T-SCMA: Time Domain Sparse Code Multiple Access for Narrow Band Internet of Things (NB-IoT) (Invited Paper)

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Abstract. Nowadays the development of internet of things (IoT) has become the next major growth point of wireless communication. And narrow band has become a new trend in the development of IoT. Achieving massive connectivity and ever-increasing network capacity has become an important subject of our research. We find that sparse code multiple access (SCMA), a type of non-orthogonal multiple access, is supposed to meet these needs, but it can hardly apply to NB-IoT because narrow band does not have the ability of spread spectrum. On this basis, we introduce SCMA into time domain, named T-SCMA, for NB-IoT. By multiplexing SCMA in the time domain and defining a MAC frame structure, we can significantly improve both connectivity and network capacity, ultimately obtain a much higher throughput property gain over time division multiple address (TDMA).

Keywords: Internet of Things · Sparse code multiple access
NB-IoT · Connectivity · Network capacity

1 Introduction

Internet of things (IoT) has become a vital technology in our life. Nowadays both the fifth generation wireless network (5G) and wireless local area networks (WLAN) have become important driving forces at the development of IoT [1, 2]. But we have to face challenges that IoT has massive connectivity demands especially in narrow band.

At present, narrow band has become a new trend in the development of IoT. Characteristics of wide coverage, massive connectivity, low energy consumption etc. make NB-IoT widely used. However, orthogonal multiple access methods are difficult to meet the requirements of both the massive connectivity and the increasing network capacity.

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Sparse code multiple access (SCMA) is a non-orthogonal multiple access (NOMA) technology. Based on the characteristics of non-orthogonal multiplexing in the frequency domain, sparsity, overloading, SCMA aims to solve the massive connectivity and increasing network capacity problems of 5G [3]. But it can hardly apply to NB-IoT because narrow band does not have the ability of spread spectrum.

As a very promising application in the future, NB-IoT attracts keen interests of many scholars recently. A new NOMA strategy, named multi-user shared access (MUSA), applying to IoT, has proposed [4] which utilizes code domain non-orthogonality to implement massive connectivity in grant-free mode. Ding et al. [5] introduce a multiple-input multiple-output NOMA (MIMO-NOMA) technique for small packet transmission. It works co-efficiently, for that one user's quality of service (QoS) requirements are satisfied dynamically according to the channel condition and power allocation, while the demands of the other user are satisfied fully. In addition, the authors in [6] present a frequency-hopping based on SCMA (FH-SCMA) project to enhance the connectivity and interference alleviation. Summarizing current research about NOMA schemes apply to IoT, we can obtain that almost all of them do not consider using SCMA scheme in NB-IoT.

In order to make SCMA in motion in NB-IoT and satisfy the massive connectivity and increasing network capacity, this paper proposes an idea of time domain SCMA (T-SCMA) scheme, it introduces SCMA to time domain for the first time and then combines T-SCMA with NB-IoT together. By being multiplexed into time domain and making a MAC frame structure designed, T-SCMA can significantly improve both the connectivity and network capacity. Furthermore, masses of simulation results manifest that T-SCMA can effectively solve both the two challenges of NB-IoT.

The main contribution of this paper is summarized as following.

- This paper introduces SCMA into time domain for the first time and then combines T-SCMA with NB-IoT together to hoist capacity dramatically.
- Masses of simulation results prove that throughput performance of T-SCMA scheme is improved significantly in contrast to the traditional orthogonal way, for example, time division multiple address (TDMA) in our paper in the case that the packet error rate (PER) is almost the same.

The rest of this paper is organized as follows. The system model of this paper is described in Sect. 2. In Sect. 3, we introduce the principle of T-SCMA scheme and present a MAC frame structure. Then we record the simulation process in IV. Lastly, we summarize this paper in Sect. 5.

2 System Model

2.1 Network Scenario

As we all know, NB-IoT has many advantages such as massive connectivity, wide coverage, high reliability, low power consumption, low latency, etc. It is applicable to intelligent products, wisdom city and many other fields. And it is also expected to emerge a large number of innovative solutions or businesses.

However, it is a huge challenge of satisfying the massive connectivity and increasing network capacity of NB-IoT nowadays. It is precisely what our article wants to solve.

2.2 Resources Scenario

For uplink, NB-IoT defines two classes of physical channels. One is narrow band physics uplink sharing channel (NPUSCH) and the other is narrow band physics random access channel (NPRACH). In addition to NPRACH, all the data is transferred through NPUSCH.

NPUSCH is used for transferring uplink data and control information using single frequency or multiple frequencies. It defines two types of formats. For one type, NPRACH supports single frequency transmission when carrier space is 3.75 kHz, and supports single frequency or multiple frequency transmission when carrier space is 15 kHz. For the other, each resource block (RB) occupies only one frequency to transfer data.

Obviously, narrow band limits the connectivity and increasing network capacity to some degree. Increasing further those performances is exactly what to be solved in this paper.

3 T-SCMA Scheme

3.1 Basic Ideas

The basic ideas of T-SCMA system has the following characteristics as we can see in Fig. 1.

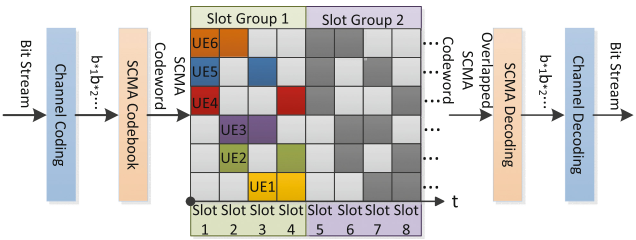

Fig. 1. Illustration of T-SCMA system

- Non-orthogonal multiplexing in the time domain. Codewords between different users are non-orthogonally overlapped on the same RBs, which are made up of several time slots. Compared with the traditional orthogonal method TDMA, T-SCMA can accommodate more users on the same number of RBs. Thus it can effectively improve connectivity and network capacity on narrow band.

– Overloading. Codewords of multiple users are overlapped in each RB. Obviously, overloading means the number of users exceeds the number of time slots on each RB. It is also the biggest characteristic of T-SCMA. Assuming that on each RB, J represents the number of users and K represents the number of time slots, then we can define the overloading factor as:

$$OF = \frac{J}{K} \tag{1}$$

– Sparsity. As given in Fig. 1, data is spread from single time slot to four time slots, every six users shares the four time slots on each RB. Every user's data occupies all the four time slots on each RB while only two time slots are allocated with non-zero elements. It is noteworthy that this feature helps to reduce the complexity of receiver.

3.2 Encoder

For the sender, the SCMA encoder directly maps the bit stream after channel coding to complex domain multi-dimensional SCMA codewords, which is defined by the SCMA codebook. Then the codewords are mapped to time domain and become T-SCMA codewords.

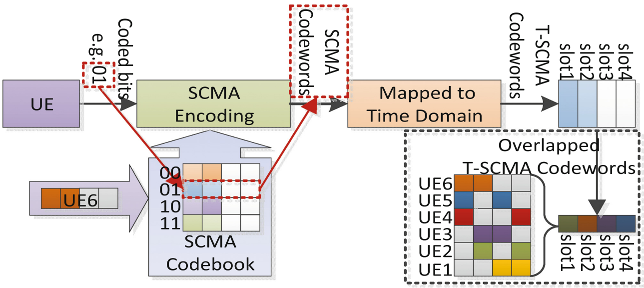

Fig. 2. Illustration of T-SCMA encoder

Codewords of different users are non-orthogonally overlapped on each RB by means of sparse spread spectrum. As shown in Fig. 2, per two bits after channel coding is corresponded to a four-dimension codeword, which occupies the whole four time slots on each RB, and we get the following formula:

$$Ts = 2^B \tag{2}$$

Here, Ts represents the number of time slots on each RB and B represents the number of dimensions corresponding to a codeword.

3.3 Decoder

SCMA decoder will carry out joint multi-user detection algorithm iteratively to decode overlapped SCMA codewords. This algorithm takes advantage of the low complexity of SCMA and increases the robustness of SCMA decoder. And it also supports higher overloading factor.

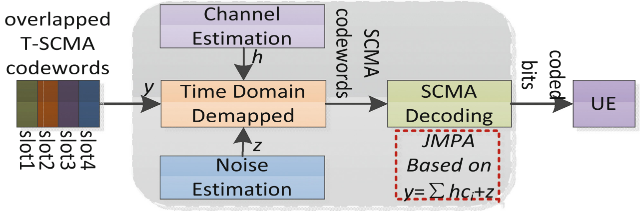

Fig. 3. Illustration of T-SCMA decoder

As shown in Fig. 3, y represents the received signal, h is the channel coefficient, c_i represents the SCMA codewords of each user and z represents the additive white gaussian noise (AWGN), then the received signal can be expressed as the following formula:

$$y = \sum h * c_i + z \tag{3}$$

Thus we can obtain c_i from the above formula and complete restoring the bit stream by channel decoder.

3.4 MAC Frame Structure

In order to achieve the goal of this paper, we need to define a MAC frame structure as shown in Fig. 4.

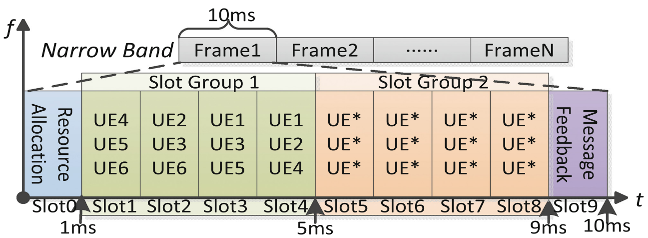

Fig. 4. Illustration of MAC frame structure

Under the background of NB-IoT, each MAC frame is divided into ten time slots, which can be divided into four parts, zeroth time slot, first slot group, second slot group and the last time slot respectively according to different functions.

The zeroth time slot works for resource allocation. Then follows two slot groups, each consists of four consecutive slots, as a T-SCMA RB. The two slot groups will access users and transfer data according to the T-SCMA transmission mode. The ninth time slot performs information feedback function.

4 Performance Evaluation

4.1 Simulation Configuration

Based on the MAC frame structure designed in this paper and other typical configurations in the standards and the literatures, we establish the simulation parameters as given in Table 1.

Table 1. Simulation parameters

Parameters	Value
Length of frame structure	10 Solts
Number of time slot group	2
Number of user group	2
Length of per time slot group	4 Solts
System bandwidth	1 MHz
Length of bit sequence on per slot	1000 Bits
Length of per time slot	1 ms
Channel model	AWGN channel without noise
Channel coding	LDPC with 1/2 coding rate
Transmission mode	Granted/Grant-free

4.2 Performance Comparison

Granted Mode. As we can see from Fig. 5, PER performance is similar for the two schemes. When SNR < 10, PER of T-SCMA scheme is slightly better than that of TDMA scheme because T-SCMA receiver can recover data from several time slots. When SNR > 11, PER of T-SCMA scheme is less than e^{-4}.

From Fig. 6 we can see that the throughput performance of T-SCMA scheme is about 1.5 times more than that of TDMA scheme. At the beginning, throughput of T-SCMA scheme or TDMA scheme increases monotonically with the growth of SNR. Then throughput stays almost constant when SNR > 9 as network capacity becomes gradually saturated.

Grant-Free Mode. By fixing signal noise ratio (SNR) to 11, we evaluate the throughput gain varying with the sending rate of users. Figure 7 shows the result. At first, throughput of both two schemes increases with the growth of sending probability. Then throughput based on TDMA scheme gradually comes to its

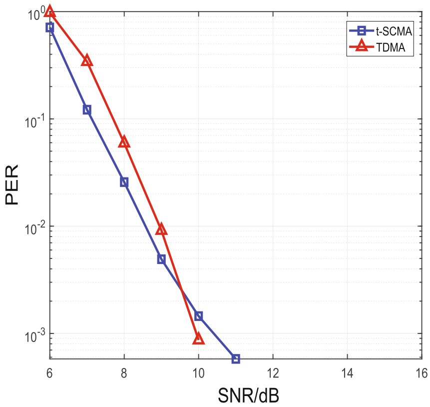

Fig. 5. PER versus SNR on granted mode

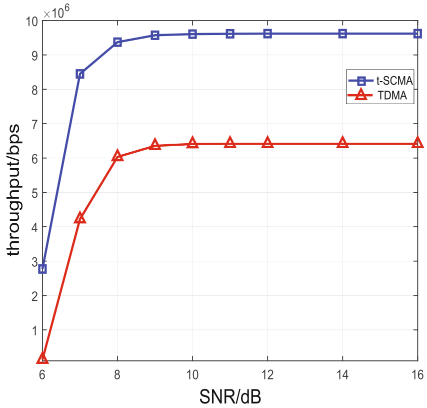

Fig. 6. Throughput versus SNR on granted mode

highest point as network capacity reaches saturation point and later drops off as signal collisions between users become seriously, causing unsuccessful data transmission. However, throughput of T-SCMA scheme sustains growth due to the superiority of overlapping.

As we can see from Fig. 8, PER of T-SCMA scheme is apparently higher than that of TDMA scheme because the poor performance of joint message passing algorithm (JMPA) than orthogonal decoding algorithms in this mode.

After fixing the sending probability to $\frac{2}{3}$, we evaluate the throughput gain varying with SNR. Figure 9 illustrates the result. At beginning, PER of T-SCMA scheme is much higher than that of TDMA scheme so throughput of

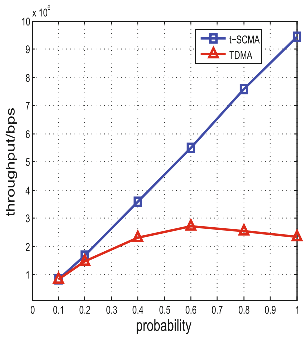

Fig. 7. Throughput versus probability on grant-free mode

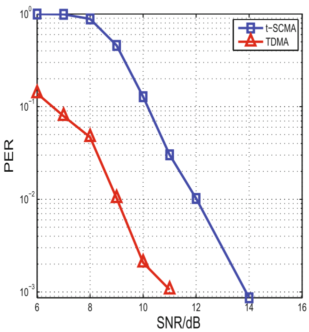

Fig. 8. PER versus SNR on grant-free mode

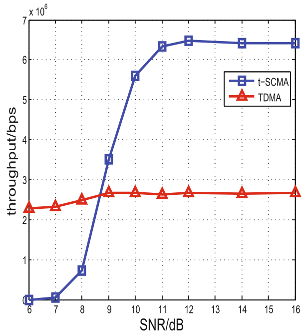

Fig. 9. Throughput versus SNR on grant-free mode

T-SCMA scheme is far lower than that of TDMA scheme. When SNR increases, with the PER of both two schemes gradually decrease, the throughput of them increases as well. As different users of TDMA scheme may have collided with each other when accessing on the slot groups, which does not happen with T-SCMA scheme, throughput of T-SCMA scheme grows faster and gradually exceeds that of TDMA scheme. Then their throughput stay constant when network capacity is saturated.

5 Conclusions

In order to satisfy massive connectivity and ever-increasing network capacity of NB-IoT, we raise a method named T-SCMA which introduces SCMA to time domain for the first time and combine T-SCMA with NB-IoT. By multiplexing SCMA into time domain and defining a MAC frame structure, we can significantly improve connectivity and network capacity of NB-IoT. And masses of simulation results manifest that throughput performance of T-SCMA scheme increases very much in comparison to TDMA. So we can say that T-SCMA can effectively solve the above challenges of NB-IoT. In the future, other schemes of non-orthogonal multiple access applying to NB-IoT will be researched.

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