Sparse Code Multiple Access

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I. SYNONYMS

Sparse spreading multiple access

II. DEFINITION

Sparse code multiple access (SCMA) is a non-orthogonal multiple access technique based on codebooks of sparse structure.

III. HISTORICAL BACKGROUND

Future 5G wireless networks are expected to support massive connectivity, higher throughput, lower latency and lower controlling signal overhead. Compared with the conventional orthogonal multiple access techniques such as *code division multiple access(CDMA)* and *orthogonal frequency division multiple access (OFDMA)* utilized in current networks, *non-orthogonal multiple access (NOMA)*, which has the advantage of higher resource utilization, is more promising in 5G network.

Motivated by the design of CDMA chip sequences, the idea of sparse spreading, called *Low Density Signature (LDS)*, was first proposed by Reza Hoshyar [1]. LDS is a special case of multi-carrier CDMA with a few non-zero elements in a long spreading signature. This sparsity characteristic can reduce the complexity of the multi-user detection called *Message Passing Algorithm (MPA)* [2], [3]. In an LDS combined with Orthogonal Frequency Division Multiplexing (OFDM) system, which is called LDS-OFDM [4], the capacity is proved to have a superior performance than OFDMA.

To meet the requirements of 5G, *Sparse Code Multiple Access (SCMA)* [5], a new non-orthogonal codebook-based multiple access method, is proposed by Huawei in 2013. SCMA can be seen as a generalization of LDS. In LDS, incoming bits are mapped to a QAM symbol, and the repetitions of the QAM symbol are transmitted through the subcarriers according to the designed signature. But in SCMA, incoming bits are directly mapped to multi-dimensional complex codewords selected from predefined codebook [6]. Instead of simple repetition of QAM symbol in LDS, SCMA provides significant shaping gain with the multi-dimensional constellation design [7]. Similar to LDS, only a small number of dimensions are used to transmit data, therefore the codewords of SCMA are sparse. In the SCMA codebook, the non-zero dimensions are corresponding to the subcarriers in use. Besides, SCMA can also utilize iterative MPA detection with near optimal performance in the MAP sense.

The current researches of SCMA are mainly focused on *capacity analysis*, *codebook design*, *low-complexity decoding*, *resource allocation*, *blind detection* and so on. In *capacity analysis* area, researchers compare the capacity of SCMA system with the LDS system [8], and analyse the capacity of downlink massive MIMO MU-SCMA system [9]. In *codebook design* area, the method of *Shuffling* [6] and the method based on star-QAM [10] are proposed to decrease the *Bit Error Rate(BER)*. In *low-complexity decoding* area, some algorithms like PM [11], Quasi-ML [12], List Sphere Decoding [13] are proposed to reduce the decoding complexity. In *resource allocation* area, the SCMA downlink power allocation to maximize weighted sum-rate has been studied in [14] and uplink resource allocation based on a special structure codebook studied in [15]. In *blind detection* area, contention based blind detection is proposed to support Grant-free transmission [16], [17].

IV. FOUNDATIONS

SCMA system mainly consists of 2 parts: SCMA encoder and SCMA decoder.

SCMA encoder can be defined as a mapping from $\log_2(M)$ bits to a K-dimensional codeword of size M selected from a predefined codebook. K dimensions are corresponding to K different orthogonal tones, such as OFDMA subcarriers. The K-dimensional codeword is a vector with only $N < K$ non-zero entries. Users can't transmit data through the subcarriers represented by the other $N - K$ zero entries. Theoretically, each user can be allocated to more than one codebook, and each codebook can be utilized by more than one user generally.

Fig. 1 shows an example of an SCMA encoder, with 6 layered codebooks (*variable nodes*) and 4 subcarriers (*function nodes*). Each row denotes a dimension, and each column means a 4-dimensional codeword. In each codebook, the constellation size is 4, which means there are 4 different codewords can be chosen. The white entries denote the zero elements and the colored entries denote the non-zero elements in the codebooks. For example, in Codebook 1, the entries in the first row is colored and the entries in the third row is white, which means the first dimension is non-zero and third dimension is zero. In each codebook, there are 2 non-zero dimensions with colored lattice. In an AWGN channel, the signal received in the base station is the superposition of the codewords selected from the codebooks.

Codebook design is the most important part in SCMA encoder. The target is to design a multi-dimensional lattice constellation with dimensional dependency and power variation of the constellation while maintaining large minimum Euclidean distance. Generally, there are 3 stages to design SCMA code [5], [6]: 1) *Mapping Matrix* determines the number of layers interfering at each subcarrier, which represents the complexity
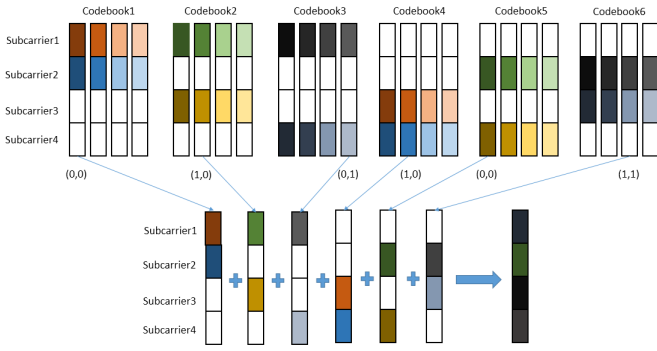
Fig. 1: SCMA encoder.

of MPA detection. For example, Fig. 1 can be considered as a *mapping matrix*, which means that each layer will be interfered by two other layers. 2) *Constellation Points and Multi-dimensional Mother Constellation* design. First, design a base constellation with a maximized minimum Euclidean distance. Second, a unitary rotation, which might be designed to maximize the minimum product distance of the constellation, can be applied on the base constellation to control the dimensional dependency and power variation. Third, build the complex constellation using the rotated base constellation by shuffling. Last, utilize the rotation to minimize the projection points. 3) *Constellation Function Operator*, which includes several operators like *complex conjugate*, *phase rotation* and *dimensional permutation*, aims to design distinct codebooks for the collision layers.

Currently, SCMA decoder usually utilizes MPA detection or improved version of MPA detection. There are three steps of the conventional MPA detection: 1) *Initialize the conditional probability*. For the SCMA system in Fig. 1, in each resource node, there are 3 layers collided and each layer has 4 possibilities of constellation points. Then there are $4 * 4 * 4$ combinations of transmitted signals which determine the number of conditional probabilities. 2) *Iterative message passing through the variable nodes and function nodes*. Function node passes the updated message to its neighbouring variable nodes, then the variable node passes the updated message to its neighbouring function node, which constitutes an iteration. 3) *Log-Likelihood-Rate(LLR) calculation*. After several iterations, LLR output can be calculated by the probability guess of codeword at each layer.

V. Key Applications

Sparse code multiple access technique will be utilized in future 5G networks, which will be applied mainly in 3 scenarios: 1) *Enhanced mobile broadband (eMBB)*, for example, Ultra HD video transmission and High Speed Mobile Broadband Wireless Communication. 2) *Ultra-reliable and low latency communications (uRLLC)*, for example, unmaned and automatic driving. 3) *massive machine type of communication (mMTC)*, for example, Internet of things (IoT).

VI. Cross-references

code-division multiple access
frequency-division multiple access
5G Communication Technology
Internet of Things
Technologies Enabling The Internet of Vehicles
Non-Orthogonal Multiple Access (NOMA) for Future Radio Access

VII. Recommended Reading

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