SCMA

A Modern Approach to Wireless Communication

Struminsky Kirill

Contents

Contents

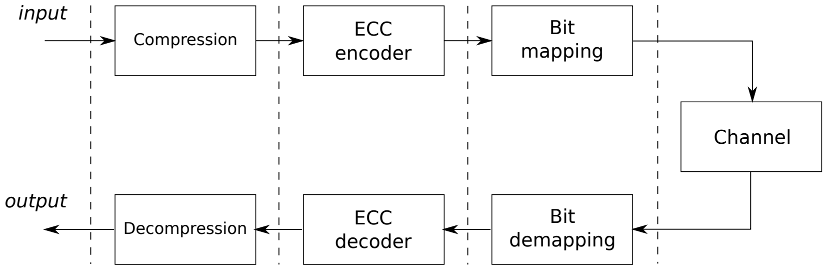
Contents

- General remarks on wireless digital communication
- A few examples of multiple access channel designs
- Sparse Code Multiple Access system model and description

Contents

- General remarks on wireless digital communication
- A few examples of multiple access channel designs
- Sparse Code Multiple Access system model and description
- Sparse Code Multiple Ace's codebook design

A typical digital communication scheme

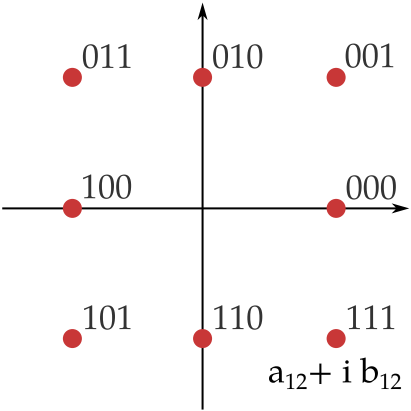


Methods of compression hugely rely on type of input data.
ECC coding add redundant bits, used to deal with errors in transmitted messages.
SCMA deals with bit mapping problem.

Transmitting waveforms

Wireless communication systems allow us to transmit bit sequences using *arbitrary* complex vectors.

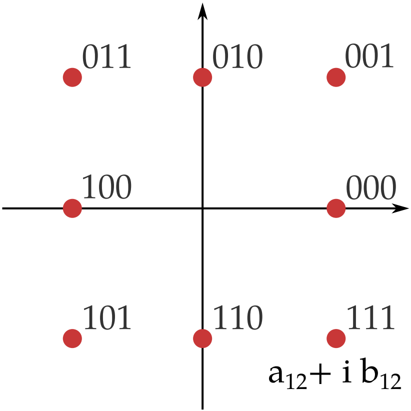
- Divide bit sequence into triplets.



Transmitting waveforms

Wireless communication systems allow us to transmit bit sequences using *arbitrary* complex vectors.

- Divide bit sequence into triplets.
- Map bit triplets into an array of complex numbers $a_k + ib_k$ (QAM-symbol).

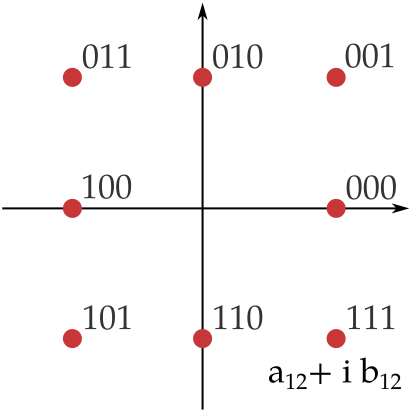


Transmitting waveforms

Wireless communication systems allow us to transmit bit sequences using *arbitrary* complex vectors.

- Divide bit sequence into triplets.
- Map bit triplets into an array of complex numbers $a_k + ib_k$ (QAM-symbol).
- Send the waveform

$$\sum_k a_k \cos(k\omega t) + b_k \sin(k\omega t).$$



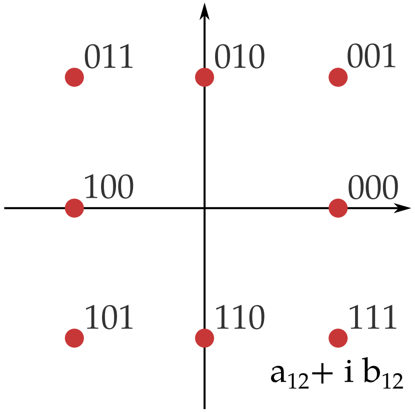
Transmitting waveforms

Wireless communication systems allow us to transmit bit sequences using *arbitrary* complex vectors.

- Divide bit sequence into triplets.
- Map bit triplets into an array of complex numbers $a_k + ib_k$ (QAM-symbol).
- Send the waveform

$$\sum_k a_k \cos(k\omega t) + b_k \sin(k\omega t).$$

- Recover $(\mathbf{a}, \mathbf{b})$ using Fourier expansion of the received signal.



Bad news

- Everybody is exploiting the same channel:

$$\mathbf{y} = \sum_j \mathbf{x_j}.$$

Bad news

- Everybody is exploiting the same channel:

$$\mathbf{y} = \sum_j \mathbf{x_j}.$$

- Signals fade:

$$\mathbf{y} = \sum_j diag(\mathbf{h_j})\mathbf{x_j}.$$

Bad news

- Everybody is exploiting the same channel:

$$\mathbf{y} = \sum_j \mathbf{x_j}.$$

- Signals fade:

$$\mathbf{y} = \sum_j diag(\mathbf{h_j})\mathbf{x_j}.$$

- And there is some noise:

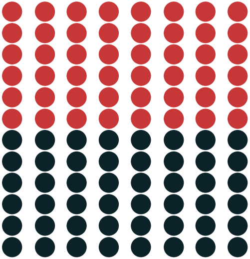
$$\mathbf{y} = \sum_j diag(\mathbf{h_j})\mathbf{x_j} + \mathbf{n}$$

where $\mathbf{n}$ is a vector of i.i.d. unbiased Gaussian variables.

Space and time sharing

Let's get forget about fading and ambient noise for a while. How can one design channels with multiple access?

Alice and Bob use different frequencies for broadcasting.

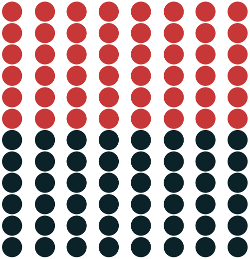


OFDMA

Space and time sharing

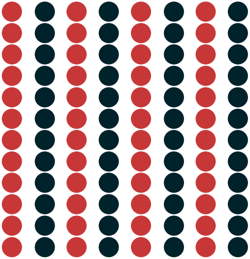
Let's get forget about fading and ambient noise for a while. How can one design channels with multiple access?

Alice and Bob use different frequencies for broadcasting.



OFDMA

In this case they send messages at different periods of time.



TDMA

Code division

Alice and Bob choose two orthogonal vectors $\mathbf{u}$ and $\mathbf{v}$ that consist of ± 1. Say,

$$\mathbf{u} = (1, 1), \mathbf{v} = (1, -1)$$

These vectors are called spreading sequences.
Alice builds an analog representation $\mathbf{a} = (1, -1, 1)$ of her message and sends $\mathbf{a} \otimes \mathbf{u}$ over the channel. Correspondingly, for $\mathbf{b} = (-1, 1, 1)$ Bob sends $\mathbf{b} \otimes \mathbf{v}$:

$$\mathbf{x_A} = \mathbf{a} \otimes \mathbf{u} = (1, 1, -1, -1, 1, 1)$$
$$\mathbf{x_B} = \mathbf{b} \otimes \mathbf{v} = (-1, 1, 1, -1, 1, -1).$$

The receiver receives the vector $\mathbf{y} = \mathbf{x_A} + \mathbf{x_B} = (0, 2, 0, -2, 2, 0)$.
He also knows the vectors $\mathbf{u}$ and $\mathbf{v}$. In order to find out a_i he may calculate $(a_i\mathbf{u} + b_i\mathbf{v}, \mathbf{u})/(\mathbf{u}, \mathbf{u})$:

$$a_1 = (0, 2)(1, 1)^T/2 = 1.$$

Code division

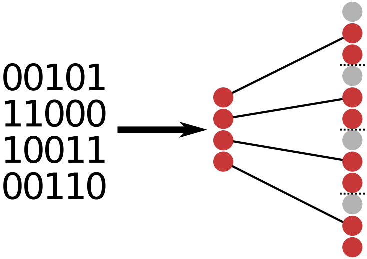
Effectively, Code Division Multiple Access scheme uses spreading sequences to broadcast one QAM symbol over several different tones.

It allows several users to share a band of frequencies.

Low Density Signature (LDS) is a variation of CDMA with low density spreading sequences, i.e. most elements of each spreading sequence are equal to zero. It allows to take advantage of the low complexity message passing algorithm with ML-like performance.

LDS illustration

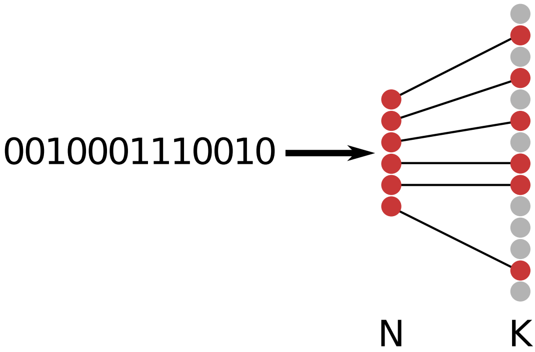
An LDS encoder spreads a message over different tones using sparse spreading sequence *s*.



s = (0, 1, -1)

Sparse Code Multiple Access: encoding

For each user SCMA defines a unique mapping from $log_2(M)$-bit sequences a subset in $\mathbb{C}^K$. Such subset is called **codebook**.
The K-dimensional complex codewords of the codebook are sparse vectors with $N < K$ non-zero entries. All the codewords in the codebook contain 0 in the same $K - N$ positions.



Sparse Code Multiple Access: encoding

In fact, this mapping can be regarded as a composition of mapping bits into N-dimensional lattice g_j and addition of $K - N$ zero entries to the vector V_j. The latter linear tranfomation also can be represented by N-dimensional vector $\mathbf{f_j}$ indicating the positions of nonzero entries of the codebook.
So each user generates message

$$\mathbf{x_j} = V_j g_j(\mathbf{b_j}).$$

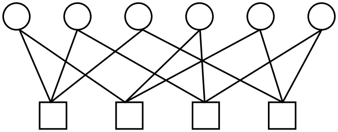
The received signal can be expressed as

$$\mathbf{y} = \sum_{j=1}^{J} diag(\mathbf{h_j})\mathbf{x_j} + \mathbf{n}.$$

Sparse Code Multiple Access: decoding

The structure of SCMA code can be represented by a factor graph. Let's consider an example:

$$N = 2$$
$$K = 4$$
$$J = 6$$
$$F = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$



SCMA vs. LDS

SCMA may be regarded as a generalization of LDS.

- LDS generates messages using spreading sequences. SCMA scheme fixes a mapping from bits to points in multidimensional constellation.

SCMA vs. LDS

SCMA may be regarded as a generalization of LDS.

- LDS generates messages using spreading sequences. SCMA scheme fixes a mapping from bits to points in multidimensional constellation.
- Codewords are sparse in both cases. LDS uses sparse spreading sequences, SCMA generates sparse codewords.

SCMA vs. LDS

SCMA may be regarded as a generalization of LDS.

- LDS generates messages using spreading sequences. SCMA scheme fixes a mapping from bits to points in multidimensional constellation.
- Codewords are sparse in both cases. LDS uses sparse spreading sequences, SCMA generates sparse codewords.
- SCMA uses codeword-MPA, LDS uses symbol-based MPA.

Designing an SCMA code

The design of SCMA code is defined by

1. Number of users J
2. Dimensionality of constellation point N
3. Codeword length K
4. Contellations $\mathcal{G} = [g_j]_{j=1}^{J}$
5. Sparse mappings $\mathcal{V} = [V_j]_{j=1}^{J}$

Designing an SCMA code

The design of SCMA code is defined by

1. Number of users J
2. Dimensionality of constellation point N
3. Codeword length K
4. Contellations $\mathcal{G} = [g_j]_{j=1}^{J}$
5. Sparse mappings $\mathcal{V} = [V_j]_{j=1}^{J}$

For a given design criterion m the design problem can be defined as:

$$\mathcal{V}^*, G^* = \arg\max_{\mathcal{V}, G} m(\mathcal{V}, G; J, M, N, K)$$

However, there is no appropriate definition of m and solution of the problem is unknown.

Multi-stage optimization approach is proposed to construct an SCMA code.

1. The sparser the coderwords are, the less complext is the MPA detection. $J = \binom{K}{N}$ mappings $V_j \in \mathbb{C}^{K\times N}$ are defined by all possible ways of inserting $N - K$ all-zero rows into I_N. Denoted as $\mathcal{V}^+$.
2. Each constellation g_j is defined as a linear tranfomation of a "mother constellation" g:

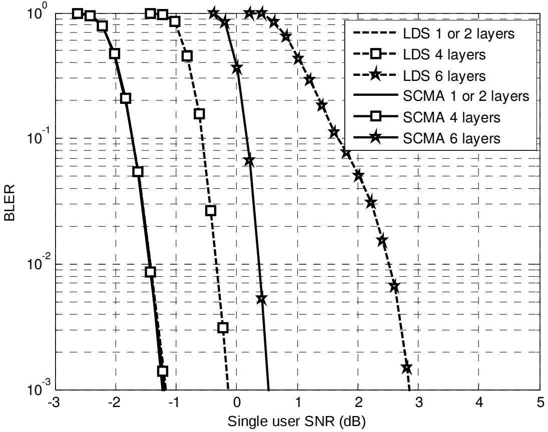
$$g_j \equiv \Delta_j g, \quad j = 1, \ldots, J$$

   Δ_j is a unitary rotation, the choice of Δ_j depends on fading coefficients $\mathbf{h_j}$ and on structure of a factor graph.

So the optimization problem transforms into

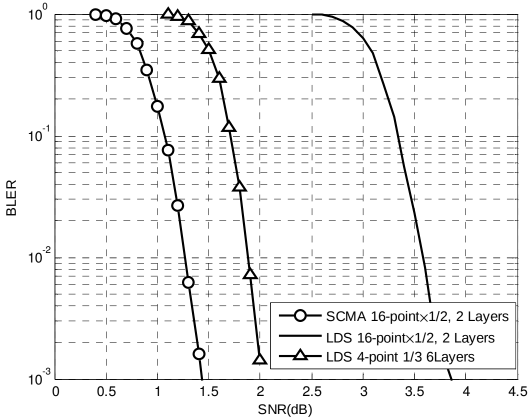
$$g^+, [\Delta_j^+]_{j=1}^J = \arg \max_{g, [\Delta_j]_{j=1}^J} m(\mathcal{V}^+, [\Delta_j g]_{j=1}^J; J, M, N, K)$$

Numerical results 1



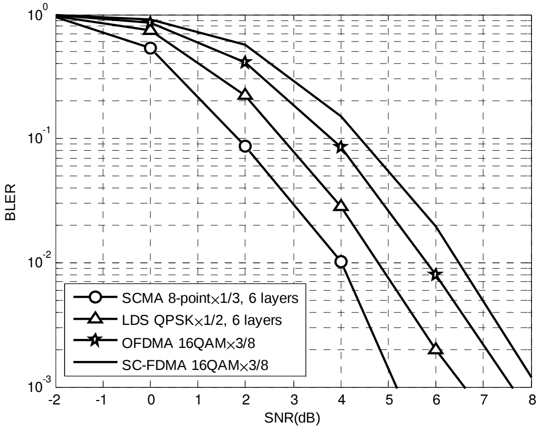
http://arxiv.org/abs/1408.3653

Numerical results 2



http://arxiv.org/abs/1408.3653

Numerical results 3



http://arxiv.org/abs/1408.3653