Comparative Study on 5G Communication Channel Coding Technology

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Abstract. The fifth-generation mobile communication network (5G) technology is a hot topic in the current mobile communication field, and the channel coding technology is the foundation to realize the reliable communication of 5G mobile system. This paper introduces the development of 5G technology and the development of standards, with emphasis on the features and applications of Turbo, LDPC and Polar codes, and compares these three technologies. Finally, the future development of 5G channel coding standard is prospected.

Keywords: 5G, Channel coding, Turbo code, LDPC code, Polar code.

1. Introduction

Because there are interference and fading in the mobile communication system, the digital signal will generate error code during transmission. In order to improve the reliability of the system, a variety of methods (use error correction/error detection coding technology, increase signal transmission power, etc.) are needed to improve the signal robustness. Channel coding is a common way to reduce the system error rate.

There are two very important theorems on the channel capacity and reliability of data communication network: Nyquist theorem and Shannon theorem. Nyquist theorem C=2B log2N, where C is channel capacity and B is channel bandwidth. It points out the relation between channel capacity and bandwidth in noiseless channel. However, the channel of the actual transmission signal cannot be noiseless. Shannon theorem C=B log2(1+S/N) indicates that the capacity of the channel with noise is related to the bandwidth and signal-to-noise ratio of the transmission channel under certain bandwidth. Shannon also pointed out that if the information rate R of the information source is not greater than the communication channel capacity C, there may be a coding method to realize the reliable transmission of information. But Shannon theorem doesn't indicate how this system can be implemented, and for decades scientists have struggled to find channel coding ways closest to Shannon's capacity limits.

2. Mobile Communication Technology and Channel Coding

The fourth-generation mobile communication technology (4G) has been commercialized all over the world, and the debate over the fifth-generation mobile communication technology (5G) standard has already begun. In the 5GNR (NewRadio) standard that has been formulated, the peak rate of data download can reach 20Gbps, the end-to-end connection data delay is less than 1ms, and the user surface data delay in the URLLC scenario is 0.5ms [1].

The 5G standard has defined three application scenarios: eMBB (enhanced mobile broadband), mMTC (large connected Internet of things) and URLLC (ultra-reliable ultra-low latency communication). Among them, eMBB corresponds to broadband of large-traffic mobile services such as 3D/ ultra-high definition video, mMTC corresponds to large-scale Internet of things business, and URLLC corresponds to services requiring low-delay and high-reliability connection, such as manless driving and industrial automation.

At the 3GPPTSGRANWG1 conference in October 2016, LDPC code was determined as a long block coding scheme for mobile broadband eMBB scenario business data channel coding. In November 2016, at the 3GPPRAN1 conference, the channel coding scheme of 5G short block of eMBB scenario was determined to use Polar code as the control channel coding scheme [2]. The debate on 5G physical layer coding technology standards mainly focuses on the technology of Turbo code, LDPC and Polar code.

3. Turbo Code (Convolutional Code)

Before the Turbo code was discovered, there was always a gap of 2 to 3dB between the designed system gain and Shannon theoretical limit. Turbo code is also known as parallel concatenated convolutional code. The sending end generates random coding through encoder and interleaver, and the receiving end uses decoder and deinterleaver to do multiple iterations to generate maximum likelihood decoding. Theoretical studies show that under the circumstances of $E_b/N_0 \geq 0.7$dB and BPSK encoding modulation, the error rate BER of reliable transmission conducted by Turbo code with error rate of 1/2 is $\leq 10^{-5}$ in additive white Gaussian noise channel AWGN, which is very close to Shannon limit [3]. Turbo code has been widely used in mobile communication technology. This technique is used for channel coding from 3G to 4G and even 4.5G.

The error control design of communication system depends largely on the performance of the decoder, because the decoder usually performs more complicated operations than the encoder. In proving the second theorem, Shannon used the random code with infinite code length to encode and the maximum likelihood algorithm to decode. The complexity of maximum likelihood decoding algorithm increases exponentially with the length of the code word. Therefore, such a design will greatly increase the complexity of the system, which is extremely difficult to implement. The decoding algorithm of Turbo code uses an iterative method to approximate the maximum likelihood algorithm. There is a linear relationship between the complexity and the length of the information sequence. By contrast, iterative decoding is easier to implement.

Literature [4] analyzed and compared the performance and complexity of Turbo code 2-class decoding algorithm. Literature [5] studied the application of Turbo code in joint network channel coding.

4. LDPC(Low-Density Parity Check)

LDPC (Low-Density Parity Check) was first proposed by Gallarger in 1962, but it could not be realized due to the backward conditions at that time. Until 1995, Mackay and Neal found that the LDPC decoding algorithm is closer to Shannon limit than Turbo code system capacity when the code is longer. Theoretical research shows that when the code length tends to be infinite, an irregular LDPC code with error rate of 1/2 is used to conduct reliable communication on the additive white Gaussian noise channel AWGN, and the required E_b/N_0 threshold limit distance from Shannon limit is only 0.0045db [6]. Therefore, LDPC decoding is closer to Shannon limit than Turbo code.

Compared with Turbo code system, LDPC system has many advantages :(1) low system complexity, low time delay and easier hardware implementation; (2) better frame error ratio performance; (3) error-floor is greatly reduced to meet the demand of extremely low error rate for communication system; (4) the decoder has smaller power, adopts parallel decoding, and has higher data throughput [7]3.

The initial theory of LDPC is based on binary domain, that is, binary LDPC. With the further research on LDPC, LDPC is extended to multivariate domain, namely multivariate LDPC. Binary LDPC has been widely used in the field of communication and broadcasting, and the research on multivariate LDPC has achieved remarkable results. LDPC has been adopted as channel coding standard by 802.11ac of WiFi.

Literature [7]3-4 gives the coding schemes of binary LDPC and multivariate LDPC technology and their application in the communication field.

5. Polar Code (Polarization Code)

Polar code is the only coding method so far discovered by human, which proves that the capacity of communication system in binary discrete memoryless channel can reach Shannon limit. In 2009, professor Arikan from Turkey proposed a linear channel coding method, Polar code, based on the theory of channel polarization. Its coding and decoding complexity is low. When the coding length is N, the complexity is only O(NlogN) [8].

The theoretical basis of Polar code is Chanel Polarization, which occurs when the length of the code tends to infinity. Multiple independent channels will be equivalent to noiseless channels with channel capacity close to 1, while other channels are full-noise channels having transmission rate close to zero. This phenomenon is the polarization of channels. The Polar coding strategy applies this phenomenon by using the noiseless channel to transmit useful information of the user and the conventional information or no information of the full-noise channel [7]5.

Polar code is a relatively new algorithm. A lot of research is still on theoretical research, and the research on device implementation is not very mature. China's Huawei company has been developing Polar code for many years, and has made great achievements in the development of coder and decoder of Polar code.

Literature [9] introduced a construction method of limited accompanying base polar code (selecting a good quality part from multiple channels as the information transmission channel and the rest as the frozen bit transmission channel), and gave the simulation curve results of block error rate when different code lengths are given and the deletion probability is ½ [10, 11].

6. Conclusion

Turbo code has many iterations and large decoding delay, which is difficult to meet the network requirements of 5G with high speed and low delay. However, some manufacturers have designed parallel Turbo decoder, which can meet the KPI of 5G network.

LDPC code and Polar code, which are popular candidates for 5G channel coding standards, have their own characteristics. Polar code has low complexity in the complexity of encoding and decoding. It is easy to implement and can reach the channel capacity limit. However, systems using multivariate LDPC have better band utilization, and they also perform better in middle and short code length than Polar code. Single coding technology can no longer meet the needs of all scenarios and users, and the use of multiple technologies is a foreseeable development trend. The reason why 3GPP determines the data channel coding standard and control channel coding standard as LDPC and Polar code respectively in eMBB scenario may be based on this.

Literature analyzed and compared the cascade schemes and system implementation complexity of Polar-LDPC and LDPC-Polar, the two cascaded code, and compared the decoding performance of these two schemes with Polar decoding performance.

From a device implementation perspective, 5G phones need to support at least 4G and 3G networks. In 3G and 4G, the channel coding adopts Turbo code, while 5G has been confirmed to adopt LDPC and Polar code, which means at least 3 sets of coder and decoder on the phone. The coder and decoder is an important part of the baseband processor. This design will increase the load and power consumption of the baseband processor, thus reducing the standby time and increasing the cost of 5G terminal. At the same time, the operating equipment of operators cannot achieve the smooth upgrade from 4.5G to 5G, so it needs to invest money to buy equipment to rebuild the network, which may also delay the formal commercial time of 5G.

The final solution of 5G is most likely to be composed of multiple channel coding modes in different scenarios, and the equipment can flexibly choose the appropriate coding and decoding mode according to user requirements. The debate over 5G standards will continue before 3GPP organization officially launches the Rel-16 in 2020.

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