Interference Management for 5G Networks

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Abstract

The rapid evolvement of the fifth generation(5G) of wireless cellular networks will bring revolutionary upgrade to the existing cellular networks. 5G means higher data rate, greater end-to-end performance, vaster, more user coverage, lower latency, and more efficient transmission.

At the same time, 5G is also facing unprecedented challenges. How to cover more users and transmit more data while reducing interference between transmissions, and even approaching the limit of Shannon, is an important issue facing 5G and even next generation of cellular networks.

Sliding-window code modulation (SWCM)[2] algorithm can effectively overcome the rate loss of treating interference as noise(IAN) when the interference to noise ratio(INR) is large. This project will simulate SWCM in the case of LDPC, and compare it with IAN under the same scenario, in order to obtain the performance of SWCM transmitted by LDPC channel code.

1. Introduction

Due to the overlapping of frequency range and the interleaving of network coverage, mutual interference of signals in wireless transmission is unavoidable. The idea of treating interference as noise(IAN) treats these interference as Gaussian or discrete noise,utilizing the great decoding ability of channel code to tackle the interference. But as the interference to noise ratio(INR) increases, the rate loss of transmission will be unacceptable. This sliding-window superposition coding(SWSC) take advantage of block Markov coding, sliding-window decoding, superposition coding, and successive cancellation decoding, fully utilized the power of interference to improve the transmission efficiency.[2] simulated the SWCM in the case of Turbo code under LTE scenario, while this paper will apply LDPC channel code to simulate SWCM under 5G scenario. This paper proceeds three different simulation models. Besides the baseline point-to-point regular transmission model, there are point-to-point SWSC transmission model, two-uesr IAN model, and SWSC model interfered by the second user. Separately, the simulations are performed both in MATLAB and in Linux system with C++ which is closer to the actual transmission environment.

2. Model

2.1. Baseline Model

The baseline simulation is set to a simple point-to-point transmission. The original message will pass through a Gaussian channel after LDPC encoding and modulation then reach the user. To get the message, user need to demodulate and decode the received codeword. The process is shown in Figure 1.

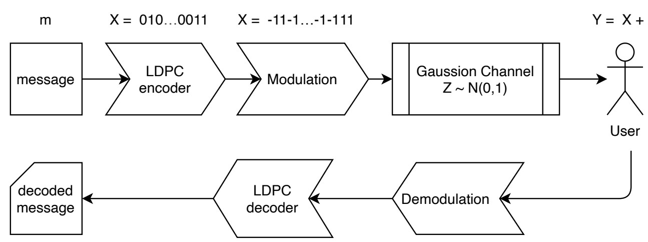

Figure 1: Baseline model

In the case of 5G, the baseline model has redundant operations to achieve a better performance. First, the original message will be proceeded Cyclic Redundancy Check(CRC) Calculation for error detection purpose. Then, the data will be separated into code block segments based on the CRC calculation, further at this step, CRC and filler bits will be attached to each code block segment. Next, the data will be encoded by LDPC channel code before ratematching. To obtain the specific rate of code we desired, some bits will be punctured out of data to achieve a higher rate. Finally, these code segments will be concatenated together according to the previous segmentation. So far, we finish the encoding part before we modulate the data. The decoding procedure are inverse operation as what we do for encoding.

Figure 2 shows the entire flow of the message both in encoding and decoding.

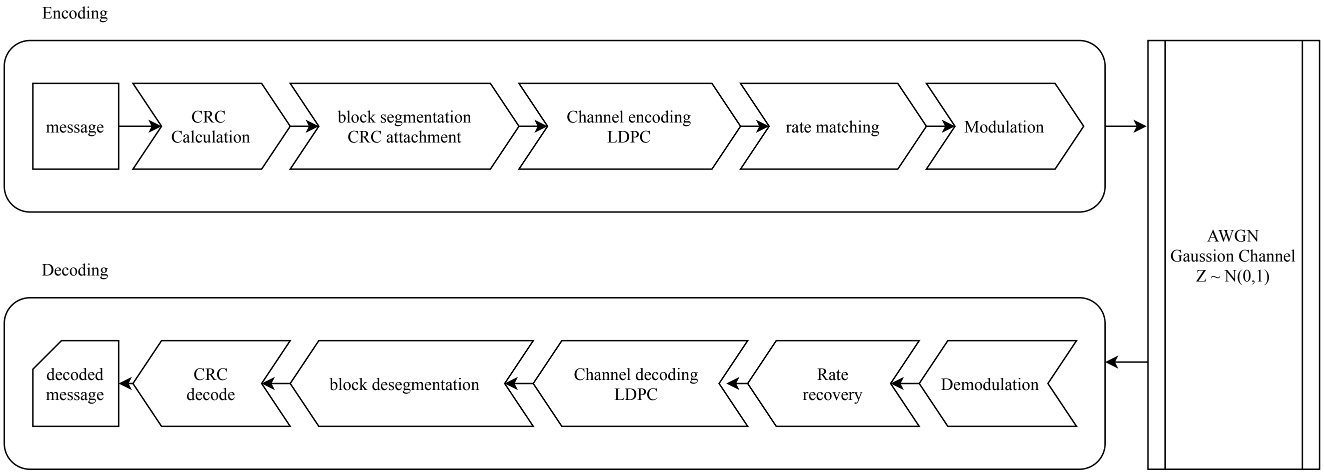

Figure 2: 5G Baseline model

2.2. Treating interference as noise (IAN)

IAN model simulates the transmission from two signals to two users through the same AWGN channel. Y is the sequence a user can receive. It composed of codeword X multipled by its gain and interference X' multipled by its gain and noise N which follows Gaussian. So in the case of two user, the expression between the received sequence Y and the transferred codeword X should be written as Equation 1. For our case, we only care about the influence from user2 to user1. Since the signal transmitted to user2 is treated as noise, the model can be simplified to what shown in the right in the Figure 3.

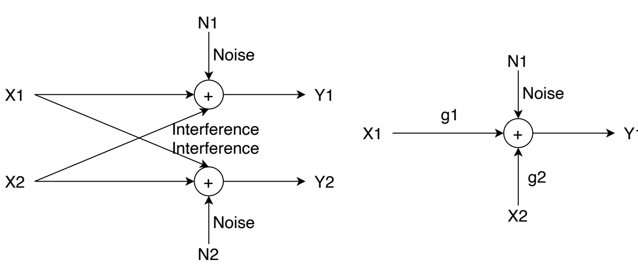

Figure 3: IAN model

Normally, the received the signal should be:

$$\begin{aligned} Y_1 &= g_{11}X_1 + g_{21}X_2 + N_1 \\ Y_2 &= g_{12}X_1 + g_{22}X_2 + N_2 \end{aligned} \tag{1}$$

where g_{ij} denotes the channel gain from transmitter i to user j. N_1 and N_2 are independent Gaussian noise follows $N(0, p)$. We suppose there is no fading and the gain of first signal should be 1. Thus, the expression of Y_1 should be simplified as:

$$Y_1 = X_1 + g_2X_2 + N \tag{2}$$

Besides, the relationship among INR, power of signal2: p, in the case of N follows $(0, P)$, should be:

$$g_2^2 = \frac{P_{X_2}}{P_{NOISE}} \tag{3}$$

The aim of this model is to explore the relationship between the power of interference and the transmission rate of signal. In other words, this model try to find the maximum rate can restrict the block error rate under 0.1 with different INR.

2.3. Point-to-Point SWSC

Figure 4 shows how SWSC scheme process the data. As shown, SWSC encodes multiple blocks from k bits symbols to $2n$ bits codewords, separates each codeword into two halves, and places each n bits to different layers. With 2 layers, SWSC proceeds superposition calculation to get $b+1$ blocks of n bits which is x, to be transmitted message through Gaussian channel.

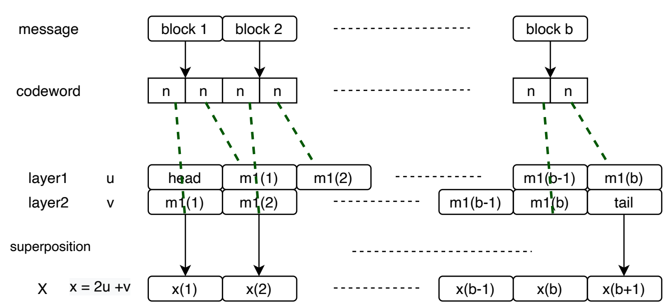

Figure 4: Point-to-Point SWSC model

Specifically, suppose that messages share kb bits symbols long message, SWSC scheme divides kb bits into b subblocks, and each subblock has k bits. Our encoder encodes each subblock, which contains k bits into $2n$ bits codeword. For the sake of superposition calculation, there would be two layers. The first n bits of the layer1 and the last n bits of the layer2 are set and known to users. Denotes the first n bits of codeword is $m1_{i1}$, and the second n bits is $m1_{i2}$. The scheme places $m1_{i1}$ into layer1, and $m1_{i2}$ into layer2. And, the most important, the two parts belonging to the same codeword will be staggered and placed in different layers,like shown in Figure 4.

Superpostion calculation is a mapping from $\{-1, +1\}$ to $\{+3, +1, -1, -3\}$.

Table 1: Superposition Mapping.

Superposition Mapping				
u	1	-1	1	-1
v	-1	1	1	-1
x	1	-1	3	-3
x = 2u + v				

As shown in the Table1, the mapping criteria is $x = 2u + v$, there are other different criteria, but this one is friendly to implementation. Here we can find that, the ratio of encoding is

$$R_{LDPC} = \frac{k}{2n} \tag{4}$$

But, the ratio of the SWSC scheme is

$$R_{SWSC} = \frac{kb}{n(b+1)} \tag{5}$$

If the number of blocks b is large enough, the rate of scheme is nearly twice of the rate of LDPC.

2.4. SWSC with interference

Like IAN model, there are two transmitters and two users. The difference is one transmits under SWSC scheme, the other sends the signal normally. Two signal will interfering each other when transmitting through the Gaussian channel.

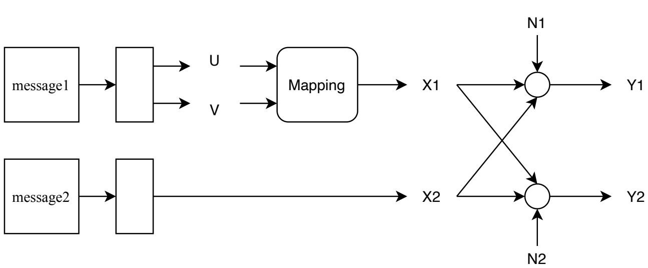

Figure 5: SWSC with interference

The expression of Y_1 and Y_2 is:

$$\begin{aligned} Y_1 &= 2U + V + g_2 X_2 + N_1 \\ Y_2 &= X_2 + g_1 X_1 + N_2 \end{aligned} \tag{6}$$

Unlike the former models whose decoding processes are straight forward, the decoding process of this model is more complex. Since we don't simply treating the interference as noise, we need to decode the interference signal X_2 at the same time, to obtain the accuracy of decoding of X_1, Figure 6 shows how we do this.

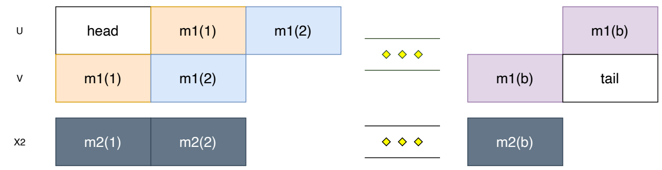

Figure 6: Decoding process

Take $m_1(1)$ and $m_2(1)$ for example. Based on expression 6:

$$y_1 = 2u + v + g_2 x_2 + noise$$

, specifically,

$$y_1 = 2 \cdot head + m_1(1) + m_2(1) + noise$$

. Since we head is the part we know, we first cancel out the head part. Then treat $m_1(1)$ as noise to decode x_2,

$$\bar{x_2} = m_2(1) + m_1(1)$$

After got x_2, it should be cancelled out from this subblock, thus we got cleaned n bits. Concatenated with next n bits, we can take advantage of LDPC code to decode the whole $2n$ bits. Next, we re-encode the decoded message m_1 to get the second n bits of it to clean the next subblock.

This decoding approach, for each subblock, we always decode u first, then decode x_2 and finally decode v. So we name this decoding order

$$u \rightarrow x_2 \rightarrow v$$

. Other then $u \rightarrow x_2 \rightarrow v$, the received codewords can be decode in $u \rightarrow v \rightarrow x_2$ and $x_2 \rightarrow u \rightarrow v$. When decoding an interfered codeword, the later one decoded, the higher rate the code can reach.

3. Simulation

3.1. MATLAB

For convenience, we first use MATLAB to simulate these models. The advanced 5G toolbox in MATLAB, which can easily implement the models mentioned in section 2, realize the functions that require complex code to achieve.

In order to explore the performance of SWSC at different rates. We simulate rates from 0.1 to 0.9 in steps of 0.1. Then we will simulate a smaller and more accurate interval according to the decoding situation. Of course, we have also tried to obtain a relatively reasonable simulation interval through theoretical calculations. But because theoretical calculations have optimized many situations, which are far from the results of actual simulations, if we want to reach the range of the calculation, our model needs to consider more and more complicated situations. Hope that it can be further optimized in future work.

For power of the signal, we set the power of X_1 and X_2 both to 10 dB. For the power of interference, we set it around the target signal power, from 8 to 12 dB.

3.2. C++ in Linux

In the actual signal transmission, the operating system is usually Linux, and for the other part like signal calculation, encoding, and decoding are often implemented by C language. Although MATLAB is more convenient, in order to be closer to reality, we once again use C++ to implement the simulation in the Linux environment. With the help of the powerful IT++ library, C++ can perform a series of operations and simulations on vectors in the communication field. But if it is for the 5G scenario, we need to write the code for each step by reading the 3GPP documents in detail to realize the simulation of SWSC in the 5G scenario.

For the time being, we can only simulate the basic model as Figure 1 shown, and the exploration of SWSC and IAN on this basis. The settings of other parameters are the same as MATLAB.

4. Result

4.1. Baseline

For baseline simulation, the performance of Low Density Parity Check (LDPC) code is powerful. The block number is 20, and the codeword length of it is 4096. After 1000 simulations, we got the average Block Error Rate as shown in Figure 7

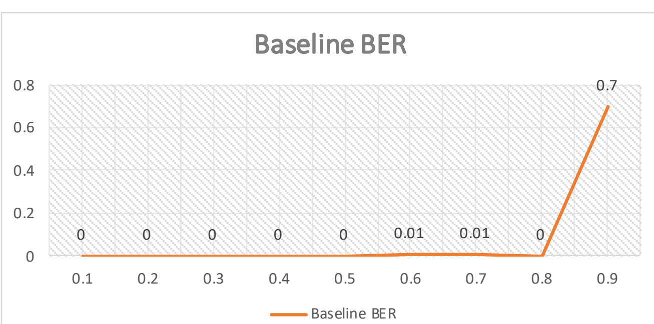

Figure 7: Baseline BER

4.2. Point-to-Point SWSC

For p2p SWSC model, as shown in Equation 5, the rate of the scheme is nearly double the rate of LDPC code. We can find that, even the rate reached 0.95, the BER still is 0.

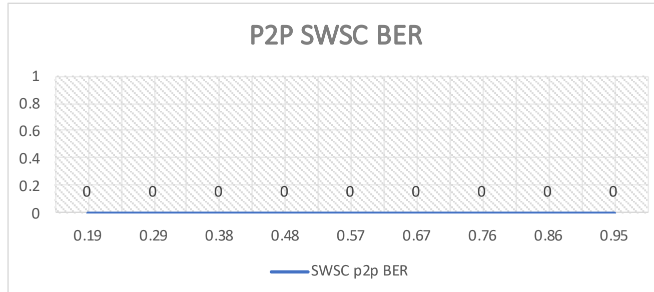

Figure 8: P2P SWSC BER

4.3. SWSC vs. IAN

Now, we simulate the 2-user situation, and plot the results together to compare. As shown in Figure 9, when INR increasing the rate of the scheme can reach with 0 BER is decreasing. This is not a reasonable result compare with [2].

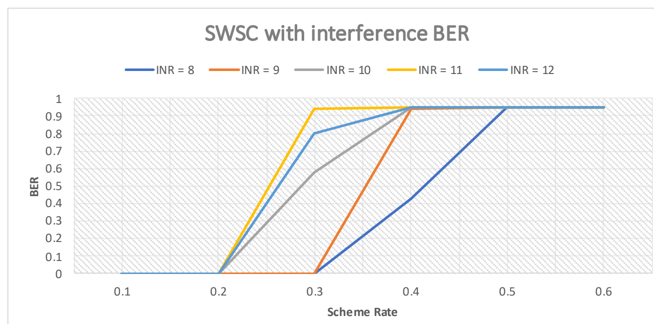

Figure 9: SWSC with interference BER

Since different decoding order will affect the result, we simulate SWSC with interference in other orders.

We can see, from the Figure 10,when decoding order is $x_2 \to u \to v$, the rate SWSC can reach is increasing as the INR grows. After simulating more, we can compare the performance of SWSC and IAN through different INR. With the increase of INR, the trend of maximum rate of IAN and SWSC can achieve is completely opposite. When INR exceeds 10dB, SWSC has obtained a higher rate than IAN. This means, when the power of interference is larger than the target signal, SWSC scheme has advantages.

4.4. C++ in Linux

Currently, simulations in C++ on Linux has not achieved good results. Except for rate 0.5, the appearance of LDPC

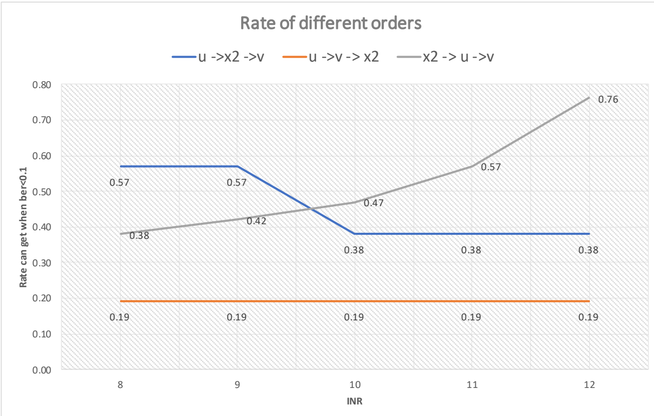

Figure 10: Rate cant get in different INR

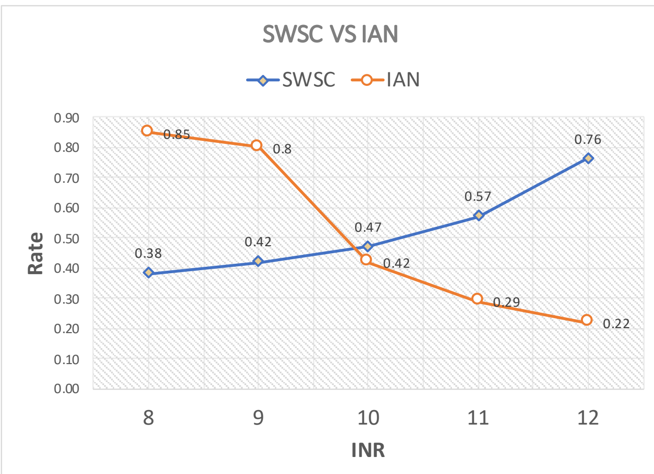

Figure 11: SWSC vs. IAN

codes with different rates in C++ is not stable, and it cannot be compared with the results obtained in MATLAB simulation.

5. Future Work

This project studied the mitigation degree of SWSC for interference under different INRs. Compared with IAN, SWSC has a great advantage when interference is large. When studying the performance of SWSC, we did not take into account the fading characteristics of the channel. At the same time, it has not simulated the situation of more than two users.

Since the simulation is mainly carried out in MATLAB, the realization of SWSC is largely based on the original functions of the 5G toolbox in MATLAB. The simulation in C++ requires more study and research on 3GPP[1]. To complete this project, we need to write the C++ programs to implement all the functions mentioned in Figure 2 and increase the number of users. At the same time, the fading feature of the channel should also be took into consideration, and a conclusion that is closer to reality will be obtained.

References

[1] 3GPP. NR; Multiplexing and channel coding. Technical Specification (TS) 38.212, 3rd Generation Partnership Project (3GPP), 10 2020. Version 16.3.0.

[2] K. T. Kim, S. Ahn, Y. Kim, J. Park, C. Chen, and Y. Kim. Interference management via sliding-window coded modulation for 5g cellular networks. *IEEE Communications Magazine*, 54(11):82–89, 2016.