ALTERA UNIVERSITY PROGRAM

# 5G

# 5G第一届移动通信算法创新大赛
## 赛题及要求

## SCMA

主办单位 | ALTERA UNIVERSITY PROGRAM 西安电子科技大学 XIDIAN UNIVERSITY terasIC Terasic Inc.

赞助厂商 | HUAWEI HIRP Innovation intel SPREADTRUM

# 1st 5G Algorithm Competition – SCMA

| Task | Description | Requirements |
|---|---|---|
| SCMA – 下一代无线通信的稀疏码多址接入 | 多址接入是无线通信物理层最核心的技术之一，它使得无线基站能区分并同时服务多个终端用户。现有系统采用正交的多址接入方式，即多个用户通过在不同维度上（频分、时分、码分等）正交划分的资源来接入，现在4G系统中采用的OFDMA多址技术也是其中之一，但它是将二维时频资源栅进行正交划分来接入不同用户的。<br><br>正交多址技术由于其接入用户数与正交资源成正比，因此不能满足5G大容量、海量连接、低延时接入等的需求，非正交多址接入就成为当下5G多址接入的研究重点。SCMA，稀疏码多址接入，就是应5G需求设计产生的一种非正交多址技术。在发送端，她将编码比特直接映射为复数域多维码字，不同用户的码字在相同的资源块上以稀疏的扩频方式非正交叠加；接收端则利用稀疏性进行低复杂度的多用户联合检测，并结合信道译码完成多用户的比特串恢复。其最大特点是，非正交叠加的码字个数可以成倍大于使用的资源块个数。相比4G的OFDMA技术，它可以实现在同等资源数量条件下，同时服务更多用户，从而有效提升系统整体容量。<br><br>请根据材料中对SCMA编译码原理的介绍，设计并实现抽象的SCMA上行通信系统，验证将稀疏码扩频作为非正交接入的可行性和性能。 | **要求：**<br>根据培训资料中对SCMA的介绍，实现简化的（抽象的，而非基于现有完整通信系统的）SCMA上行多接入通信系统，重点在SCMA编码和低复杂度译码模块的开发和验证。<br>**作品格式：**<br>1. 完成简化SCMA上行多接入系统设计文档，尤其是低复杂度译码器的设计<br>2. 完成简化SCMA上行多接入系统Matlab仿真，并给出BER v.s Eb/No的性能瀑布曲线<br>3. 完成简化SCMA上行多接入系统FPGA系统逻辑设计与实现，测试其性能并与仿真曲线比对，并报告资源使用情况。<br>**交付材料：**<br>1. SCMA上行多接入系统设计文档，代码和仿真结果<br>2. FPGA设计说明书，代码，比特文件及测试结果<br>**评选标准：**<br>初赛：<br>1. 正确理解SCMA系统，完成简化SCMA上行多接入系统设计文档，重点设计低复杂度译码器<br>2. 完成该系统链路的Matlab/C仿真，并给出BER v.s Eb/No的性能瀑布曲线<br>3. 提供以参赛 FPGA 平台来进行SCMA系统设计的框架和方法<br>复赛：<br>1. 完成FPGA逻辑设计文档，在FPGA系统中成功完成简化SCMA上行多接入系统FPGA开发，译码正确率超过99.9%<br>2. 测试BER v.s Eb/No的性能瀑布曲线，并与仿真（允许刷新优化）比对，差别小于1dB<br>3. FPGA设计所实现的算法、数据吞吐率、处理时延及使用的FPGA芯片资源 |

# Outline

- What is SCMA?
- Why we need SCMA in 5G?
- How does SCMA work?
- What will you implement?
- What reference to read?

# Helpful Documents for Understanding SCMA

## MUST Read Papers:

1. 《SCMA Codebook Design》(to understand SCMA)
   http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6966170
2. 《Novel low-density signature for synchronous cdma systems over AWGN channel》(to understand MPA)
   http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4471881

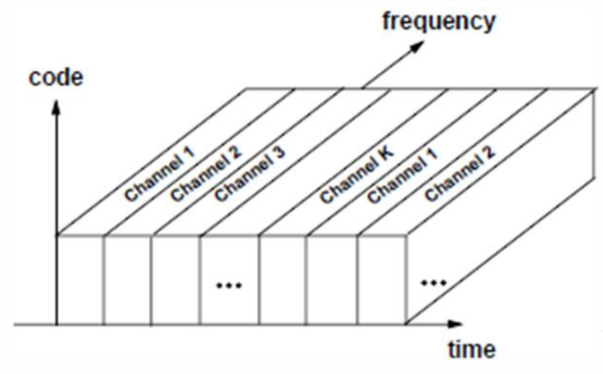
## SCMA Related Publications:

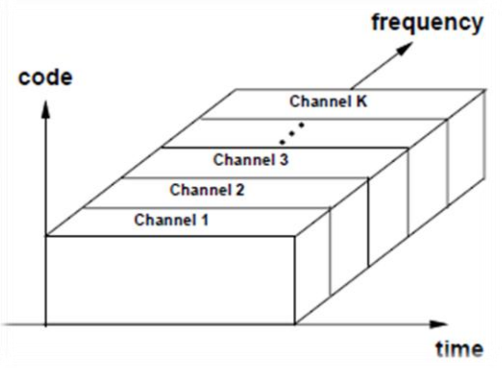

- H. Nikopour and H. Baligh, "Sparse Code Multiple Access," IEEE PIMRC, 2013.
- M. Taherzadeh, H. Nikopour, A. Bayesteh, and H. Baligh, "SCMA Codebook Design," IEEE VTC-fall, 2014.
- Kelvin Au, Liqing Zhang, Hosein Nikopour, Eric Yi, Alireza Bayesteh, Usa Vilaipornsawai, Jianglei Ma, Peiying Zhu, "Uplink Contention Based SCMA for 5G Radio Access," IEEE Globecom 5G workshop 2014.
- H. Nikopour, E. Yi, A. Bayesteh, K. Au, M. Hawryluck, H. Baligh, and Jianglei Ma, "SCMA for Downlink Multiple Access of 5G Wireless Networks," IEEE Globecom 2014.
- S. Zhang, X. Xu, L. Lu, Y. Wu, G. He, and Y. Chen, "Sparse Code Multiple Access: An Energy Efficient Uplink Approach for 5G Wireless Systems," IEEE Globecom 2014.
- A. Bayesteh, E. Yi, E. , H. Nikopour, H. Baligh, "Blind Detection of SCMA for Uplink Grant-Free Multiple-Access", ISWCS 2014.
- Y. Wu, S. Zhang, and Y. Chen, "Iterative multiuser receiver in sparse code multiple access systems," IEEE ICC 2015.

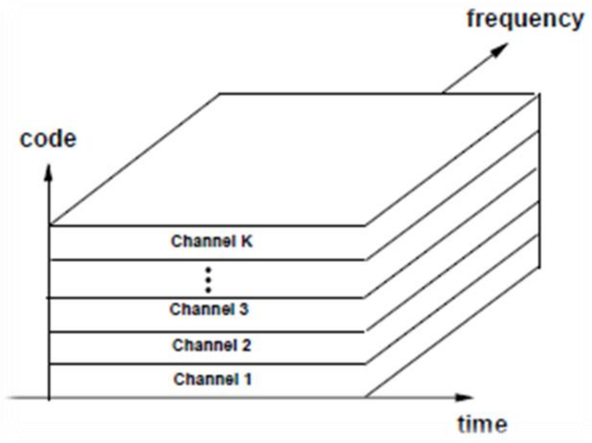
To have a gut feeling what is sparse code multiple access

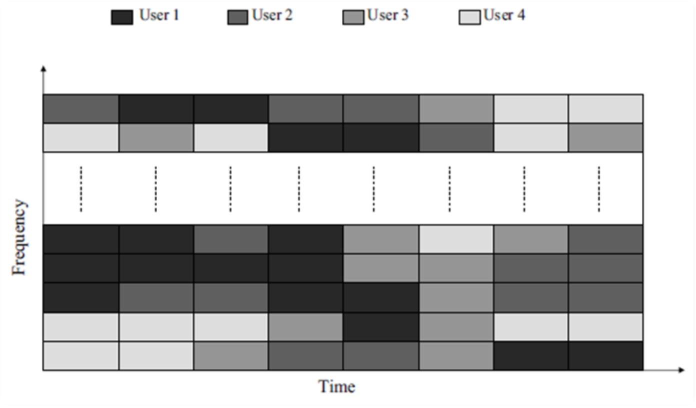
# WHAT IS SCMA?

# Existing Multiple Access Schemes




## TDMA/FDMA

- 2G Communication system, e.g. GSM
- Orthogonal in time or frequency domain
- Users are scheduled on orthogonal time slots

## CDMA

- 3G Communication system, e.g. WCDMA
- Non-orthogonal in time and frequency but orthogonal in code domain
- Users are scheduled on orthogonal sequences

## OFDMA

- 4G Communication system, e.g. LTE
- Orthogonal in 2D time-frequency lattice domain
- Users are scheduled on orthogonal time-frequency lattice

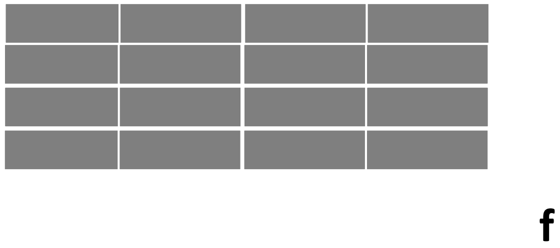
# From OFDMA to SCMA

**OFDMA**


## Orthogonal multi-user multiplexing

- Users occupy orthogonal resources for communication
- Easy to implement (single user detection)
- Number of connections limited by the number of physical resource blocks that can be scheduled

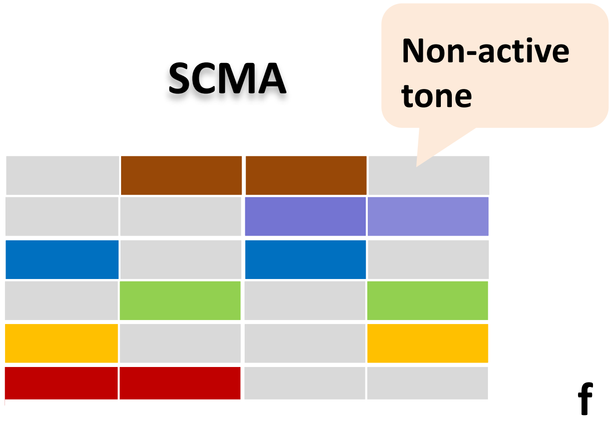
**OFDM-CDMA**




## Non-orthogonal multi-user multiplexing

- Users occupy the same resource blocks using CDMA
- Non-practically high multi-user joint detection complexity
- Limited number of concurrent users due to limited sequences
- Better coverage due to spreading gain

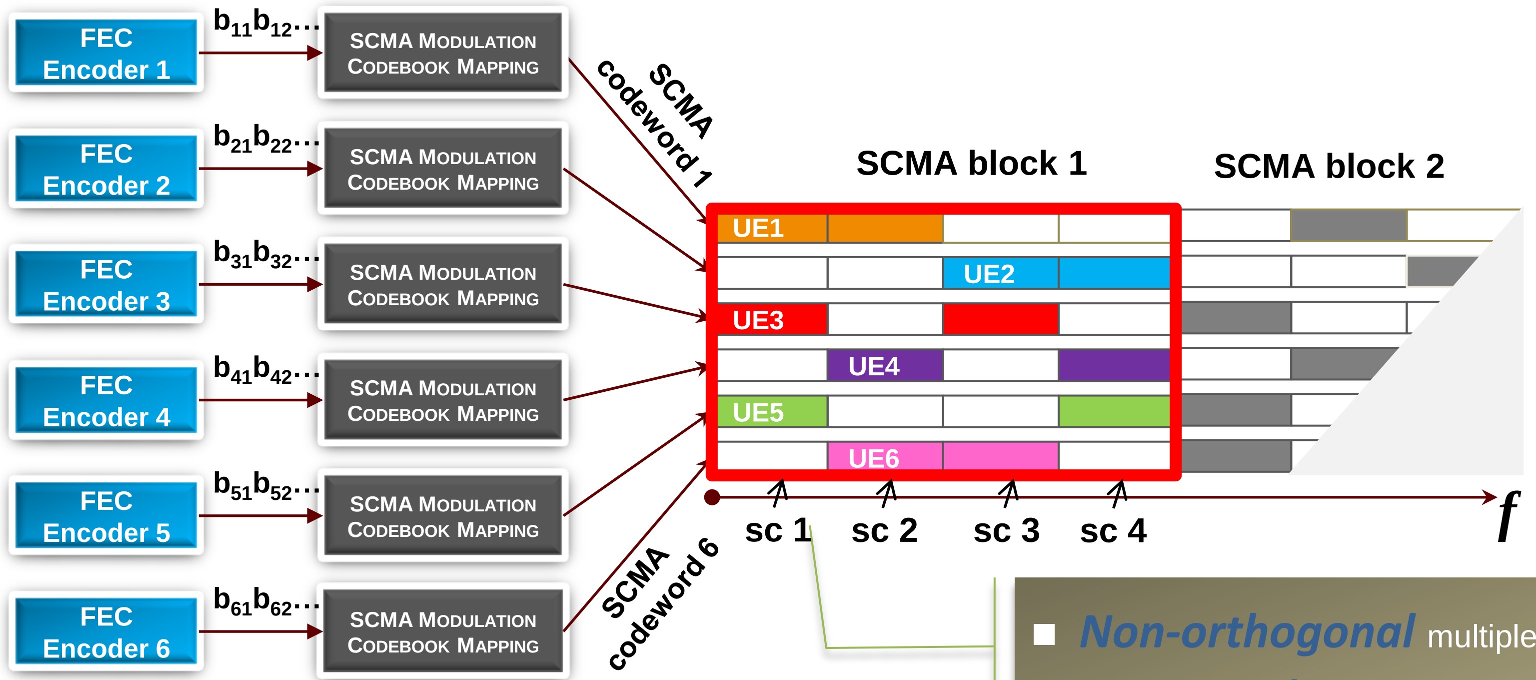
**SCMA**




## Overloaded multi-user multiplexing

- Users occupy the same resource blocks in a low density way
- Affordable low multi-user joint detection complexity
- Less collision even for large number of concurrent Users
- Better coverage due to spreading gain

# SCMA (Sparse Code Multiple Access)

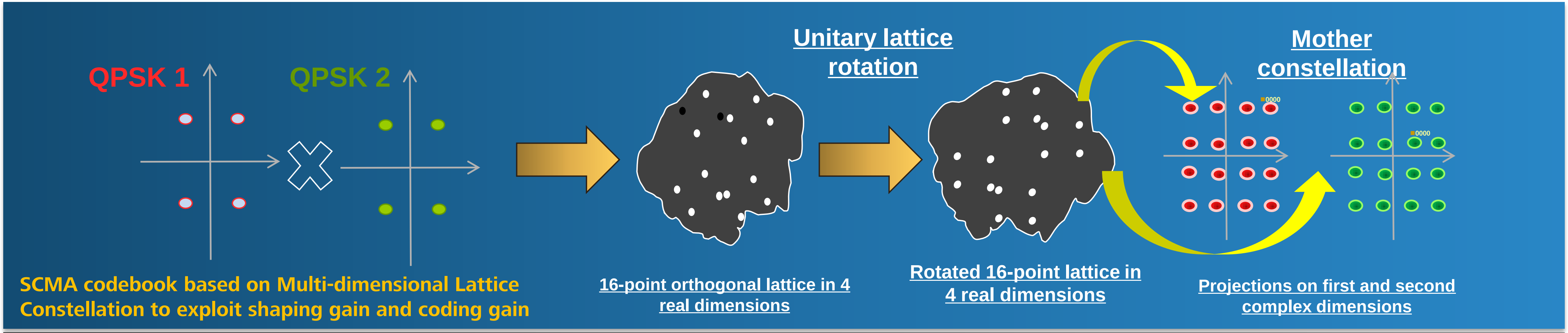


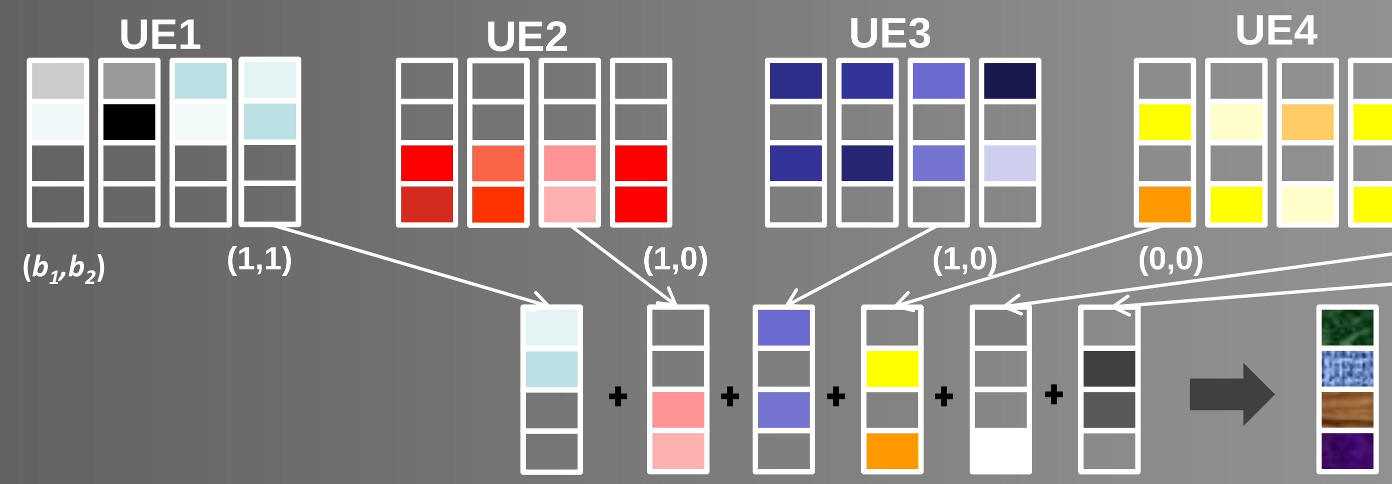

***A new frequency domain non-orthogonal waveform***

- Input bits are directly mapped to codewords and spread over multiple sub-carriers
- Codewords can be assigned to same UE or different UEs

- ***Non-orthogonal*** multiplexing of code layers
- ***Over-Loading*** to increase overall rate and connectivity
- ***Sparsity*** to limit Rx complexity for detection
- ***Spreading*** for robust link-adaptation, coverage
- ***Multi-dimensional*** codewords with shaping gain

# SCMA Codebook Design



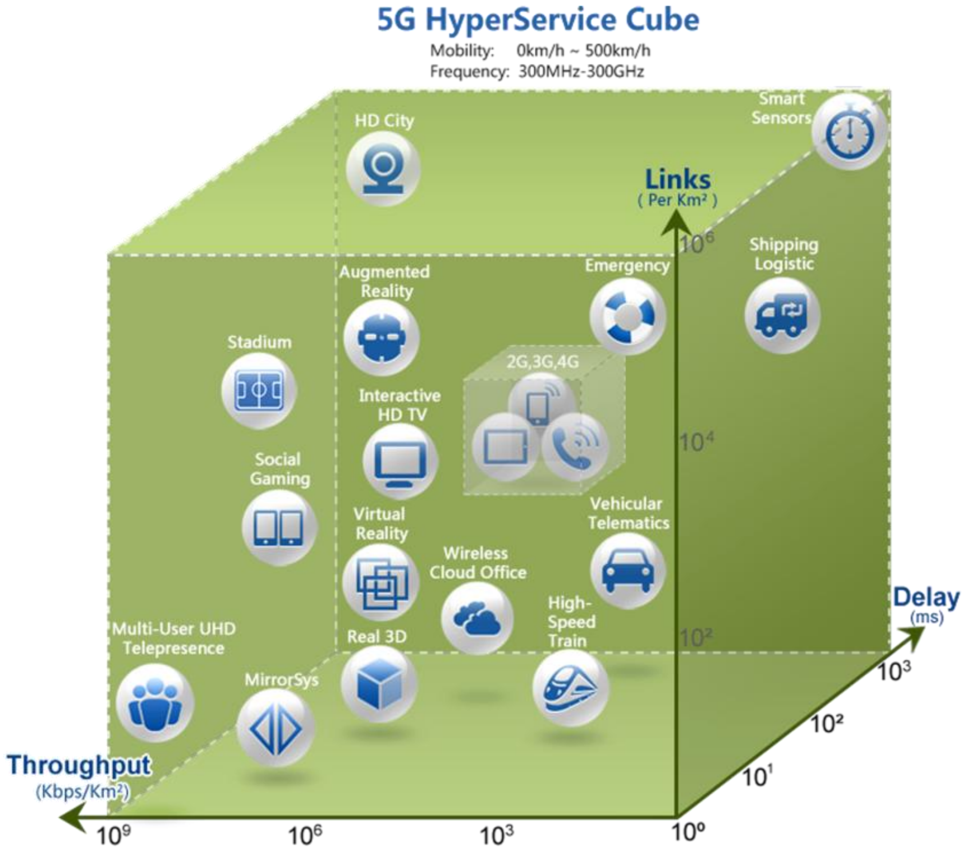

- Each UE/layer stores a unique codebook
- Binary input data is mapped to a codeword of the corresponding codebook

M. Taherzadeh, H. Nikopour, A. Bayesteh, and H. Baligh, "SCMA Codebook Design," IEEE VTC-fall, 2014.

To know what role SCMA plays in 5G and what benefit it brings along

# WHY WE NEED SCMA IN 5G?

# 5G Vision: Zero Distance Communications




**Massive Capacity**

$10^3$ Times Traffic Flooding

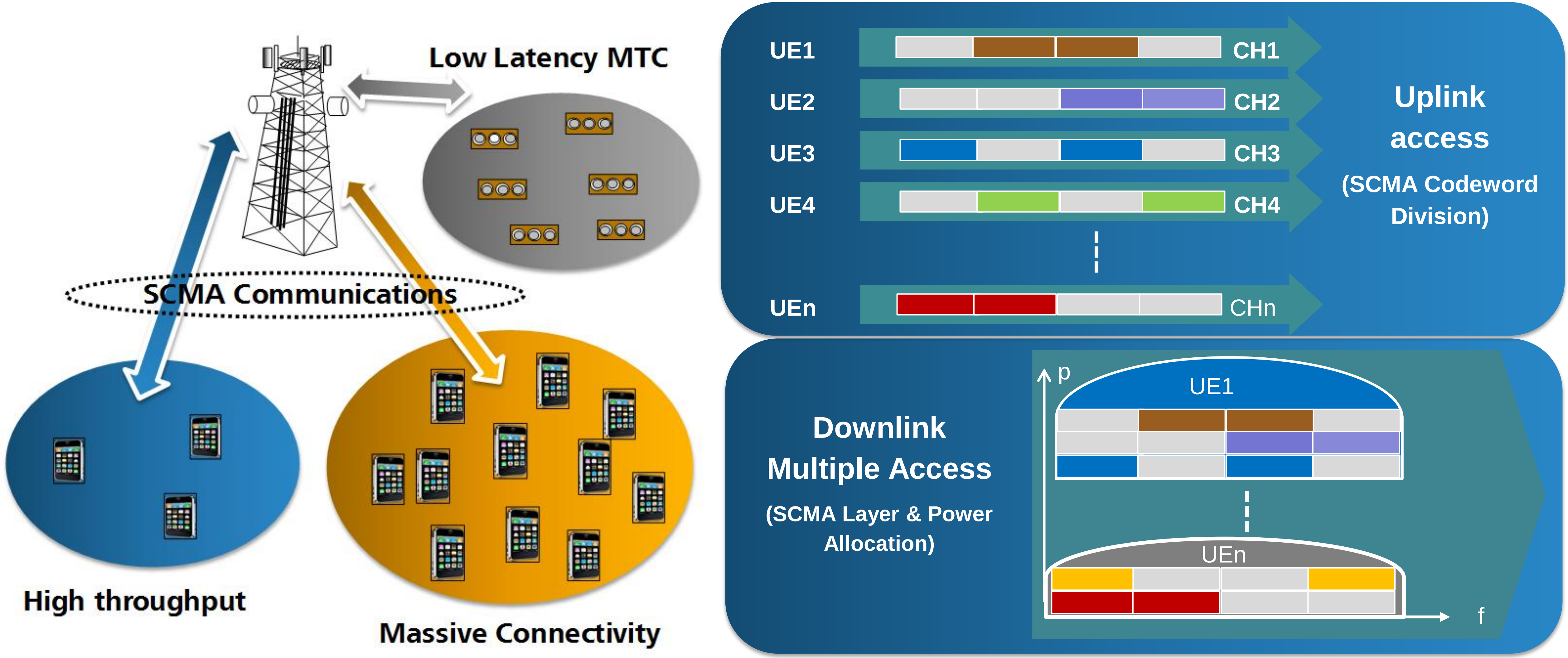
**Massive Connectivity**

$10^2$ Billion Connections

**Zero Waiting**

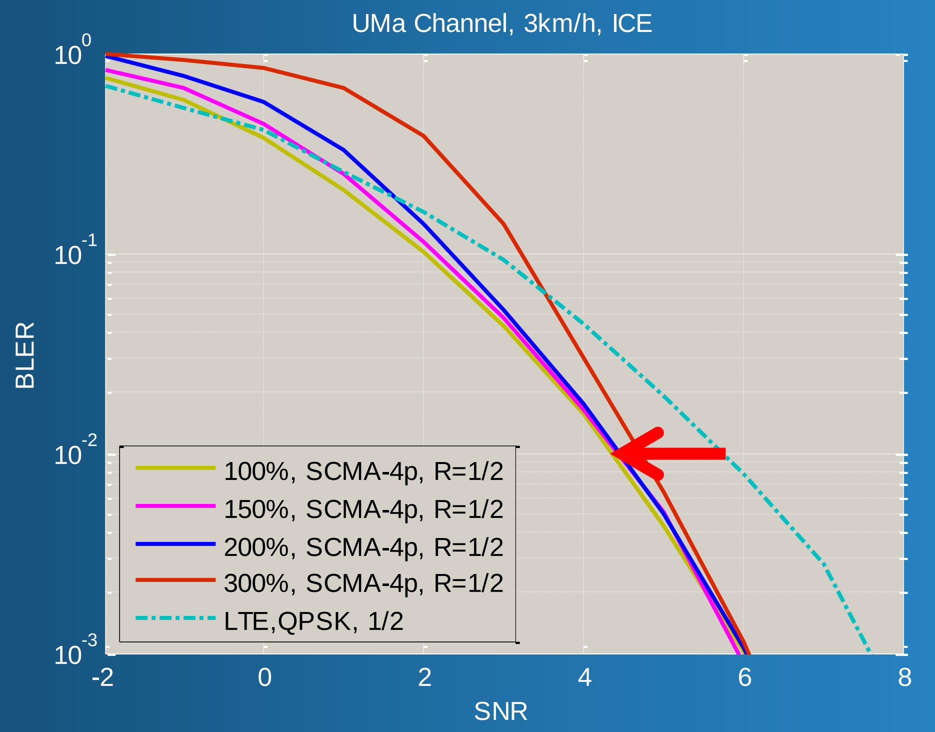
$10^0$ ms Delay Experience

# Example of SCMA Application Scenarios



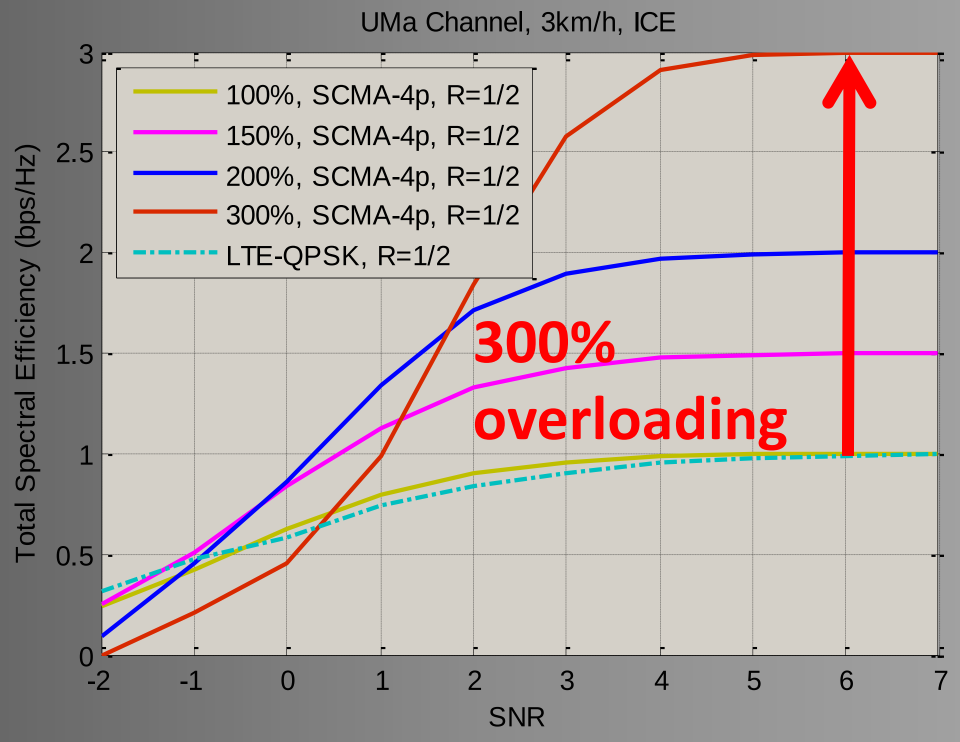
# SCMA Offers Better Link Quality and 300% Larger Number of Physical Link Connections over LTE

## Better Link Quality over LTE



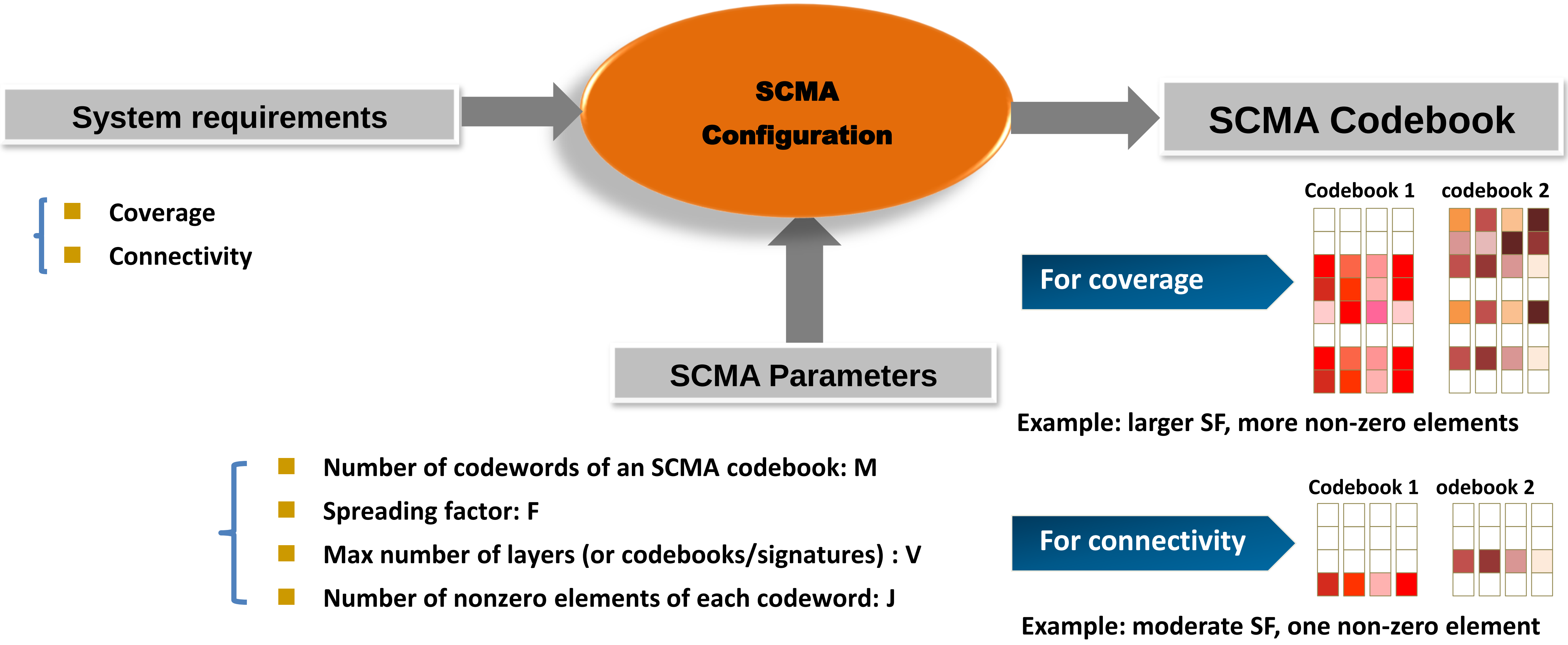

- SCMA has SNR gain over LTE (same rate & power per user)
- SCMA with overloading performs towards single user

## 300% Larger Number of Connected Users




- **Given the same SNR, SCMA can boost total system throughput up to 300% over LTE (@LTE BLER=0.01)**

# SCMA Codebook Design Can Flexibly Adapt to Meet Diversified System Requirements

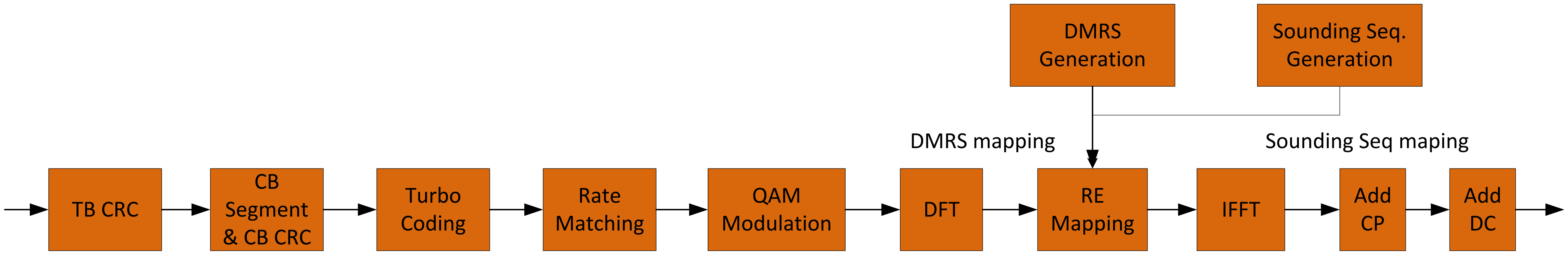


To have a gut feeling how SCMA will be implemented in the 5G wireless systems

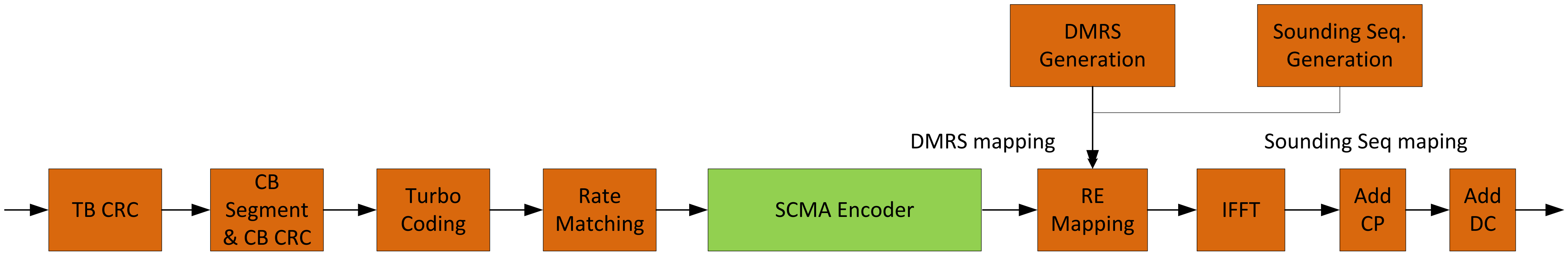
# HOW DOES SCMA WORK?

# SCMA Uplink Transmission System Diagram

LTE SC-FDMA Transmitter

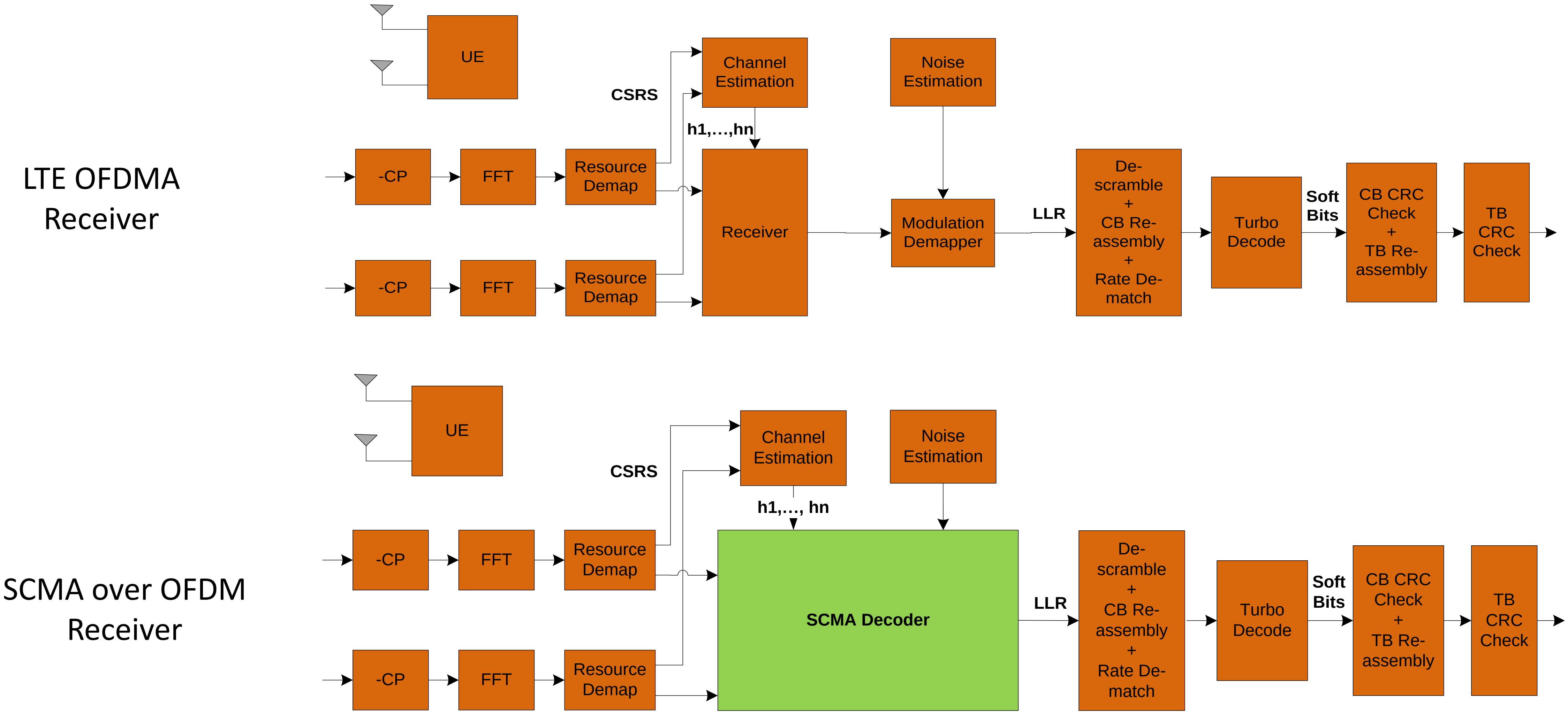



SCMA over OFDM Transmitter




Wanna know more about 4G LTE? Please refer to 3GPP standards or the book “LTE the UMTS Long Term Evolution, from Theory to Practice” from Wiley Press.

# SCMA Uplink Transmission System Diagram

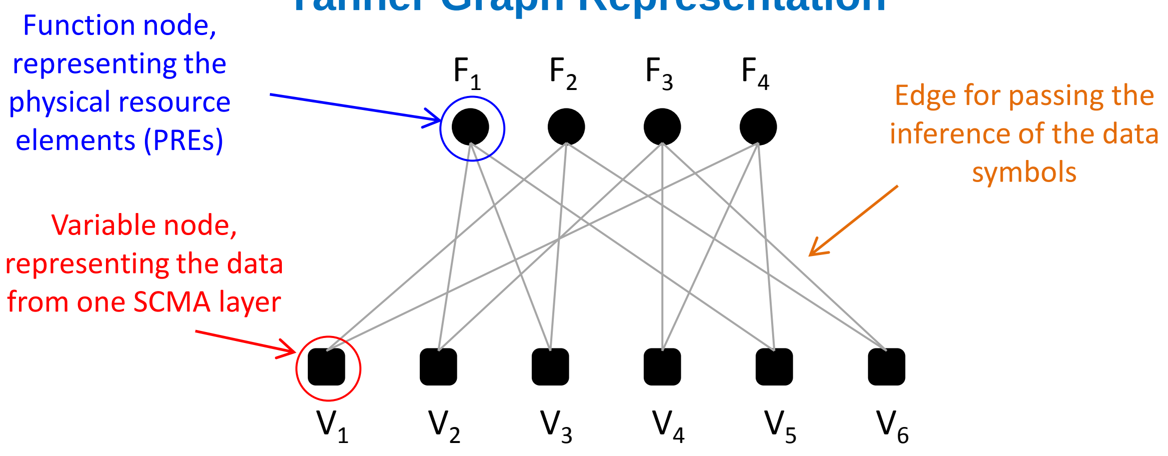


# Example of SCMA Codebook

## Codebook Related Parameters

| Related Variables | Typical value | Description |
|---|---|---|
| V | 6 | 6 variable nodes (VN), number of data layers |
| F | 4 | 4 function nodes (FN), number of physical resources |
| d_f | 3 | Each FN is connected to 3 VNs |
| d_v | 2 | Each VN is connected to 2 FNs |
| M | 4 | Number of codeword in each codebook |
| CB_i | F-by-M matrix | Codebook for one SCMA data layer |

## Tanner Graph Representation




## Codebook in Storage (V=6, F=4, df=3, dv=2, M=4)

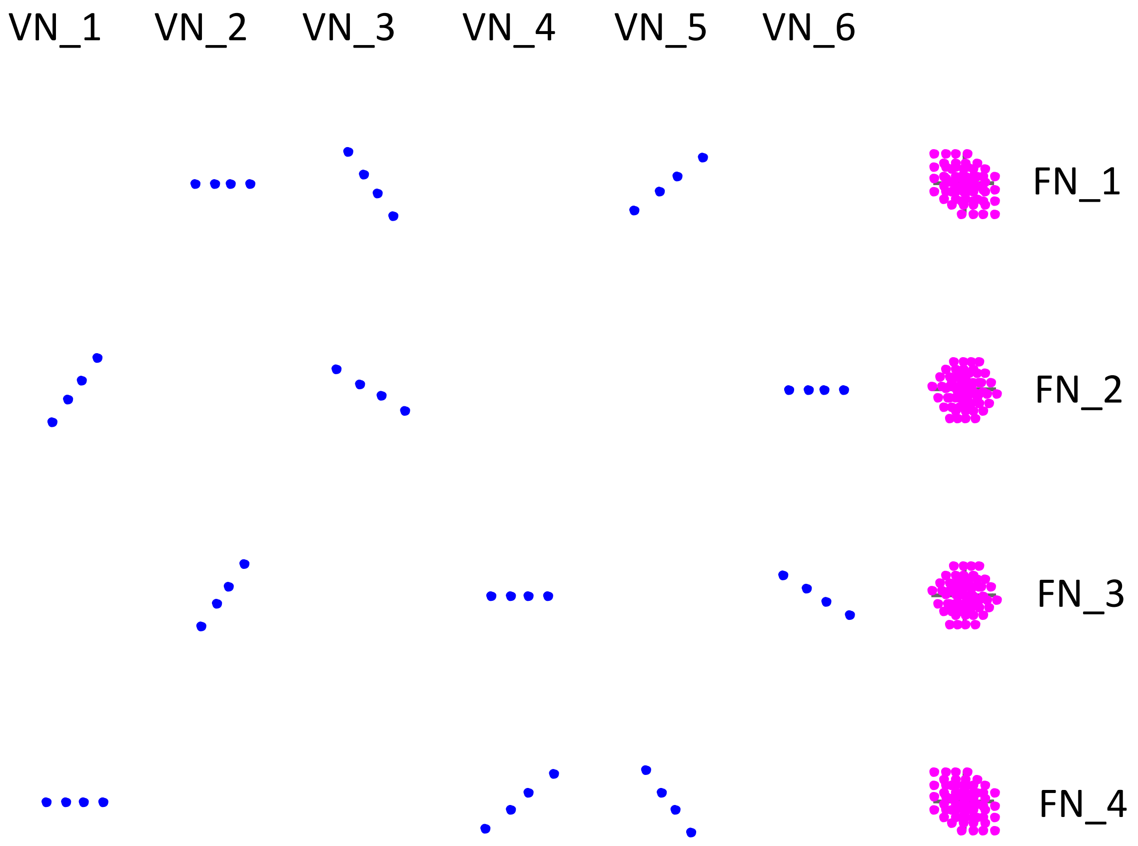
| SCMA Codebook index | SCMA codebook for each layer |
|---|---|
| CB_1 | $\begin{bmatrix} 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \end{bmatrix}$ |
| CB_2 | $\begin{bmatrix} 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \end{bmatrix}$ |
| CB_3 | $\begin{bmatrix} -0.6351+0.4615i & 0.1815-0.1318i & -0.1815+0.1318i & 0.6351-0.4615i \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ |
| CB_4 | $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ -0.0055-0.2242i & -0.0193-0.7848i & 0.0193+0.7848i & 0.0055+0.2242i \end{bmatrix}$ |
| CB_5 | $\begin{bmatrix} -0.0055-0.2242i & -0.0193-0.7848i & 0.0193+0.7848i & 0.0055+0.2242i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.6351+0.4615i & 0.1815-0.1318i & -0.1815+0.1318i & 0.6351-0.4615i \end{bmatrix}$ |
| CB_6 | $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \end{bmatrix}$ |

# Example of SCMA Codebook

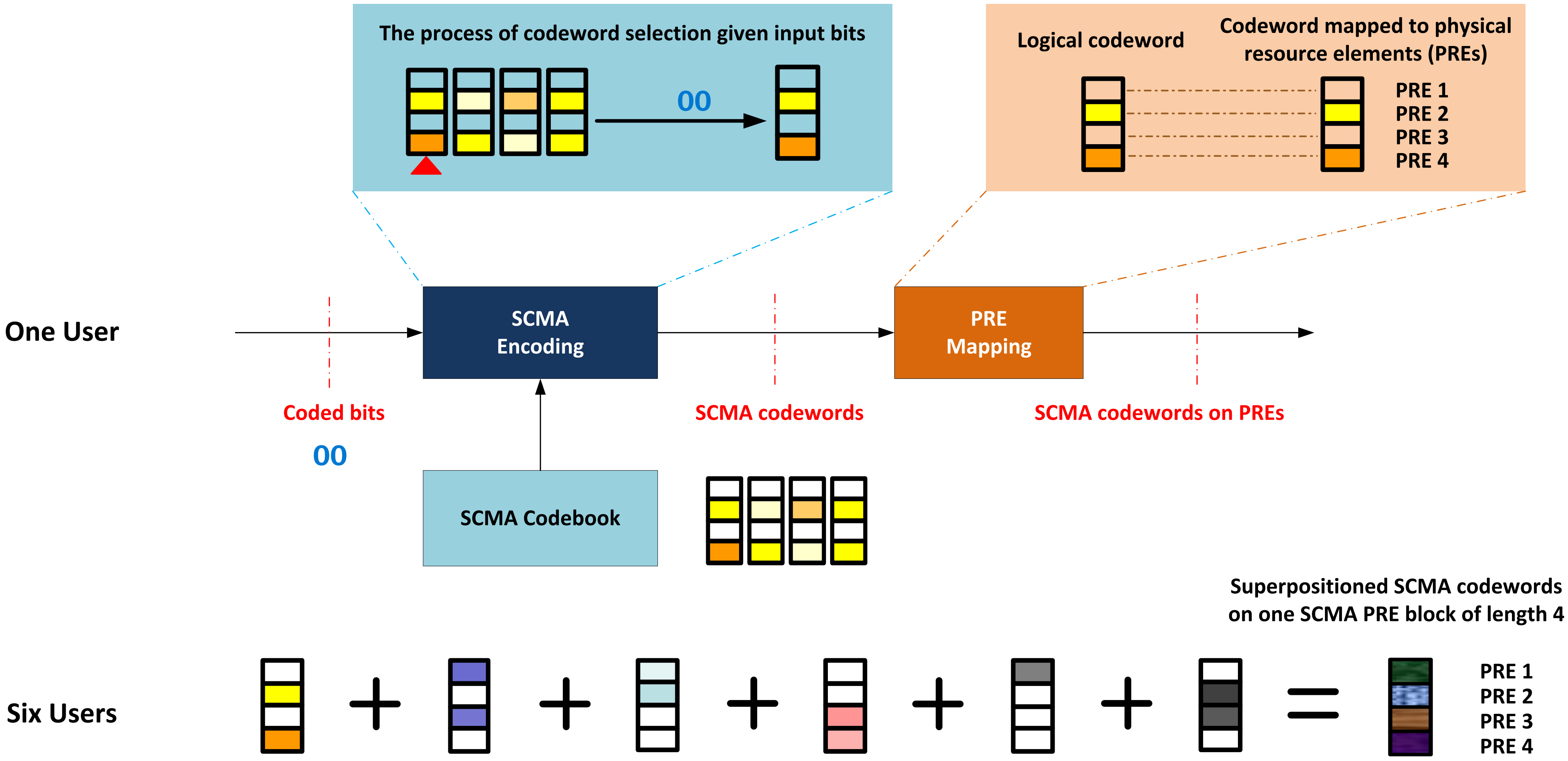
## Codebook in Storage (V=6, F=4, df=3, dv=2, M=4)

| SCMA Codebook index | SCMA codebook for each layer |
| --- | --- |
| CB_1 | $\begin{bmatrix} 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \end{bmatrix}$ |
| CB_2 | $\begin{bmatrix} 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \end{bmatrix}$ |
| CB_3 | $\begin{bmatrix} -0.6351+0.4615i & 0.1815-0.1318i & -0.1815+0.1318i & 0.6351-0.4615i \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ |
| CB_4 | $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ -0.0055-0.2242i & -0.0193-0.7848i & 0.0193+0.7848i & 0.0055+0.2242i \end{bmatrix}$ |
| CB_5 | $\begin{bmatrix} -0.0055-0.2242i & -0.0193-0.7848i & 0.0193+0.7848i & 0.0055+0.2242i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.6351+0.4615i & 0.1815-0.1318i & -0.1815+0.1318i & 0.6351-0.4615i \end{bmatrix}$ |
| CB_6 | $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \end{bmatrix}$ |

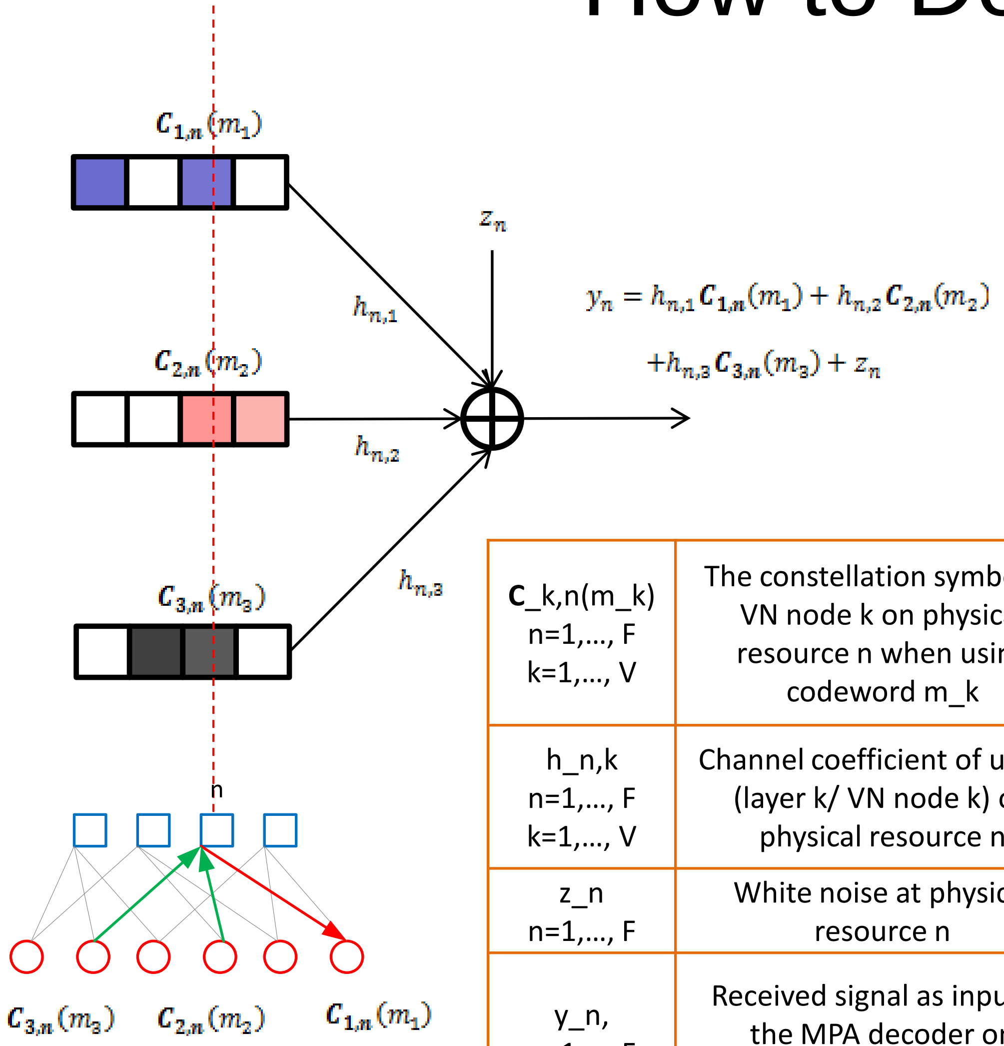
## Codebook Presented by Constellation Points



# How to Do SCMA Encoding with SCMA Codebook



# How to Do SCMA Decoding




| | |
|---|---|
| c_k,n(m_k)<br>n=1,…, F<br>k=1,…, V | The constellation symbol of VN node k on physical resource n when using codeword m_k |
| h_n,k<br>n=1,…, F<br>k=1,…, V | Channel coefficient of user k (layer k/ VN node k) on physical resource n |
| z_n<br>n=1,…, F | White noise at physical resource n |
| y_n,<br>n=1,…, F | Received signal as input to the MPA decoder on resource n |

- **Optimal Maximum joint A posteriori Probability (MAP) detection**

$$\hat{\mathbf{x}} = \arg\max_{\mathbf{x}\in\mathbb{X}^K} p(\mathbf{x}|\mathbf{y}).$$

$$\hat{x}_k = \arg\max_{a\in\mathbb{X}} \sum_{\substack{\mathbf{x}\in\mathbb{X}^K \\ x_k=a}} p(\mathbf{x}|\mathbf{y}), \quad \forall k$$

- **Equivalence of MAP with Maximum Likelihood (ML) detection when the a prior probabilities of x_k are the same**

$$p(\mathbf{x}|\mathbf{y}) = \frac{p(\mathbf{y}|\mathbf{x})P(\mathbf{x})}{P(\mathbf{y})} \propto p(\mathbf{y}|\mathbf{x})P(\mathbf{x})$$

$$P(\mathbf{y}) = \sum_{x\in\mathbb{X}^k} p(\mathbf{y}|\mathbf{x})P(\mathbf{x})$$

$$P(\mathbf{x}) = \prod_{k=1}^{K} P(x_k)$$

$$p(\mathbf{y}|\mathbf{x}) = \prod_{n=1}^{N} p(y_n|\mathbf{x})$$

$$p(y_n|\mathbf{x}) = p\left(y_n|\mathbf{x}^{[n]}\right)$$

$$\hat{x}_k = \arg\max_{a\in\mathbb{X}} \sum_{\substack{\mathbf{x}\in\mathbb{X}^K \\ x_k=a}} P(\mathbf{x}) \prod_{n\in\zeta_k} p\left(y_n|\mathbf{x}^{[n]}\right)$$

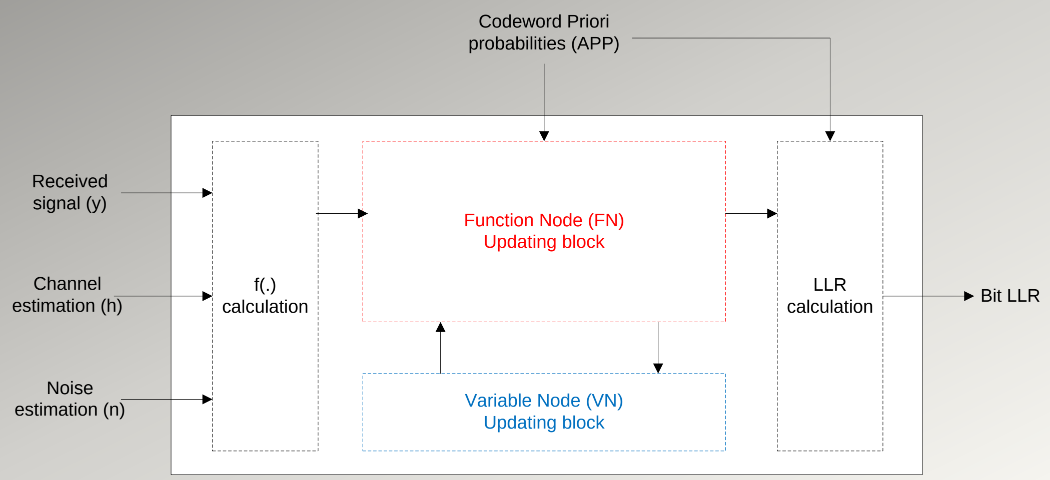
R. Hoshyar, F. P. Wathan, R. Tafazolli, ‘’Novel low-density signature for synchronous CDMA systems over AWGN channel,” IEEE Trans. Signal Processing, vol. 56, No. 4, Apr 2008.

# How to Do SCMA Decoding with MPA Algorithm

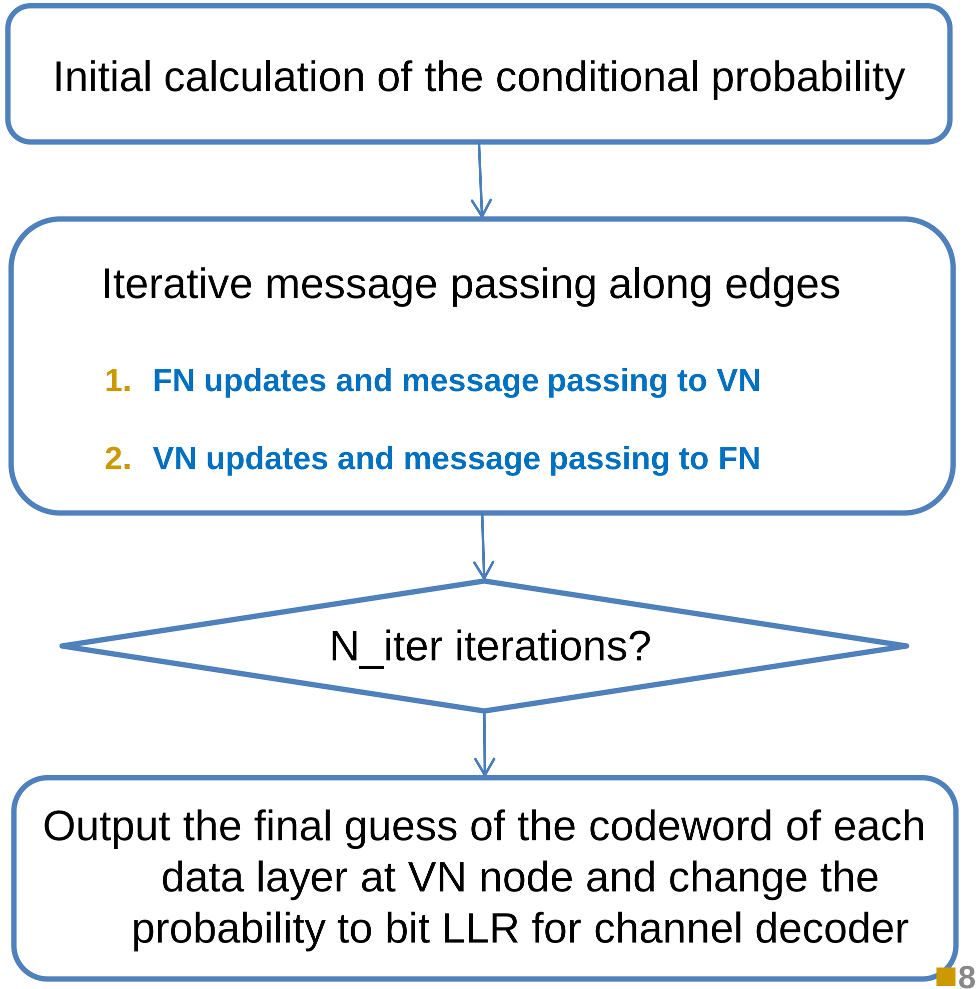
## Selection of SCMA Decoder

- The optimal multi-user detection can be done by using the maximum joint a posteriori probability (MAP) detection with excessive search – non-practical complexity
- With the low density spreading structure employed in SCMA, we can derive near ML performance multi-user detection with message passing algorithm (MPA) – affordable complexity

## Diagram for Massage Passing Algorithm

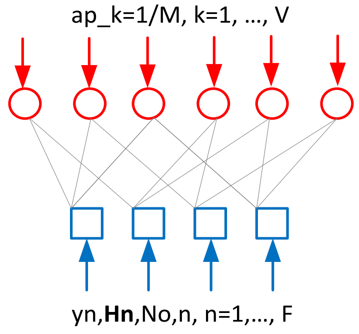



## MPA Decoder (Performed for each SCMA block)



# How to Do SCMA Decoding with MPA Algorithm

| Parameters | Description of the parameters |
|---|---|
| y_n, n=1,…, F | Received signal as input to the MPA decoder on resource n |
| m_k, k=1,…, V | Codeword selected by layer k, m_k = 1,…, M |
| No_n, n=1,…, F | Noise power estimation on physical resource n |
| **C**_k,n(m_k) | The constellation symbol of VN node k on physical resource n when using codeword m_k |
| **H**_n = {h_n,k} | Channel gain of user k on physical resource n |
| Ap_k, k=1,…, V | A prior probability of codeword k, assuming equal probability 1/M |
| LLR_k,b | logarithm of the likelihood ratio of layer k bit b |
| N_iter | Number of iterations in the MPA |




**Step 1: Initial calculation of the conditional probability**

- For each function node FN, calculate the f_n() function, which is the set of all possible residual signals given the known or estimated channel h_n,k and the assumed transmitted codeword C_k,n(m_k)
- When d_f = 3, as in the example, for each FN node n, there are M*M*M combinations of transmitted signals, so there are in total F*M*M*M values to store for f() function calculation

$$f_n(y_n, m_1, m_2, m_3, N_{0,n}, H_n) = \frac{-1}{N_{0,n}} \left\| y_n - \left(h_{n,1} C_{1,n}(m_1) + h_{n,2} C_{2,n}(m_2) + h_{n,3} C_{3,n}(m_3)\right) \right\|^2$$

$m_1 = 1, \dots, M \quad m_2 = 1, \dots, M \quad m_3 = 1, \dots, M \quad n = 1, \dots, F$

- Phi_n() function is actually the conditional probability for given codeword combination, for Gaussian noise case, it is the exponential operation over f_n function, so the storage needed is the same

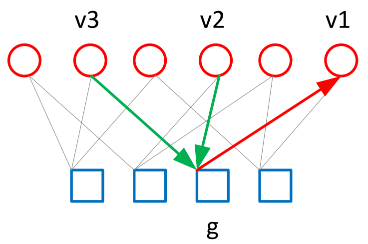
P(yn|x1, x2, x3) -----
$$\Phi_n(y_n, m_1, m_2, m_3, N_{0,n}, H_n) = \exp\left(f_n(y_n, m_1, m_2, m_3, N_{0,n}, H_n)\right)$$

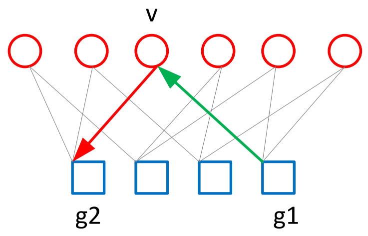
- To prepare for the iterations, we assign the a prior probability for each codeword, which is assumed to be equal

P(x1), P(x2), P(x3) -----
$$I_{v_1 \to g}^{init}(m_1) = I_{v_2 \to g}^{init}(m_2) = I_{v_3 \to g}^{init}(m_3) = \frac{1}{M}$$

# How to Do SCMA Decoding with MPA Algorithm

| **Parameters** | **Description of the parameters** |
|---|---|
| y_n, n=1,…, F | Received signal as input to the MPA decoder on resource n |
| m_k, k=1,…, V | Codeword selected by layer k, m_k = 1,…, M |
| No_n, n=1,…, F | Noise power estimation on physical resource n |
| **C**_k,n(m_k) | The constellation symbol of VN node k on physical resource n when using codeword m_k |
| **H**_n = {h_n,k} | Channel gain of user k on physical resource n |
| Ap_k, k=1,…, V | A prior probability of codeword k, assuming equal probability 1/M |
| LLR_k,b | logarithm of the likelihood ratio of layer k bit b |
| N_iter | Number of iterations in the MPA |




**Step 2: Iterative message passing along edges**

**[FN update]: message passing from FN to its neighboring VNs**

- FN node g passes updates obtained from extrinsic information to its neighboring VN nodes (g to v1, information from v2 and v3 are extrinsic)
- The message passed to v1 contains the guess of what signal at g may be given all possibilities of v1

$$\mathbf{I}_{g\to v_1}(m_1) = \sum_{m_2=1}^{M}\sum_{m_3=1}^{M} \phi_n(\mathrm{y_n}, m_1, m_2, m_3, \mathrm{N_{0,n}}, \mathbf{H}_n)\ \left(\mathbf{I}_{v_2\to g}(m_2)\mathbf{I}_{v_3\to g}(m_3)\right) \quad m_1 = 1, \dots, M$$

$$\mathbf{I}_{g\to v_2}(m_2) = \sum_{m_1=1}^{M}\sum_{m_3=1}^{M} \phi_n(\mathrm{y_n}, m_1, m_2, m_3, \mathrm{N_{0,n}}, \mathbf{H}_n)\ \left(\mathbf{I}_{v_1\to g}(m_1)\mathbf{I}_{v_3\to g}(m_3)\right) \quad m_2 = 1, \dots, M$$

$$\mathbf{I}_{g\to v_3}(m_3) = \sum_{m_1=1}^{M}\sum_{m_2=1}^{M} \phi_n(\mathrm{y_n}, m_1, m_2, m_3, \mathrm{N_{0,n}}, \mathbf{H}_n)\ \left(\mathbf{I}_{v_1\to g}(m_1)\mathbf{I}_{v_2\to g}(m_2)\right) \quad m_3 = 1, \dots, M$$

**[VN update]: message passing from VN to its neighboring FNs**

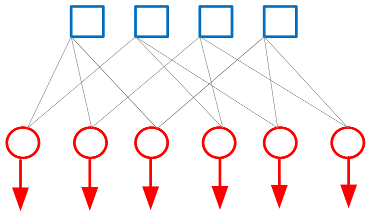
- VN node v passes updates obtained from extrinsic information to its neighboring FN nodes (v to g1, information from g2 is extrinsic)
- In the dv=2 case, it is actually a “guess” swap at VN node

$$\mathbf{I}_{v\to g_1}(m) = \text{normalize}\left(ap_v(m)\,\mathbf{I}_{g_2\to v}(m)\right) \qquad m = 1, \dots, M$$

$$\mathbf{I}_{v\to g_2}(m) = \text{normalize}\left(ap_v(m)\mathbf{I}_{g_1\to v}(m)\right) \qquad m = 1, \dots, M$$

# How to Do SCMA Decoding with MPA Algorithm

| Parameters | Description of the parameters |
|---|---|
| y_n, n=1,…, F | Received signal as input to the MPA decoder on resource n |
| m_k, k=1,…, V | Codeword selected by layer k, m_k = 1,…, M |
| No_n, n=1,…, F | Noise power estimation on physical resource n |
| **C**_k,n(m_k) | The constellation symbol of VN node k on physical resource n when using codeword m_k |
| **H**_n = {h_n,k} | Channel gain of user k on physical resource n |
| Ap_k, k=1,…, V | A prior probability of codeword k, assuming equal probability 1/M |
| LLR_k,b | logarithm of the likelihood ratio of layer k bit b |
| N_iter | Number of iterations in the MPA |




**Step 3: LLR output at variable node after N_iter iterations**

- After N_iter iterations, we shall output the guess at each VN node (for each data layer) as the detection results
- The guess at VN node v for codeword m is a chain product of all guesses from all its neighboring FN nodes and the a prior probability

$$Q_v(m) = ap_v(m)\, \mathbf{I}_{g_1\to v}(m)\, \mathbf{I}_{g_2\to v}(m) \qquad m = 1, \dots, M$$

- After getting the probability guess of codeword at each layer, we then need to calculate the Log-Likelihood-Rate (LLR) for each coded bit, so that they can serve as the input for the turbo decoder (or any other channel decoder) directly after MPA

$$LLR_x = \log\left(\frac{P(b_x = 0)}{P(b_x = 1)}\right)$$

$$LLR_x = \log\left(\frac{\sum_{\mathrm{m:b_{m,x}=0}} Q_v(\mathrm{m})}{\sum_{\mathrm{m:b_{m,x}=1}} Q_v(\mathrm{m})}\right) = \log\left(\sum_{\mathrm{m:b_{m,x}=0}} Q_v(\mathrm{m})\right) - \log\left(\sum_{\mathrm{m:b_{m,x}=1}} Q_v(\mathrm{m})\right)$$

# Hints on Low Complexity MPA Receiver Design

- **Short-comings of the current MPA algorithm**
  1. **Though much lower complexity compared with the optimal MAP algorithm (thanks to the sparse structure of the SCMA codebook), it is still of high complexity for hardware**
  2. **The exp(.) operations causes very large dynamic ranges and very high storage burden if using lookup table, which is not good news for hardware implementation**

- **Hint 1: Change to LOG domain using Jacobi's logarithm**
  1. **After changing to Log domain, exp(.) operation disappears : MPA -> MAX-Log MPA**

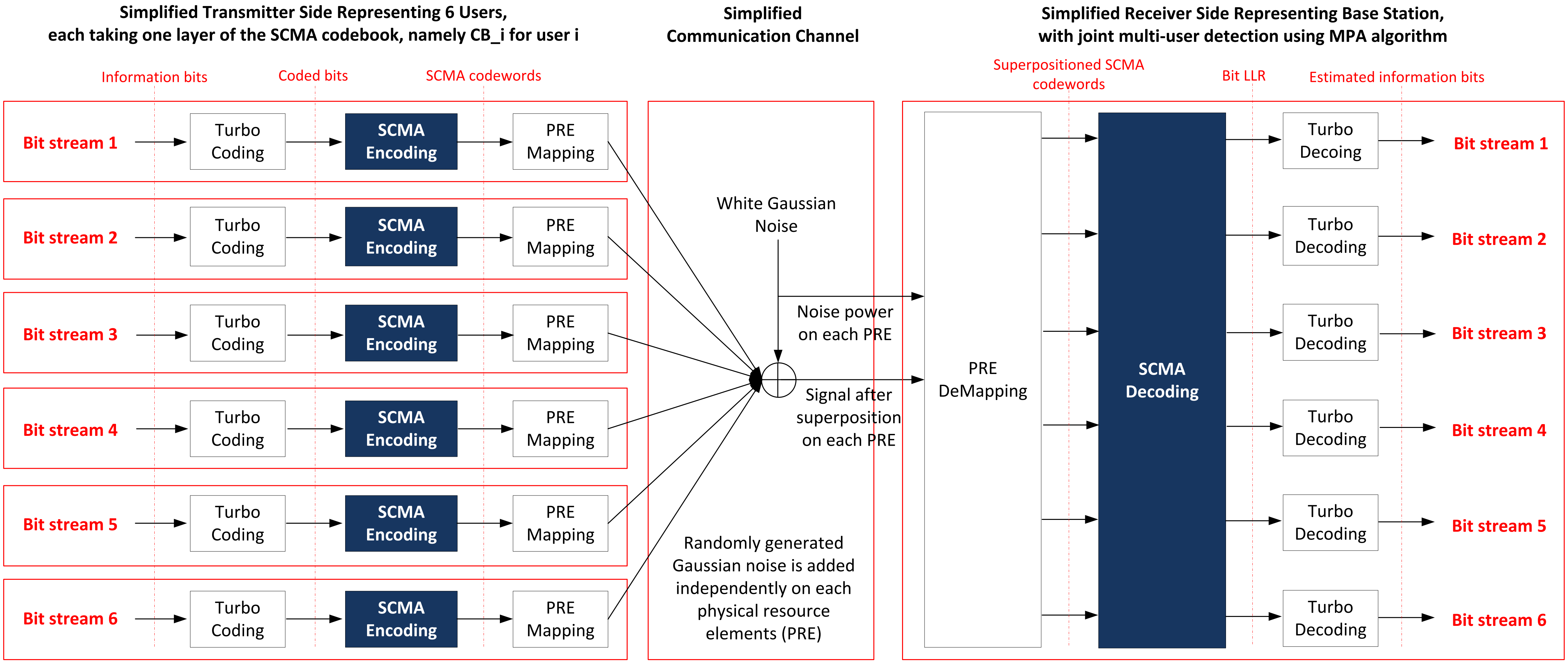
$$\log\left(\sum_{i=1}^{N}\exp(f_i)\right) \approx \max\{f_1, f_2, \ldots, f_N\}$$

- **Hint 2: Optimize the calculations during iterations**
  1. **Try to optimize the order of iterations**
  2. **Try to use as much as possible the common results in the calculation**

To have a gut feeling how SCMA will be implemented in the 5G wireless systems

# WHAT WILL YOU IMPLEMENT?

# Simplified Uplink SCMA System to be Implemented




* Turbo coding and decoding can be replaced by other forward error correction (FEC) channel coding/decoding modules.

# System Configuration Parameters for Implementation

| Parameter Categories | Related Variables | Typical value | Description |
|---|---|---|---|
| SCMA Codebook | V | 6 | 6 variable nodes (VN), number of data layers |
| | F | 4 | 4 function nodes (FN), number of physical resources |
| | d_f | 3 | Each FN is connected to 3 VNs |
| | d_v | 2 | Each VN is connected to 2 FNs |
| | M | 4 | Number of codeword in each codebook |
| | CB_i | F-by-M matrix | Codebook for one SCMA data layer, given |
| Turbo Coding | R | 1/2 | Coding rate, defined as the ratio of information bits over coded bits |
| SCMA decoding | N_iter | 3 ~ 15 | Number of iterations in MPA |
| | H_n | {1} | Channel gain, in the white Gaussian noise only case, H_n={h_n,k}={1} |
| | APP_i | 1/M | A prior probability of codeword i, assuming equal probability 1/M |
| System Scale | B | 125 bytes = 1000 bits | Total number of information bits, randomly generated |
| | N | B / R = 2000 bits | Total number of coded bits after Turbo coding |
| | L | L = F * N/log2(M) = 4000 | Total number of physical resource units |

# How We Judge and Compete the Results

- **Phase I with detailed design document and simulations**

**To deliver:**

1. Detailed design document for FPGA implementation
2. Matlab/C simulation code for the link and the BER v.s. Eb/No curve

**To check:**

1. Correct understanding of how SCMA system shall be implemented, including the SCMA encoder and the SCMA decoder
2. Low complexity design of SCMA decoder based on the hint given in the material, i.e., MAX-Log MPA

- **Phase II with complete FPGA implementation and test**

**To deliver:**

1. Complete FPGA implementation
2. BER v.s. Eb/No curves tested from FPGA implementation, should be align with simulation (1dB difference at most)

**To check:**

1. Bit streams can be decoded with the average bit-error-rate (BER) less than 0.001 (namely at most 1 bit error in the total 1000 bits)
2. FPGA resources used should be minimized through the design of low complexity SCMA decoder design and efficient way of code implementation

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# THANK YOU

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