Application of m-ldpc codes in multipath Rayleigh fading channels

Hui Zhou1*, Rui Wang1, Hairu Zhao1 and Zhenzhou An2
1 School of Physics and Electronic Engineering, Yuxi Normal University, Yuxi, Yunnan, 653100, China
2School of Mathematics and Information Technology, Yuxi Normal University, Yuxi, Yunnan, 653100, China
*Corresponding author’s e-mail: zhouhui@yxnu.edu.cn

Abstract. The fifth generation mobile communication (5G) network has been commercialized on a large scale in the world in 2020, but the wireless communication channel as an important component is a complex and changeable environment. The signal is easy to be affected by the fast time-varying channel, serious multipath interference and Doppler frequency shift, resulting in large ISI and delay. Therefore, it is necessary to process the signal before transmission. In this paper, LDPC code is used as channel coding method to study the performance of m-ldpc code in 5G wireless channel. The simulation results show that the m-ldpc code can avoid the influence of multipath channel on the signal in 5G wireless channel.

1. Introduction
Wireless channel environment is an important factor affecting the transmission performance of wireless communication system, which is essentially different from the channel state of wired communication. When transmitting, the signal is loaded on the electromagnetic wave and propagates freely in space, not along a specific transmission medium from a single path to the receiving end, and there are multiple propagation paths. Therefore, the transmitted signals have different transmission phases, and the signals may be enhanced or weakened after superposition, resulting in the fading of the received signals at the receiving end. At the same time, due to the different transmission paths, the transmission delay is also different, so that the signal received by the receiver has delay extension. All these make people face greater challenges in the study of wireless channel transmission characteristics. Nowadays, people pay more and more attention to how to improve the performance of mobile communication system. If we want to develop wireless transmission technology with higher performance and high bandwidth, we must deeply understand and study the wireless channel in order to analyze and process the transmission signal better.

2. Multipath Rayleigh channel[2]
Fading channel is one of the most complex channels in wireless communication. Generally speaking, fading is caused by two physical phenomena: One is the multipath effect caused by different paths and more paths in the process of radio wave propagation; the other is that the object is in the process of continuous movement, which will lead to the change of the relative transmission speed of the receiver and the receiver, and then cause Doppler frequency shift[1], which will affect the amplitude of the
transmission signal in the time domain and frequency domain. There are many kinds of fading channels. This paper focuses on the analysis and research of multipath Rayleigh channel.

Generally, the transmission signal in wireless channel is band-pass signal, and its expression is [2]:

\[ s'(t) = \text{Re}[s(t)e^{j2\pi f_c t}] \]  

(1)

Where \( f_c \) is the transmission frequency.

After passing through the multipath channel, the signal arrives at the receiving end by several different paths. When the receiver is stationary, the received signal is:

\[
y'(t) = \sum_i a_is\left(t - \frac{x_i}{c}\right) = \sum_i \text{Re}\left[s\left(t - \frac{x_i}{c}\right)\exp\left[j2\pi f_c \left(t - \frac{x_i}{c}\right)\right]\right]
\]

\[= \text{Re}\left[\sum_i a_is\left(t - \frac{x_i}{c}\right)\exp\left[j2\pi \left(f_c t - \frac{x_i}{c}\right)\right]\right] \]  

(2)

Where \( x_i \) and \( a_i \) represent the length and reflection coefficient of the \( i \)-th path respectively, \( C \) is the speed of light and \( \lambda = x_i/c \) is the wavelength.

\( y'(t) \) is written as a complex envelope:

\[ y'(t) = \text{Re}[y(t)e^{j2\pi f_c t}] \]  

(3)

Where \( y(t) = \sum a_i \exp\left(-j2\pi \frac{x_i}{\lambda}\right)s\left(t - \frac{x_i}{c}\right) = \sum a_i \exp(-j2\pi f_c \tau_i)y(t - \tau_i) \]  

(4)

Where \( \tau_i = x_i/c \) is the delay of each path.

If the terminal is moving in the process of communication, Doppler frequency shift will be produced in the process of communication. If the moving speed of the terminal is \( V \) and the angle between the incident direction of the received signal and the moving direction of the terminal is \( \theta_i \), the Doppler frequency shift \( f_d \) generated is:

\[ f_d = \frac{V}{\lambda} \cos \theta_i \]  

(5)

The path length variation caused by terminal motion is \( \Delta x_i = -vt \cos \theta_i \). Since the frequency of each path will change, the received signal at the receiving end can be expressed as:

\[ y(t) = \sum a_i \exp\left(-j2\pi \frac{x_i + \Delta x_i}{\lambda}\right)s\left(t - \frac{x_i + \Delta x_i}{c}\right) \]

\[= \sum a_i \exp(-j2\pi \frac{v}{\lambda} t \cos \theta_i)s\left(t - \frac{x_i + \frac{vt}{c} \cos \theta_i}{c}\right) \]  

(6)

Compared with \( x_i/c \), \( vt \cos \theta_i/c \) is small and can be ignored. At the same time,

\[ a' = a_i \exp\left(-2j\pi \frac{x_i}{\lambda}\right) \], then

\[ y(t) = \sum a' \exp(j2\pi \frac{v}{\lambda} t \cos \theta_i)s\left(t - \frac{x_i}{c}\right) = \sum a' \exp(j2\pi \frac{v}{\lambda} t \cos \theta_i)s(t - \tau_i) \]  

(7)

If the multipath is caused by scatterers around the terminal, the delay difference between the paths at the receiver is very small, and it is difficult to separate them at the receiver. (7) can be expressed as:

\[ y(t) = s(t - \tau_i) \sum a' \exp(j2\pi \frac{v}{\lambda} t \cos \theta_i) = s(t - \tau_i) \sum a' \exp(j2\pi \omega m t \cos \theta_i) \]  

(8)
Then the impulse response of the channel is as follows:

$$h(t, \tau) = \delta(\tau - \tau_i) \sum_{i=1}^{N} a_i \exp(j2\pi f_m t \cos \theta_i) \hspace{1cm} (9)$$

In this case, only one discernible path of the received signal produces flat fading, and (9) is the impulse response of the flat fading channel.

$$\sum_{i=1}^{N} a_i \exp(j2\pi f_m t \cos \theta_i) = u(t) \exp[j\varphi(t)] = \beta(t)$$

If $y(t) = s(t - \tau_i)\beta(t)$, this paper mainly studies the flat multipath Rayleigh fading channel.

3. LDPC code[3]  
LDPC code is a kind of linear block code with good error detection ability. LDPC coding needs to generate a parity check matrix $H$ to obtain the generation matrix $G$, so as to generate different codewords. At present, there are two kinds of construction methods of check matrix: random construction method and structured construction method. In this paper, the quasi cyclic (QC) code construction method of structured construction method is used. Based on AP sequence, QC-LDPC code check matrix without "4-loop" is generated. On the basis of binary LDPC code, the m-ldpc code is obtained by extending it to GF (q).

After receiving the message, the information channel is initialized by using the likelihood information channel. Define the variable node message as: $q_{nm}^{(0)}(a) = f_n(a)$, the information is replaced when it passes through a node[4], the message after replacement is shown in equation (10)

$$q_{nm}^{(i)}(a) = q_{nm}^{(i-1)} \left( \frac{a}{h_{nm}} \right)$$

Among them, $n$ is the variable node, $m$ is the check node, $h_{nm}$ is the element of the $M$th row and $n$ column in the check matrix $H_{M \times N}$, and the division is carried out in the finite field GF (q). Then, using the full probability formula, the message of the verification node is expanded:

$$r_{nm}^{(i)}(a) = p(c_m = 0 | c_n = a) = \sum_{\{c_m | h_{nm} \cdot c_m = a, c_m \in \{v \in \mathcal{V} | c_m \in \mathcal{V} \}} P(c_m = \sum_{n \in N(m)} h_{nm} \cdot c_n) \prod_{n \in N(m), n \neq n} g_{nn}(a) \hspace{1cm} (11)$$

Where $c_m$ is the $m$-th parity check relation and $\mathcal{V}$ is the set of all vectors satisfying the check relation $c_m$.

When the verification node passes the message to the variable node, it also needs to go through the replacement node. The message after replacement is shown in (12):

$$r_{nm}^{(i)}(a) = \tilde{r}_{nm}^{(i)}(a \cdot h_{nm})$$

Where $\tilde{r}_{nm}$ is the element of the $M$-th row and $n$ column in the check matrix $H_{M \times N}$, and the multiplication is carried out in the finite field GF (q).

Then update the variable node according to formula (13), calculate $Q_n(a)$ in formula (14) and find the maximum value. Finally, the decoding is stopped according to (15). If the decoded codeword meets (a) in (15) or the number of iterations reaches the maximum, the decoding will be stopped. Otherwise, it will return to initialization and continue decoding[4].

$$q_{nm}^{(i)}(a) = a_{nm} \cdot f_n(a) \prod_{m \in M(n)} \tilde{r}_{nm}^{(i)}(a) \hspace{1cm} (13)$$

$$Q_n(a) = a_n \cdot f_n(a) \prod_{m \in M(n)} \tilde{r}_{nm}^{(i)}(a), \hspace{0.5cm} \tilde{c}_n = \arg \max_a Q_n(a) \hspace{1cm} (14)$$

$$H_{M \times N} \cdot \tilde{c}^T = 0 \hspace{1cm} (a)$$

$$l = l_{\max} \hspace{1cm} (b)$$

$$l = l_{\max} \hspace{1cm} (b)$$

$$l = l_{\max} \hspace{1cm} (b)$$
4. Integrated model
In order to better reduce the impact of multipath channel on the signal, LDPC coding is carried out before the signal passes through the channel to increase the signal robustness. At the same time, the error detection ability of LDPC code is used to quickly detect the existence of error code, so as to better correct the code element and ensure the reliability of information transmission. The block diagram of the integrated model system is shown in Figure 1.

5. Simulation analysis
This paper uses MATLAB software to simulate. Firstly, the multipath Rayleigh fading channel is modeled, and the difference between multipath Rayleigh fading channel and white Gaussian noise (AWGN) channel is analyzed. The simulation results are shown in Figure 2.

It can be seen from Figure 2 that under the same transmission conditions, the pure white Gaussian noise channel has little impact on the signal, and the interference on the signal gradually decreases with the increase of SNR. In the multipath Rayleigh fading channel, even if the SNR is increasing, the ISI caused by multipath channel is still serious, which makes the BER still large. Therefore, in order to reduce the impact of multipath channel on the signal, it is necessary to process the transmitted signal. In this paper, LDPC code is used to code the signal to enhance the stability of the signal, and the error correction ability of LDPC code is used to self correct the signal at the receiving end. The simulation results are shown in Figure 3.
In the figure, the curve with loops is the bit error rate (BER) of the received signal after the transmitted signal enters the multipath Rayleigh fading channel after QPSK modulation. The curve with points is the bit error rate (BER) calculated after LDPC coding, QPSK modulation, and then transmission through multipath channel. Through the comparison of the two bit error rate, it can be seen clearly that the LDPC coded signal can well correct the influence of multipath channel on the signal, and restore the transmitted signal as far as possible.

6. Summary
First of all, this paper analyzes the multipath Rayleigh fading, and on this basis, the LDPC coding and decoding system is added to the wireless communication system. The signals are encoded before entering the channel, and the signals are rearranged according to certain rules by using the interleaving characteristics of LDPC codes. In this way, when the receiver de-interleaves, the burst errors can be dispersed in time and become independent random errors, which can reduce the correlation between error signals and avoid large-scale errors. The reliability of the system is proved by simulation.

Acknowledgments
This paper was subsidized by Youth project of applied basic research foundation of Yunnan Provincial Department of science and technology (2017FD162), Construction Plan of Key Laboratory of Institutions of Higher Education in Yunnan Province and Joint youth project fund of Yunnan Provincal Department of science and technology (2017FH001-102, 2018FH001-120).

References
[1] Song Xu. Research on modulation recognition algorithm of communication signal in multipath Rayleigh channel and FPGA implementation [D]. Harbin Institute of technology, 2018.
[2] Zhang Junming. Multipath time delay estimation and channel modeling in wireless channel [D]. University of Electronic Science and technology, 2010.
[3] Hui Zhou, Hairu Zhao, Shengping Zhao, Zhenzhou An. The Research on a parallel and synchronous encoding and decoding method of multi-level LDPC[J]. 2020 International Symposium on Electronic Information Technology and Communication Engineering(012095).
[4] Xu Wei. Implementation of non binary LDPC codes and Research on modulation pattern recognition [D]. Shandong University, 2019.