dengan sistem OFDM tanpa kode.

Kata kunci: 5G, Channel Coding, Multipath, OFDM, QC-LDPC

I. INTRODUCTION

In wireless communication, multipath fading is a phenomenon where radio signals transmitted from a transmitter to a receiver reach the receiver through multiple different paths with varying lengths and reflections. This phenomenon can lead to rapid variations in the received signal strength, resulting in distortion, degradation, or even loss of the signal [1]. Causes of multipath include changes in environmental phenomena (such as temperature, humidity, and rain rate) and reflections from terrestrial objects (such as mountains and buildings). Effects of multipath include constructive and destructive interference, as well as phase shifts in the signal [2].

The fifth-generation (5G) network is the latest generation in wireless telecommunication technology, promising improvements in speed, capacity, low latency, and support for massive connectivity and the Internet of Things (IoT) [3]. One of the main challenges in implementing 5G networks is addressing interference and channel impairments that can affect signal quality and throughput. Channel coding is one solution used to enhance data transmission reliability and minimize interference [4]. Channel coding involves adding redundant information to the data to be transmitted so that if disruptions or distortions occur during transmission, the receiver can still recover the original data more effectively [5].

This research aims to evaluate 5G networks using Orthogonal Frequency Division Multiplexing (OFDM) multiplexing techniques and the addition of channel coding, specifically Quasi-Cyclic Low-Density Parity-Check (QC-LDPC) [6]. OFDM has been adopted in various communication standards, such as Wi-Fi (802.11a/g/n/ac/ax), Long-Term Evolution (LTE), and 5G. OFDM is an effective technique for mitigating fading and multipath effects that occur in wireless communication [7]. Fast Fourier Transform (FFT) plays a crucial role in 5G technology, particularly in OFDM modulation and demodulation. FFT and IFFT operators enable the latest 5G radio standards, supporting flexible sub-carrier spacings and point sizes up to 4096 [8]. In [9], it presents a 256-point analogue discrete-time FFT design for potential use in 5G waveforms. In [10], FFT size optimization for LTE RoF systems found that a 128-point FFT provides optimal performance in their scenario. In [11], mixed-radix or higher-radix algorithms combined with Single-path Delay Commutator architecture for 5G applications. The Bit Error Rate (BER) is a crucial performance metric for 5G technology, with systems aiming for BER values around 10-3 or lower [12]. To achieve these low BER values, 5G systems employ advanced error-correcting codes such as Turbo codes, Polar codes, and Low-Density Parity-Check (LDPC) codes [13].

QC-LDPC is a channel coding scheme known for its high error correction capabilities [14]. QC-LDPC codes have been adopted as part of the 5G network standards for channel coding. This standardization ensures interoperability and compatibility across various network implementations, promoting consistency and reliability in 5G network deployments. QC-LDPC is a specialized variant of LDPC used in 5G; LDPC codes use low-density parity-check matrices and lack a specific structure [15]. In this research, QC-LDPC with a specific structure called quasi-cyclic is utilized, where the parity matrices exhibit a structured pattern, making it more efficient in system implementation. QC-LDPC offers several advantages for 5G networks, including improved performance, efficient spectrum utilization, low complexity, adaptability, diversity gain, standardization, and futureproofing. These attributes contribute to making QC-LDPC an effective and reliable channel coding solution in the context of 5G communication systems [16]. QC-LDPC tends to offer better Bit Error Rate (BER) performance at lower Signal-to-Noise Ratio (SNR) values compared to convolutional codes [17].

This research aims to evaluate the performance of QC-LDPC in 5G networks when facing various communication challenges, such as interference and multipath fading. The performance of 5G networks with QC-LDPC is crucial to understanding the extent to which these techniques can enhance transmission quality and overall network performance. Through this analysis, BER values can be assessed. With a deep understanding of QC-LDPC, this research is expected to provide valuable insights into the development of better and more reliable wireless communication systems. This information will be highly valuable in the design and development of improved 5G networks and in understanding how coding technology can be efficiently implemented in existing communication networks.

II. RESEARCH METHOD

This research using Orthogonal Frequency Division Multiplexing (OFDM) emerges as a promising technique for ensuring high-quality communication and an FFT size of 256. Moreover, several channel coding methods have been employed to enhance BER performance. Among these methods, Quasi Cyclic-Low-Density Parity Check (QC-LDPC) has become the established standard for high-speed data transmission in 5G networks.

Figure 1 shows the block diagram of the 5G network model with the addition of channel coding. On the transmitter side, bitstream b enters the CC encoder block to add redundant bits, resulting in x_c using QC-LDPC with a coding rate of $R = {}^{1}/_{3}$. M is the modulation block using Binary Phase Shift Keying (BPSK) modulation, where the information bits are mapped and modulated to generate the symbol x_m. The modulated symbols are then transformed using the (CP) to the transformed symbols, resulting in x_{cp}. The CP-OFDM symbols are then transmitted over the multipath fading channel H.

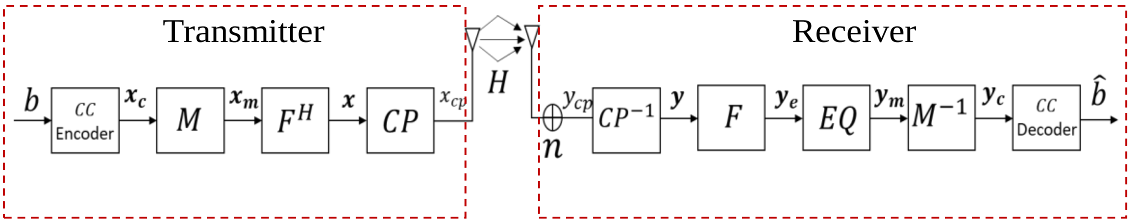

Figure. 1 Communication System of OFDM – QC-LDPC [12]

On the receiver side, the received symbols are affected by noise n before the y_{cp} symbols enter the CP^{-1} module and become the new symbols y. Symbol y is then transformed back using the F module, which is the Fast Fourier Transform (FFT), to generate the symbols y_e. In the EQ block, the equalized symbols y_m are demodulated using BPSK demodulation to produce the bits y_c. The CC decoder module decodes the final bits as the last step of CP-OFDM with channel coding. QC-LDPC is used as the channel coding method, with the parity-check matrix H obtained from TS 38.212 (3GPP, 2020). The received information bits $\hat{b}$ are evaluated for bit-by-bit matching between the transmitted and received bits with a Bit Error Rate (BER) evaluation [18].

A. QC-LDPC

QC-LDPC is a low-complexity channel coding method that shares a coding scheme similar to LDPC codes. LDPC codes serve as error correction codes and belong to the class of binary linear block codes with low density. In LDPC codes, the parity check contains fewer bit 1s compared to bit 0 [19]. Fig. 2 shows the structure of LDPC codes as a bipartite graph.

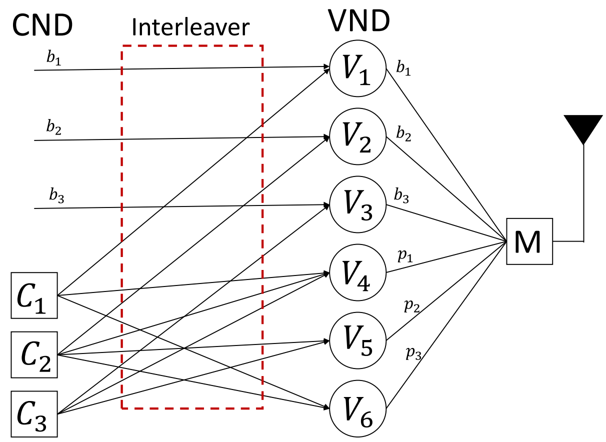

Figure 2. Birpatite Graph of QC-LDPC[14]

In 5G NR networks, QC-LDPC can be adapted for both large and short block sizes, constructed from base graphs 1 (BG_1) and 2 (BG_2) with dimensions $p = 42, n = 68$ for BG_1, and $p = 42, n = 52$ for BG_2. Here, p represents the number of rows, and n represents the number of columns in the BG matrix. A 46 ×68 matrix from BG1 with a coding rate of $R = {}^{1}/_{3}$ is used in this research. Figure 2 shows the bipartite graph of QC-LDPC codes based on (BG_1. Edges (E) connect to check node degree (CND) and variable node degree (VND) to facilitate iterative decoding [20].

B. OFDM

This research employs the CP-OFDM multiplexing technique with a Fast Fourier Transform (FFT) size of 256. OFDM is one of the multiplexing techniques used in wireless communication, especially in systems like Wi-Fi, 4G/5G, and other technologies. OFDM is used to combine multiple small frequency subchannels (subcarriers) to transmit data simultaneously. Each subcarrier carries separate information; thus, channel capacity can be increased by leveraging these multiple subcarriers [22]. The Cyclic Prefix (CP) included in OFDM plays a role in mitigating multipath fading and preventing interference between symbols. By combining multiplexing and the use of a cyclic prefix, OFDM creates an efficient and reliable transmission method for wireless communication [23]. Figure 3 illustrates the initial part of an OFDM symbol, which is a repetition of the end portion of the OFDM symbol, where Q represents the length of the CP and the length of the information symbol is denoted as N.

FFT is the process of separating the carrier frequencies from the received OFDM symbols on the receiver side before demodulating and converting them back into information bits [24]. FFT is also used to implement discrete Fourier transform to make it faster and more efficient. The FFT size refers to the number of subcarriers in an OFDM symbol, which is expected to match a size of 2^N, where N is the number of samples transformed from the time domain to the frequency domain. The FFT size is determined by balancing the protection against multipath effects, Doppler shift, and system complexity. A larger FFT size in 5G NR systems can reduce subcarrier spacing and extend symbol duration. This facilitates the protection of OFDM symbols from interference due to multipath effects. On the other hand, reduced subcarrier spacing makes the system more vulnerable to ICI caused by Doppler spread effects in wireless communication systems.

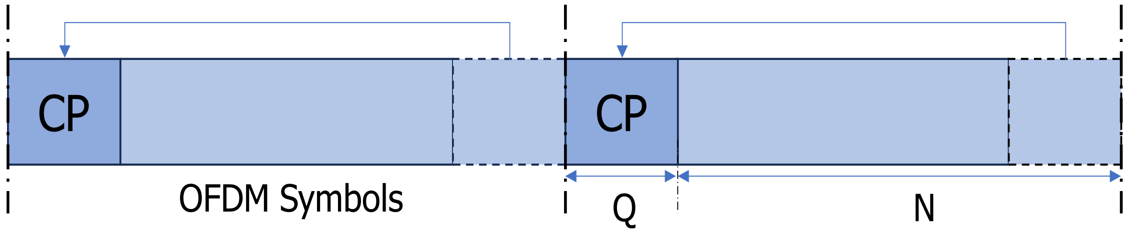

Figure 3. Ilustration of Cyclic Prefix OFDM System [19]

Inverse Fast Fourier Transform (IFFT) is the process used to generate OFDM symbols on the transmitter side, where the frequencies of each piece of information are made orthogonal to each other. IFFT transforms a spectrum, which includes the amplitude and phase of each information signal, into a time-domain signal[12]. IFFT transforms a set of complex-valued symbols into the time domain with the same number of symbols. The use of orthogonal subcarriers in IFFT is essential in OFDM signals to easily control the amplitude and phase of each symbol [25].

III. RESULTS AND DISCUSSION

BER represents the percentage of received bits that experience errors compared to the total number of transmitted bits, as defined in equation (1)

$$BER = \frac{r}{t}, \tag{1}$$

where, r is the number of bit errors, and t is the number of transmitted bits [26] .

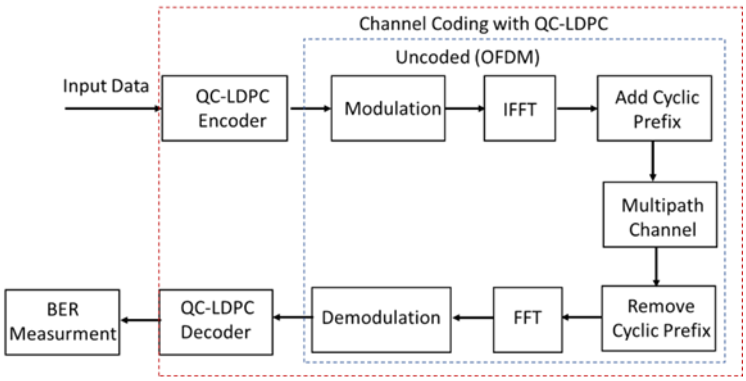

Figure 4. The BER value is measured on OFDM and OFDM with QC-LDPC

The BER is a measure of the reliability of the system as shown in Figure 4. In both OFDM and OFDM with QC-LDPC, it is measured by comparing the transmitted and received bits, but with QC-LDPC, the decoded bits after the QC-LDPC decoder are used for comparison, improving the accuracy of the BER.

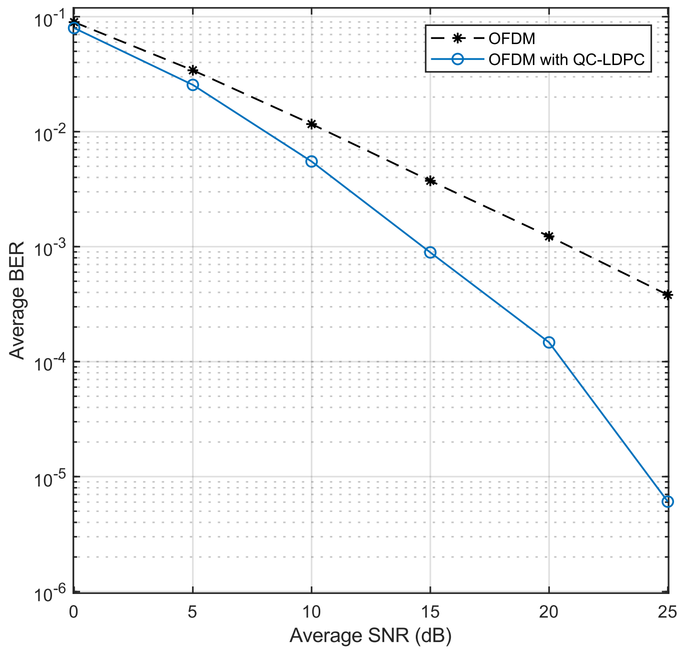

Figure 5. The BER with OFDM System and OFDM using QC-LDPC

Figure 5 shows the BER performance of 5G BPSK-modulated OFDM with and without QC-LDPC channel coding with $R = 1/3$. The x-axis represents the average SNR, and the y-axis indicates average BER value of $10^{-1} - 10^{-5}$. The dashed line with star markers depicts the performance of the OFDM system, while the solid line with circular markers represents the performance of the OFDM system with QC-LDPC channel coding.

Table 1. Performance OFDM system and OFDM using QC-LDPC

BER	SNR (OFDM system)	SNR (OFDM using QC-LDPC)
10^{-2}	10 dB	7 dB
10^{-3}	20 dB	15 dB
10^{-4}	>25 dB	21 dB

The BER reaches 10^{-3}, the OFDM system can achieve this with an SNR of 20 dB, where as the OFDM system with QC-LDPC channel coding can achieve it with an SNR of 15 dB. The research results indicate that the addition of channel coding to the OFDM system can enhance efficiency at various SNR values and minimize errors. Table 1 shows the value of performances OFDM and OFDM with LDPC codes.

This research aims to evaluate the 5G performance channel coding using QC-LDPC with $R = 1/3$. This research also using the CP-OFDM multiplexing technique with a Fast Fourier Transform (FFT) size of 256. The performance parameters analyzed in this study are BER vs SNR, where the desired value is a large SNR and small error bit value.

The performance using channel coding is better than without channel coding because channel coding can minimize error in the 5G networks. This research obtained a difference in SNR values of 5 dB on channels using channel coding and without channel coding. The performance of SNR value 20 dB without channel coding compared to 15 dB with BER 10^{-3}. The improvement in SNR when using QC-LDPC coding suggests that the system would be more robust and reliable in practical scenarios.

IV. CONCLUSION

This research evaluates the performance of a 5G network using an OFDM system with an FFT size of 256, BPSK modulation, and the addition of channel coding. The channel used in this research is QC-LDPC. The research demonstrates that in a 5G network with the inclusion of channel coding, efficiency can be improved at SNR values, achieving a diversity order of two. This indicates that communication systems on a 5G channel can achieve better performance by mitigating fading effects on the channel. As a result, they can overcome disruptions and adverse conditions in wireless communication. The performance of QC-LDPC codes at a BER of 10^{-3} can be achieved with an SNR of 15 dB for OFDM with QC-LDPC codes and an SNR of 20 dB for OFDM. Channel coding with QC-LDPC reduces the required SNR for the same BER, which is a key indicator of improved system performance. The 5 dB reduction in SNR for achieving the same BER shows that QC-LDPC improves error correction, allowing the system to perform well in noisier environments (i.e., at lower SNR levels).

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