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Application of SCMA Based on LoRaWAN Architecture

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Abstract. Low-power Wide-Area Network (LPWAN), as a wireless connection technology of the Internet of things, has met the requirements of power consumption of network providers and operators, network coverage and Internet of things equipment. As the main technology of LPWAN, Long Range (LoRa) has entered the stage of scale deployment. However, in the MAC protocol of LoRa, multiple end nodes send data to the gateway at the same time, which will cause serious collision problems. When data collision occurs, the gateway will no longer receive collision data, and the data packet needs to be retransmitted after a certain time. In order to solve this problem and improve the throughput of the whole system, this paper proposes to introduce the sparse code multiple access (SCMA) technology of 5G non-orthogonal multiple access (NOMA) into Long Range Wide Area Network (LoRaWAN) architecture from the perspective of code domain. The theory and simulation results show that SCMA can effectively solve the problem of data collision and improve the system throughput.

Keywords. LoRaWAN, SCMA, throughput

1. Introduction

Low-power Wide-Area Network (LPWAN), is a wireless connection technology suitable for machine communication and Internet of things equipment, which appeared in 2013. LPWAN has met the requirements of power consumption of network providers and operators, network coverage and Internet of things equipment. So it has become the connection option of most Internet of Things (IoT) devices. LPWAN technology has appeared in recent years. Among them, LoRa is a technology that works in unlicensed frequency bands [1].

LoRa is a modulation technology in the physical layer, which can be applied to different protocols, such as Long Range Wide Area Network (LoRaWAN) protocol, China LoRa Application Alliance (CLAA) network protocol, LoRa private network protocol [2], etc.

As a MAC protocol, LoRaWAN 's communication protocol and architecture are mainly designed for LoRa long-distance communication network. The official white paper of LoRa alliance, what is LoRaWAN, provides a schematic diagram of LoRaWAN architecture, as shown in Fig.1.

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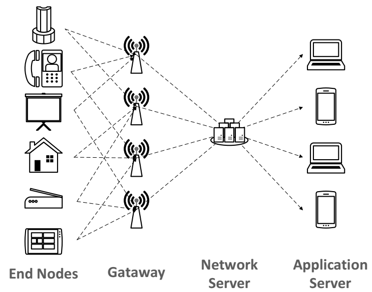

Fig. 1. LoRaWAN Architecture.

In Fig.1, LoRaWAN architecture includes four parts: end nodes, gateway, network server and application server. In LoRaWAN, multiple end nodes can send data information to the gateway at the same time, which often leads to serious collision problems. In addition, LoRa network mainly uses ALOHA protocol for simplicity and energy saving, which further aggravates data collision. When the data collides, the gateway no longer receives the collision data, and the data packet needs to be sent again after a certain time.

In wireless communication technology, the solutions to data collision mainly include conflict avoidance strategy and conflict resolution strategy. The conflict avoidance strategy first needs to detect the channel state, and then adjust the link scheduling according to the channel state. However, the key of this scheme is real-time monitoring and accurate synchronization, which will cause additional overhead. The conflict resolution strategy is to use the unique time-domain characteristics (such as fixed waveform shape) or the power difference between data packets in wireless communication technology to decode the data packets with collision, so as to improve the throughput and system efficiency [3] [4] [5]. However, the LoRa time-domain waveform shape is different, so this scheme is not suitable for LoRa collision packet decoding. In order to effectively solve the problem of data collision and improve the throughput of the end nodes of the whole system sending data to the gateway, this paper proposes to introduce the sparse code multiple access [7] (SCMA) technology of 5G non-orthogonal multiple access [6] (NOMA) into the node access location of LoRaWAN architecture from the perspective of code domain. SCMA is similar to the idea of Tanner graph in back propagation (BP) decoding of low density parity check code (LDPC) channel coding. With this idea, data collision can be effectively avoided when a single resource unit carries multiple user information. In addition, the reference of NOMA technology can effectively improve the throughput of end nodes accessing the network.

2. System Model

SCMA belongs to a multi-carrier non-orthogonal multiple access technology in the code domain. SCMA is based on code division multiple access (CDMA) [8] spread spectrum method low-density signatures (LDS). For a multi-user SCMA system with an overload factor of $\lambda = J/K$, K resource blocks in the system support access to J users ($J > K$), where each user occupies N resource blocks ($N < K$). For the SCMA system with $K = 4$ and $J = 6$, its structure is shown in Fig.2 by the factor graph. Each resource block is shared by $d_f = 3$ users, and each user is connected to $N = 2$ resource blocks.

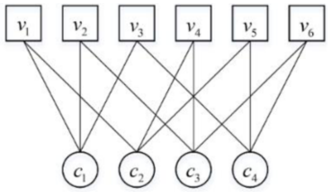

Fig. 2. Factor Graph.

In Fig. 2, each layer node represents a user, and each resource node represents a carrier resource block. It is expressed as $\mathbf{F} = (\mathbf{f}_1, \mathbf{f}_2, ..., \mathbf{f}_J)$ by a factor matrix and represents that the user J is connected to the resource block K when $\mathbf{f}_j(k) = 1$.

$$\mathbf{F} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \tag{1}$$

2.1. Sender

The transmitter first performs multidimensional modulation on the bit stream input by each user. Taking user J as an example, the modulation order is M_j and the input bit stream is $\mathbf{b}_j$. The *N*-dimensional complex codeword generated after multidimensional modulation is $\mathbf{z}_j = \left(x_1^{'}, ..., x_N^{'}\right)^{\mathrm{T}}$. The mapping from bits to N-dimensional codewords is as follows:

$$\mathbf{z}_j = g(\mathbf{b}_j) \tag{2}$$

Second paragraph. Then *K*-dimensional complex codeword $\mathbf{x}_j = (x_1, x_2, ..., x_K)^{\mathrm{T}}$ is generated through the mapping matrix, which contains N non-zero elements. The mapping matrix [9] of each user is:

$$diag(\mathbf{V}_j \mathbf{V}_j^{\mathrm{T}}) = \mathbf{f}_j \tag{3}$$

The user J has its specific codebook $\mathbf{C}_j$, which is generated by the rotation and expansion of the mother constellation [10] $\mathbf{A}$ corresponding to the modulation selected by the user J. The rotation matrix [11] and the mapping matrix of the user further make the codebook of each user different.

$$\mathbf{C}_j = \mathbf{V}_j \boldsymbol{\Delta}_j \mathbf{A} \tag{4}$$

Where $\mathbf{C}_j \in \mathrm{C}^K$ contains M_j symbols and $\mathbf{\Delta}_j$ is $N \times N$ dimensional rotation matrix.

2.2. Receiver

After the SCMA joint codeword passes through the channel, the received signal $\mathbf{y}$ can be expressed as:

$$\mathbf{y} = diag(\mathbf{h})\sum_{j=1}^{J}\mathbf{x}_j + \mathbf{n} = diag(\mathbf{h})\sum_{j=1}^{J}\mathbf{V}_j f_j(\mathbf{b}_j) + \mathbf{n} \quad (5)$$

Where $\mathbf{h} = (h_1, ..., h_K)^{\mathrm{T}}$ is the channel vector and $\mathbf{n} = (n_1, n_2, ..., n_K)^{\mathrm{T}}$ is the additive Gaussian white noise.

After receiving the signal, the receiver can use the MPA algorithm to decode. The flowchart of the decoding process is shown in Fig. 3.

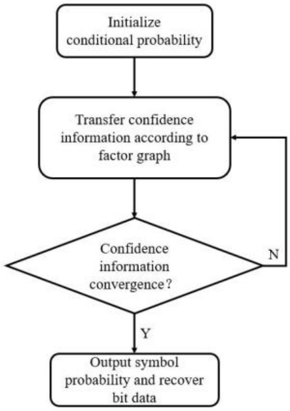

Fig. 3. Flowchart of MPA Algorithm.

The main idea of the receiver's MPA algorithm is to use the information observed by the receiver, that is, the information carried by the received signals of each resource node, to estimate the probability distribution of the symbols of the user node through multiple iterations.

3. Simulation Results

This section presents the simulation results and analysis to illustrate the bit error rate (BER) and throughput performance of the SCMA system. Channel coding is not added to the simulation SCMA system. The performance of bit error rate directly determines whether the problem of data collision can be effectively improved. In the simulation of BER performance, we consider the transmission in AWGN channel. The modulation methods included in the simulation are QPSK and 16QAM. The number of transmitted symbols is 10^7, and the average energy of each codeword is normalized to 1. The SCMA modulated signal is carried on OFDM subcarriers for transmission, including 4096 subcarriers. The sampling frequency is 60KHZ and the frame length is 20 (the number of OFDM symbols per frame is 20). The throughput is calculated according to the correct number of bits transmitted by the system and the transmission time statistics. Data frames whose BER does not meet the transmission quality requirements are directly discarded and are not included in the system throughput.

Fig. 4 shows the BER performance of SCMA for different modulation modes in AWGN channel. Fig. 5 shows the throughput performance of SCMA for different modulation modes in AWGN channel.

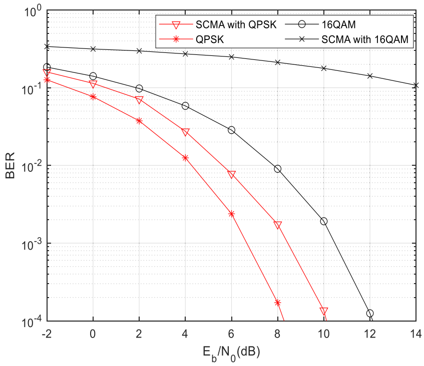

Fig. 4. BER performance in AWGN channel.

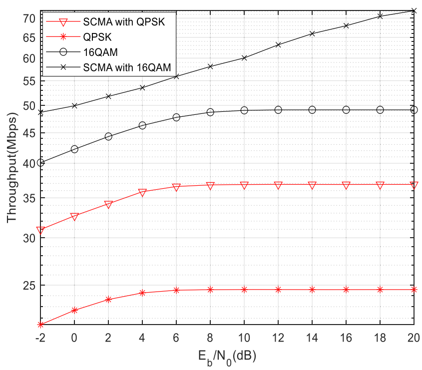

Fig. 5. Throughput performance in AWGN channel.

From Fig. 4 and Fig. 5, we can see that for QPSK, MPA iterative decoding is used to effectively solve the problem of data collision in a single resource unit. SCMA greatly improves the throughput of the whole system at the cost of losing BER performance close to 2dB. The improvement in throughput performance tends to be saturated after E_b / N_0 reaches 6dB, which is about 148%. For 16QAM, the BER performance loss of SCMA is large. But the BER performance is getting better with the gradual increase of signal-to-noise ratio (SNR), which is also confirmed in the throughput curve. Hence when the channel is ideal or the SNR is high, SCMA can also solve the data collision problem. From the throughput performance curve of 16QAM, we can see that the throughput of SCMA system whose gain is still increasing rapidly with the increase of E_b / N_0 can be improved even when the BER is poor. When E_b / N_0 is 20dB, the throughput gain of SCMA reaches 146%.

4. Conclusion

From the perspective of code domain, this paper proposes to introduce SCMA technology into the end nodes access location of LoRaWAN architecture, which effectively solves the problem of LoRaWAN data collision and improves the overall system throughput. In the process of codebook design, we use the codebook energy normalization to meet the low power consumption requirements of LPWAN.

The simulation results show that SCMA system improves the throughput of the transmission system at the expense of a certain BER performance. With the increase of E_b / N_0 , the negative gain of BER of SCMA decreases and the system throughput tends to be saturated when the E_b / N_0 reaches a certain critical value. According to Shannon's theorem and the simulation results in this paper, it is proved that when the throughput curve is saturated, its gain is infinitely close to the overload factor λ of SCMA system.

However, there are also some problems in this technology. As mentioned above, the design of λ directly affects the overall system throughput improvement. If λ is too large, the BER performance loss will increase and the complexity of the whole system will increase exponentially. Hence the increase of throughput results in the decrease of transmission bit quality. How to choose between long-distance, high throughput and high-quality transmission is a problem that can be studied at present. For example, the better modulation mode and multiple access can be selected according to different channel parameters and SNR. In addition, whether LoRa technology can use higher-order modulation determines whether SCMA has advantages over previous ones. Considering the current LoRa modulation, SCMA is mainly used in the direction of future LoRa using QPSK modulation. Compared the SCMA with 16QAM, the SCMA with QPSK is a technical reference that can be considered at present to both solve collisions and effectively improve throughput. To sum up, SCMA focuses on improving the throughput of the end nodes access LoRaWAN. The use of SCMA in the LoRaWAN structure is still at the exploratory stage, which is a technology reference that LoRa is expected to use in the future.

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