ALTERA UNIVERSITY PROGRAM

5G

The 1st 5G Algorithm Innovation Competition

SCMA

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1st 5G Algorithm Innovation Competition-SCMA

Task	Description	Requirements
SCMA- sparse code multiple access for the next generation wireless communications	Multiple access is among the core physical layer technologies of wireless communications, which enables wireless base stations to identify a large number of different terminal users and serve them simultaneously. Current systems choose to use orthogonal multiple access method, i.e., users are orthogonal to each other in at least one radio resource dimension (e.g., frequency, time, code and etc.) . The OFDMA technology used in 4G systems is one example, in which radio resources is divided into two-dimensional time-frequency grids and each grid can only be used by one user at a time. It is obvious that the number of simultaneously accessible user is strictly proportional to the number of available orthogonal resources, and is thus limited. Facing the 5G requirement of massive connectivity, non-orthogonal multiple access becomes the research focus of 5G multiple access technologies, among which, Sparse code multiple access (SCMA) is a promising candidate. At the transmitter, coded bits are directly mapped to multi-dimensional codewords in complex domain, and codewords from different users are overlapped non-orthogonally in a sparse spreading way; the receiver performs joint multiuser detection followed by channel decoding for data recovering. Thanks to the sparsity, low complexity algorithms could be design to achieve near optimal detection results. The number of non-orthogonally superposed codewords can be much larger than the number of orthogonal resource units. This leads to the advantage of SCMA to serve more users while keeping the same expanse of resources, thus effectively improve the overall system capacity. According to the introduction of SCMA encoding and decoding principles in the given material, please design and then implement a simplified SCMA uplink communication system, and verify the feasibility and performance of such non-orthogonal multiple access system by software simulations and hardware testing.	**Requirements:** According to the introduction given in the SCMA training materials, please design and then implement a simplified SCMA uplink multiple access communication system (abstract system, rather than a complete communication system) , focusing especially on the development of SCMA encoder and the corresponding low complexity decoder design. **Works format:** 1. Complete the detailed system design documents for the simplified SCMA uplink multiple access system, especially the low-complexity SCMA decoder design. 2. Complete Matlab simulation for the simplified SCMA uplink multiple access system, and gives BER vs Eb / No performance curve. 3. Complete FPGA logic design and implementation of the SCMA uplink multiple access system, test its performance, compare with simulation curves and report the resource usage. **Delivery Material:** 1. SCMA uplink multi-access system design documents, code and simulation results; 2. FPGA design specifications, code, and test results of the bit file. **Selection criteria in the first round:** 1. Correctly understand SCMA system, complete the detailed system design documents for the simplified SCMA uplink multiple access system, especially the low-complexity decoder. 2. Complete the link-level Matlab / C simulations for the simplified system, and give BER vs Eb / No performance curve . 3. Complete the framework and methodology design of using the given FPGA platform for the SCMA system implementation. **Selection criteria in the second round:** 1. Complete the FPGA logic design document, and implement the simplify SCMA uplink multiple access system with given FPGA platform, achieving a correct decoding rate more than 99.9%. 2. Test the BER vs Eb / No performance curve, and compare the results with simulation (allow refreshed optimization in simulations, the difference should be less than 1dB 3. FPGA implementation of the low complexity SCMA decoder, data throughput, processing delays and FPGA chip resource should be optimized.

References 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.

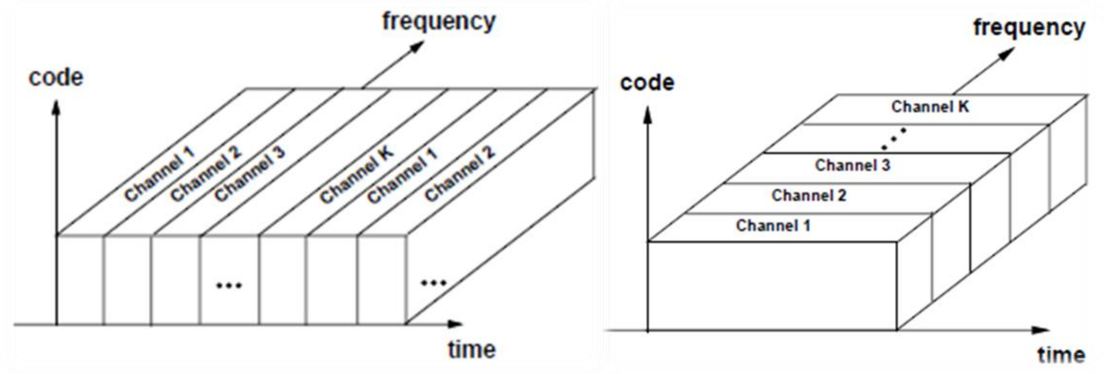
Outline

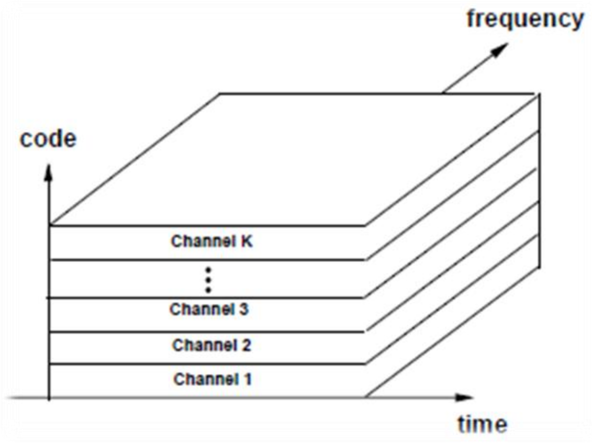
- What is SCMA?
- Why we need SCMA in 5G?
- How does SCMA work?
- What will you implement?

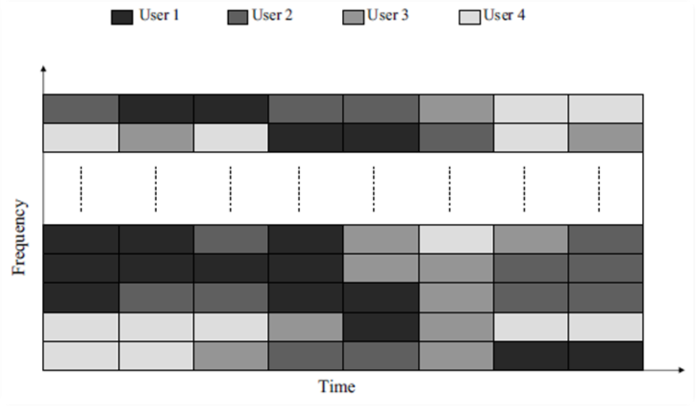
To have a gut feeling what is sparse code multiple access

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

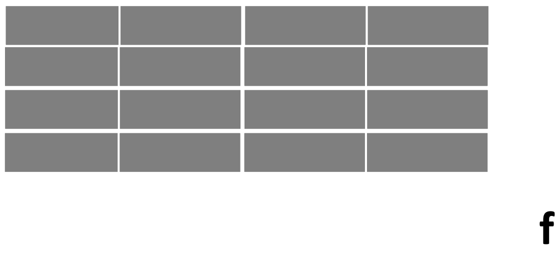
OFDMA

- 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

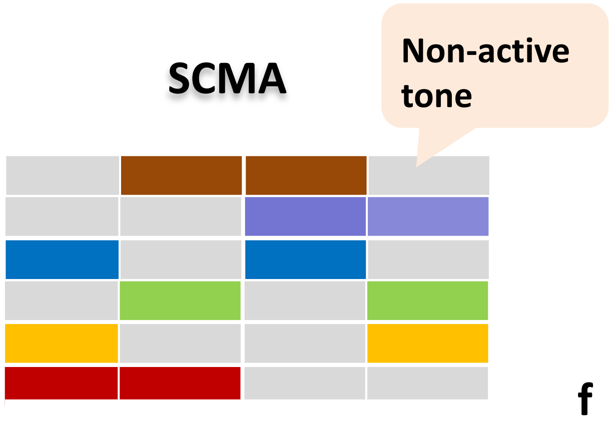
Orthogonal multi-user multiplexing

- 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



Non-orthogonal multi-user multiplexing

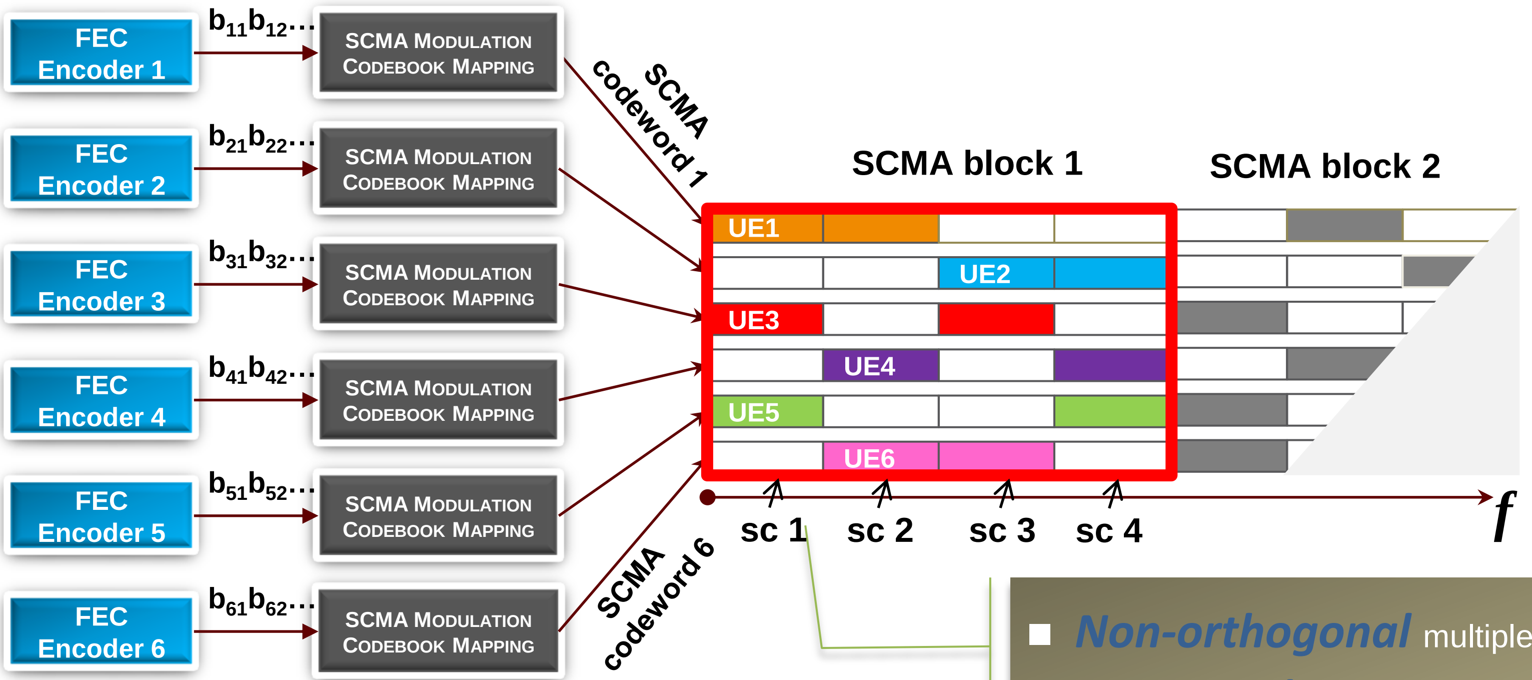
- Users occupy the same resource blocks using CDMA
- Non-practically high multi-user joint detection complexity
- Limited number of concurrent users due to limited sequences
- Better coverage due to spreading gain



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)

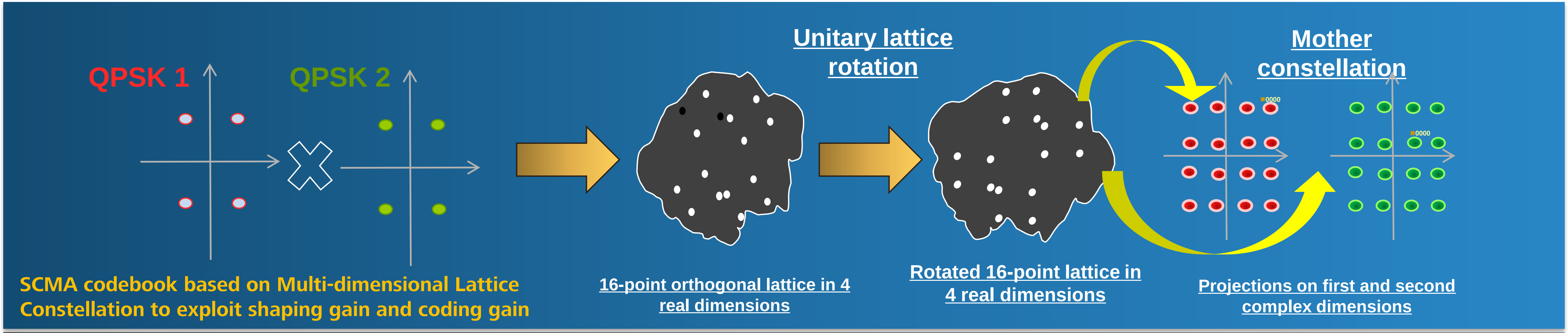


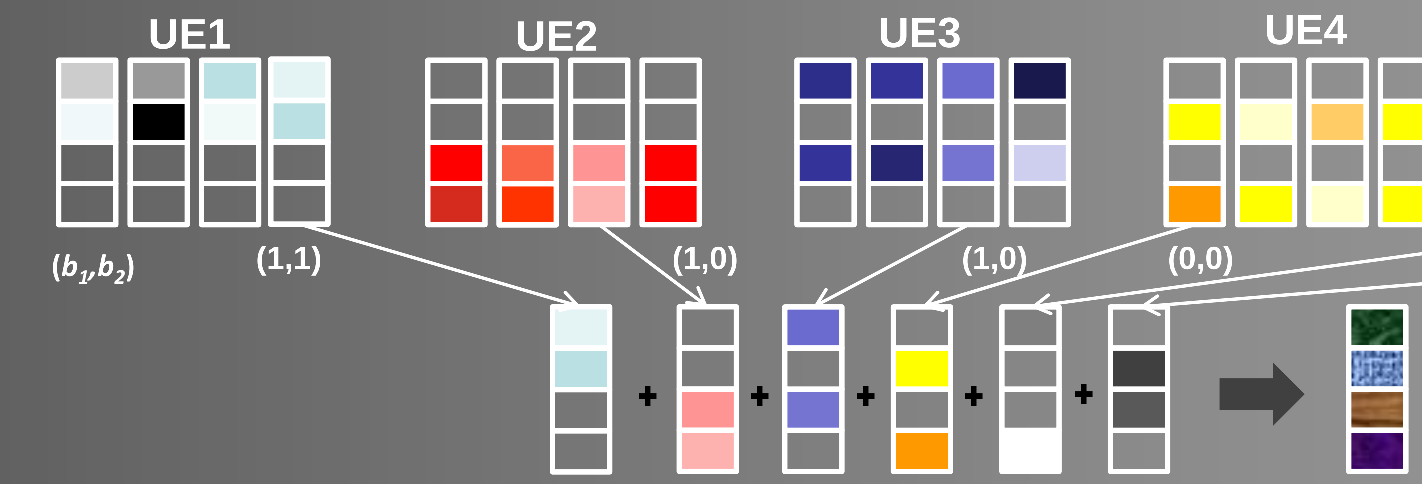
- ***Non-orthogonal*** multiplexing of code layers
- ***Over-Loading*** to increase overall rate and connectivity
- ***Sparsity*** to limit Rx complexity for detection
- ***Spreading*** for robust link-adaptation, coverage
- ***Multi-dimensional*** codewords with shaping gain

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

SCMA Codebook Design





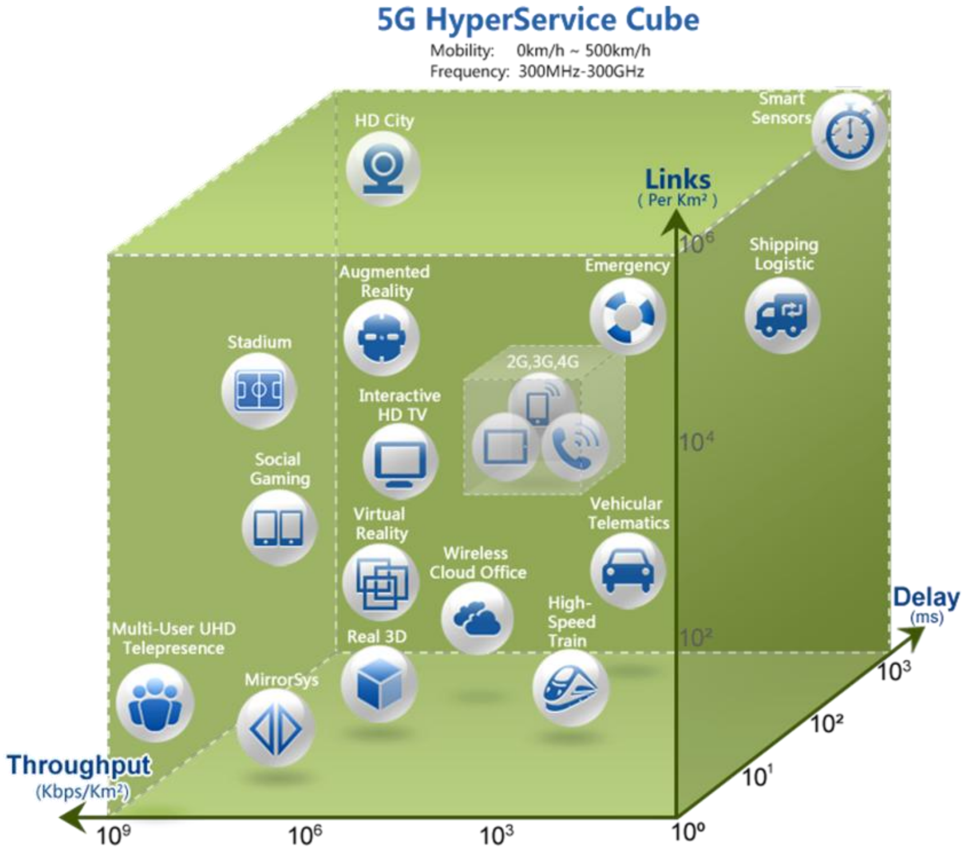
- Each UE/layer stores a unique codebook
- Binary input data is mapped to a codeword of the corresponding codebook

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

Massive Connectivity

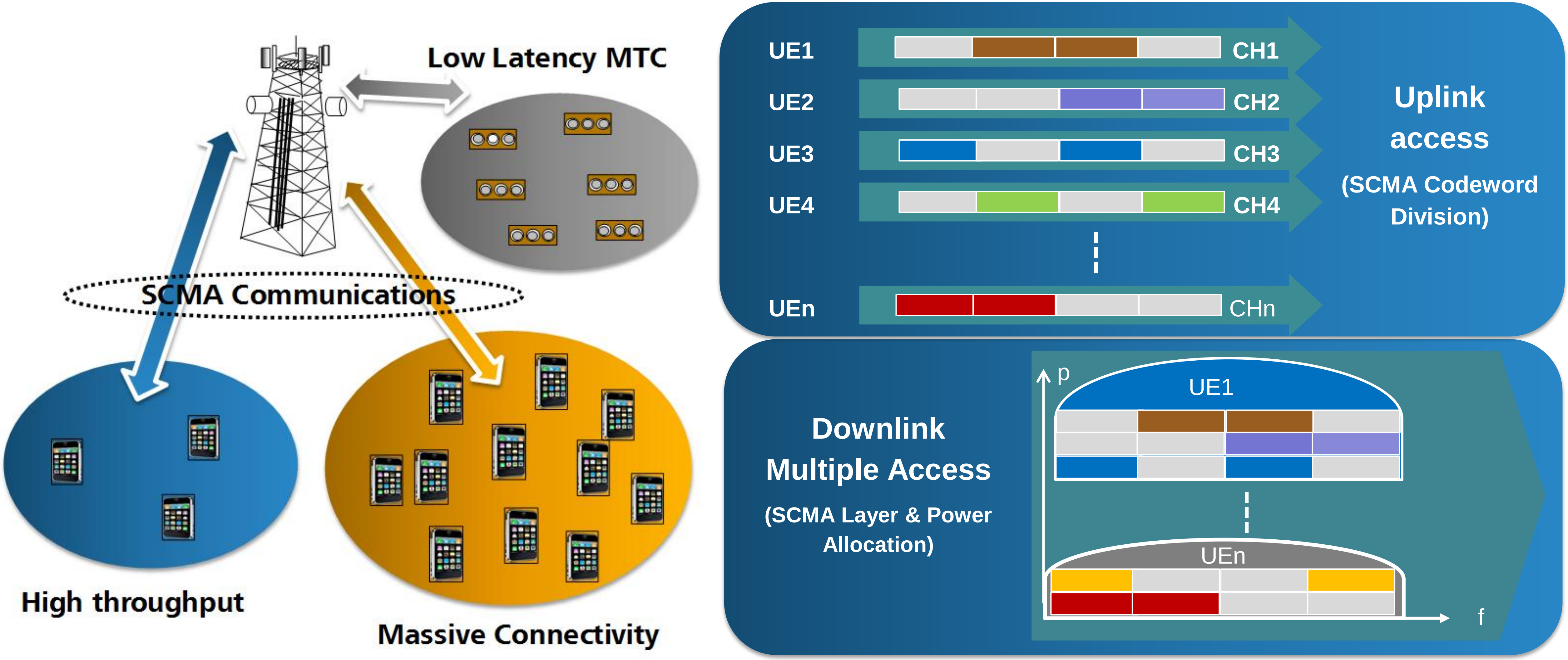
Zero Waiting

10^3 Times Traffic Flooding

10^2 Billion Connections

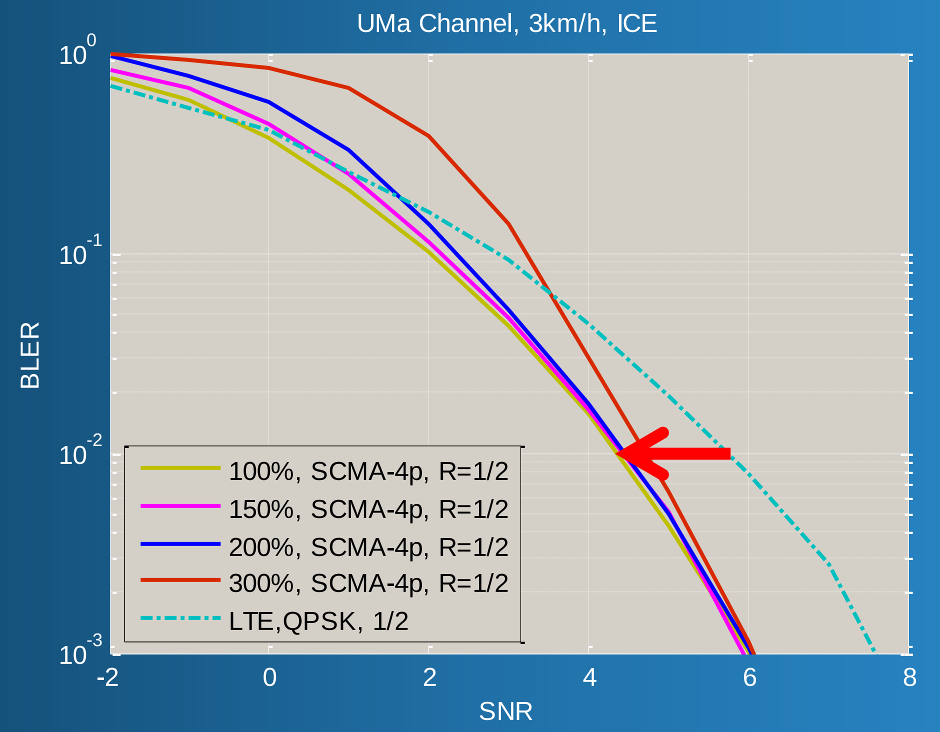
10^0 ms Delay Experience

Example of SCMA Application Scenarios



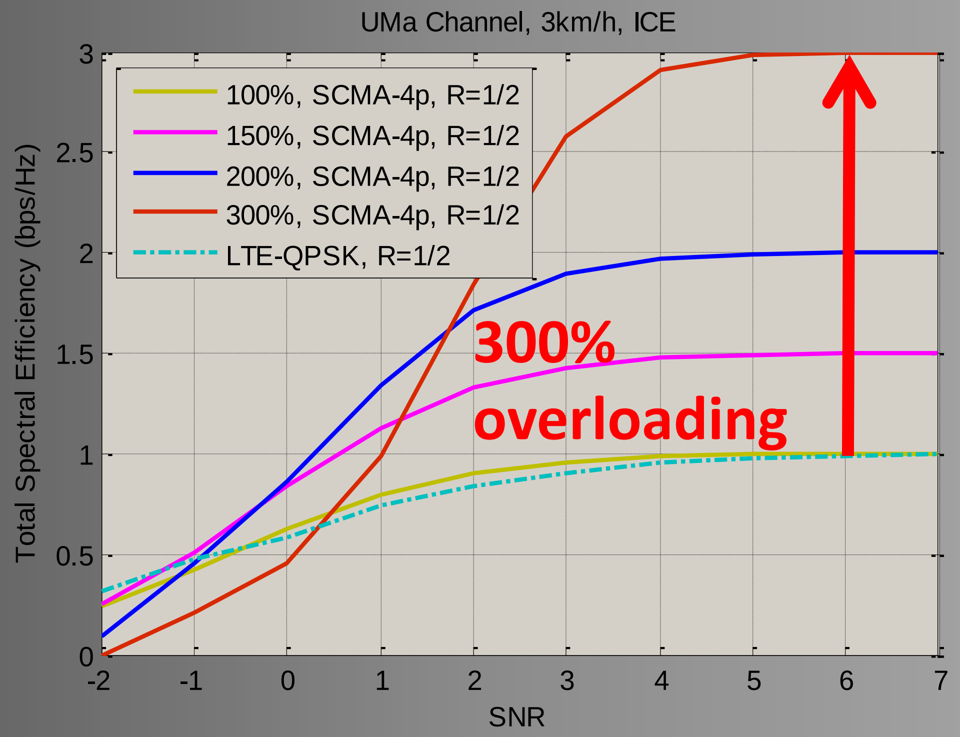
SCMA Offers Better Link Quality and 300% Larger Number of Physical Link Connections over LTE

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

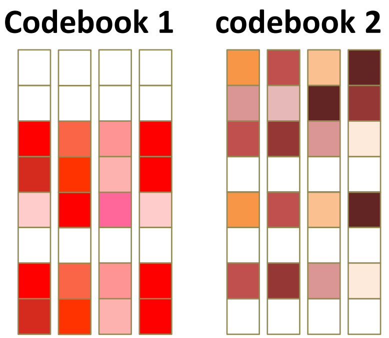
System requirements → **SCMA Configuration** → SCMA Codebook

SCMA Parameters → **SCMA Configuration**

System requirements:
- Coverage
- Connectivity

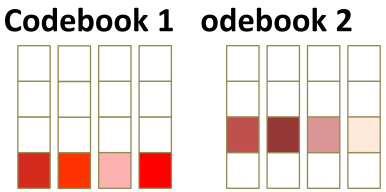
SCMA Parameters:
- Number of codewords of an SCMA codebook: M
- Spreading factor: F
- Max number of layers (or codebooks/signatures) : V
- Number of nonzero elements of each codeword: J

For coverage



Example: larger SF, more non-zero elements

For connectivity



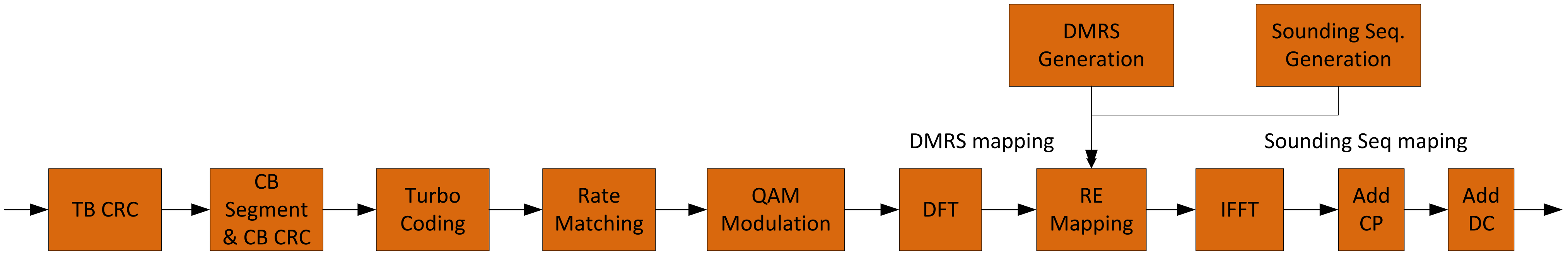
Example: moderate SF, one non-zero element

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

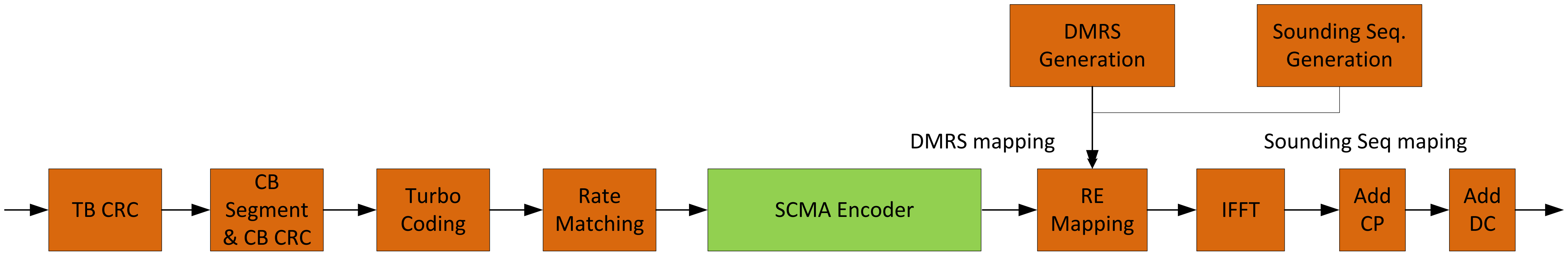
HOW DOES SCMA WORK?

SCMA Uplink Transmission System Diagram

LTE SC-FDMA Transmitter



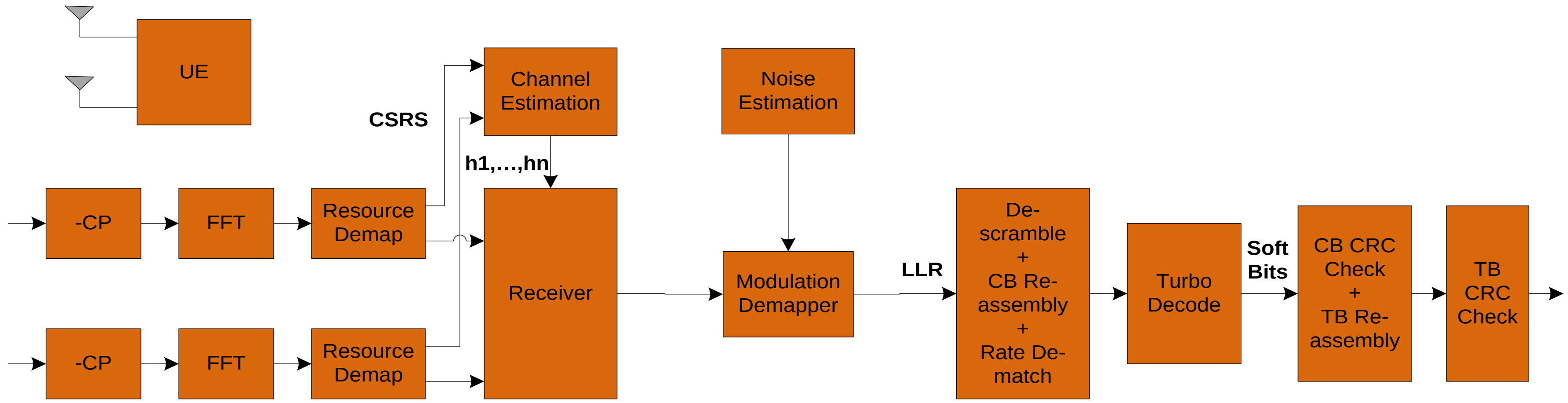
SCMA over OFDM Transmitter



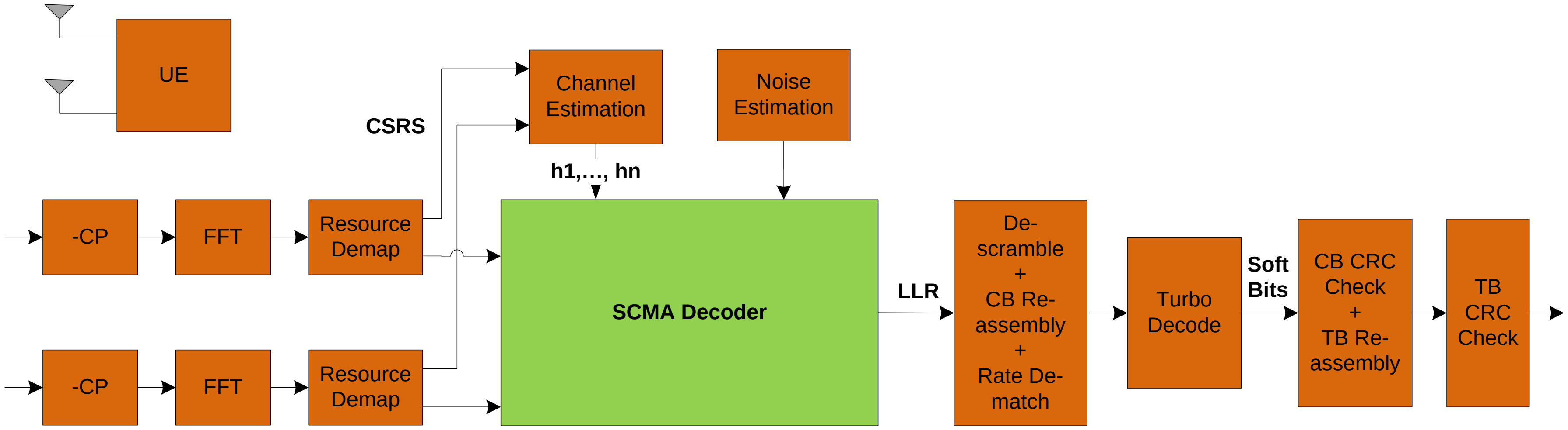
Wanna know more about 4G LTE? Please refer to 3GPP standards or the book “LTE the UMTS Long Term Evolution, from Theory to Practice” from Wiley Press.

SCMA Uplink Transmission System Diagram

LTE OFDMA Receiver



SCMA over OFDM Receiver

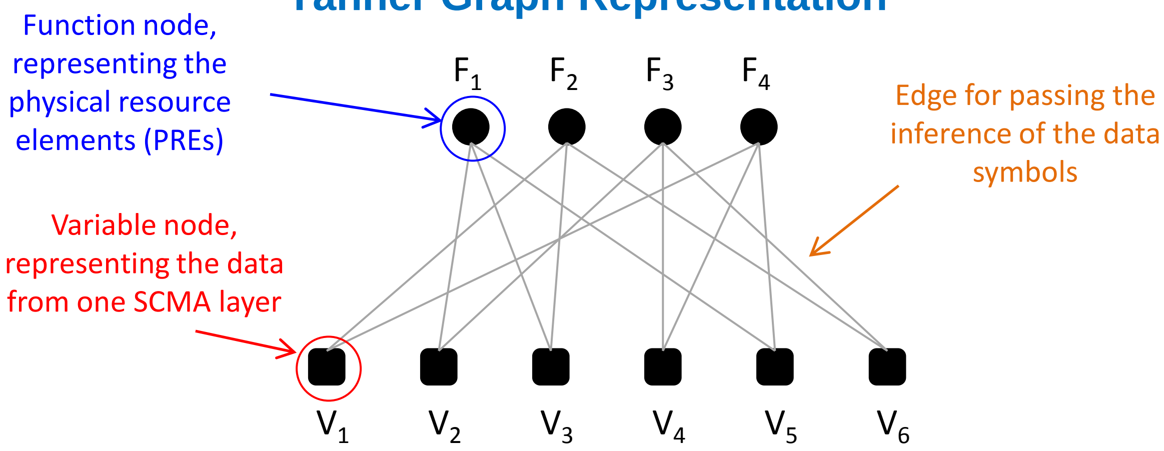


Example of SCMA Codebook

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)

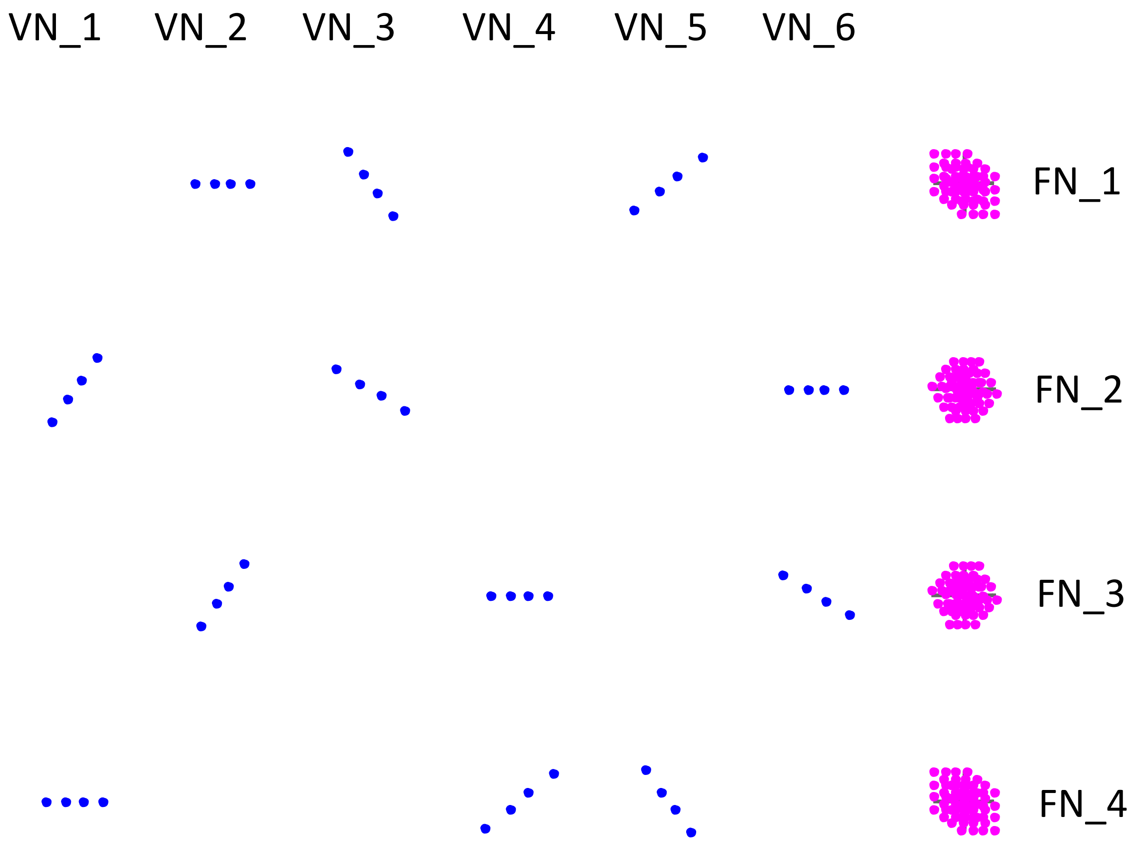
SCMA Codebook index	SCMA codebook for each layer
CB_1	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \end{bmatrix}$
CB_2	$\begin{bmatrix} 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \end{bmatrix}$
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

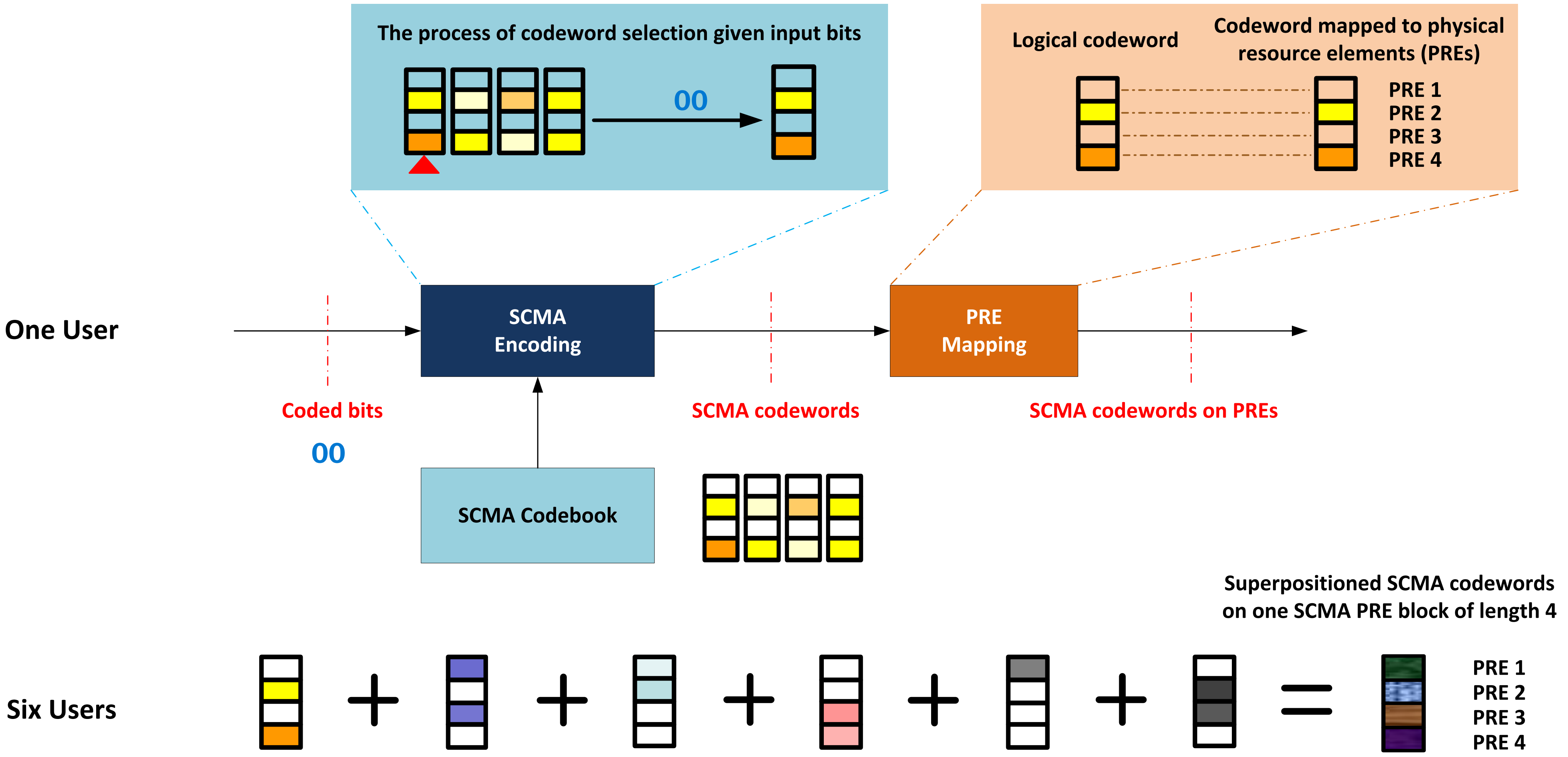
Codebook in Storage (V=6, F=4, df=3, dv=2, M=4)

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	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \end{bmatrix}$

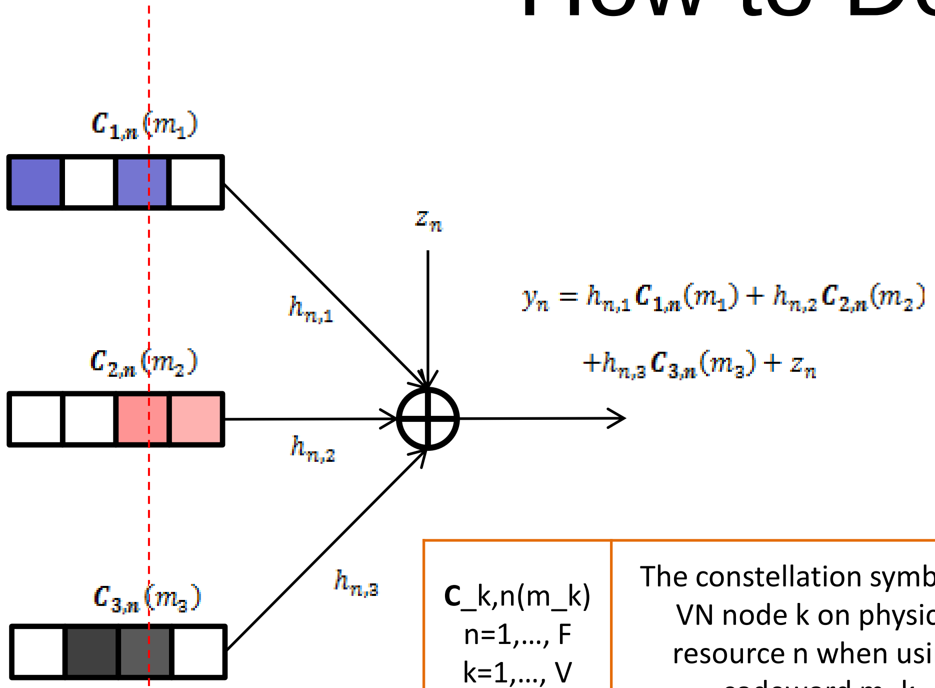
Codebook Presented by Constellation Points

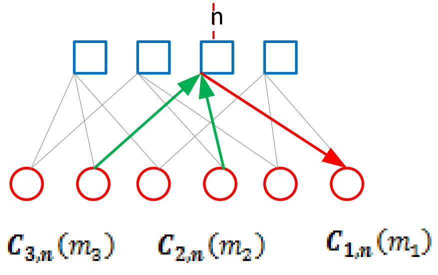


How to Do SCMA Encoding with SCMA Codebook



How to Do SCMA Decoding





C_k,n(m_k) n=1,…, F k=1,…, V	The constellation symbol of VN node k on physical resource n when using codeword m_k
h_n,k n=1,…, F k=1,…, V	Channel coefficient of user k (layer k/ VN node k) on physical resource n
z_n n=1,…, F	White noise at physical resource n
y_n, 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**

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

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

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

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

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

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

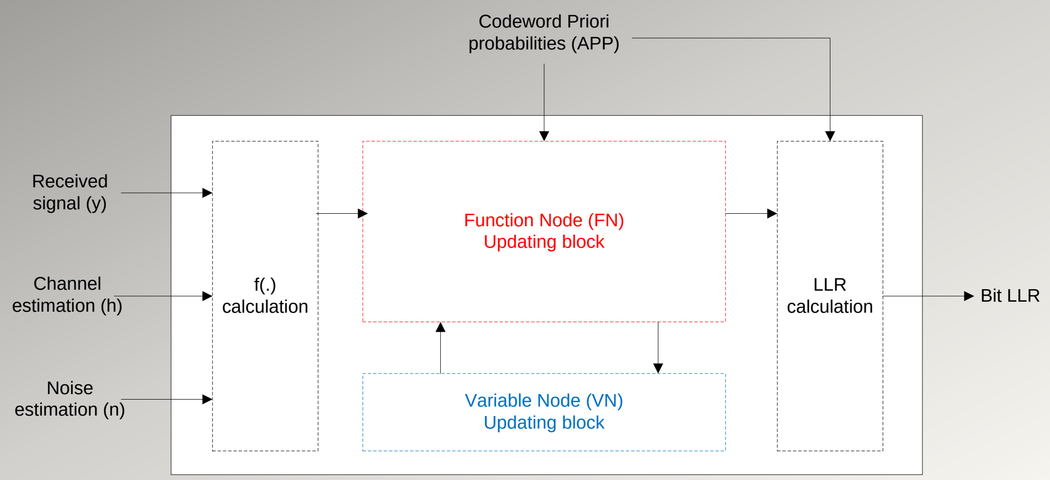
R. Hoshyar, F. P. Wathan, R. Tafazolli, ''Novel low-density signature for synchronous CDMA systems over AWGN channel,'' IEEE Trans. Signal Processing, vol. 56, No. 4, Apr 2008.

How to Do SCMA Decoding with MPA Algorithm

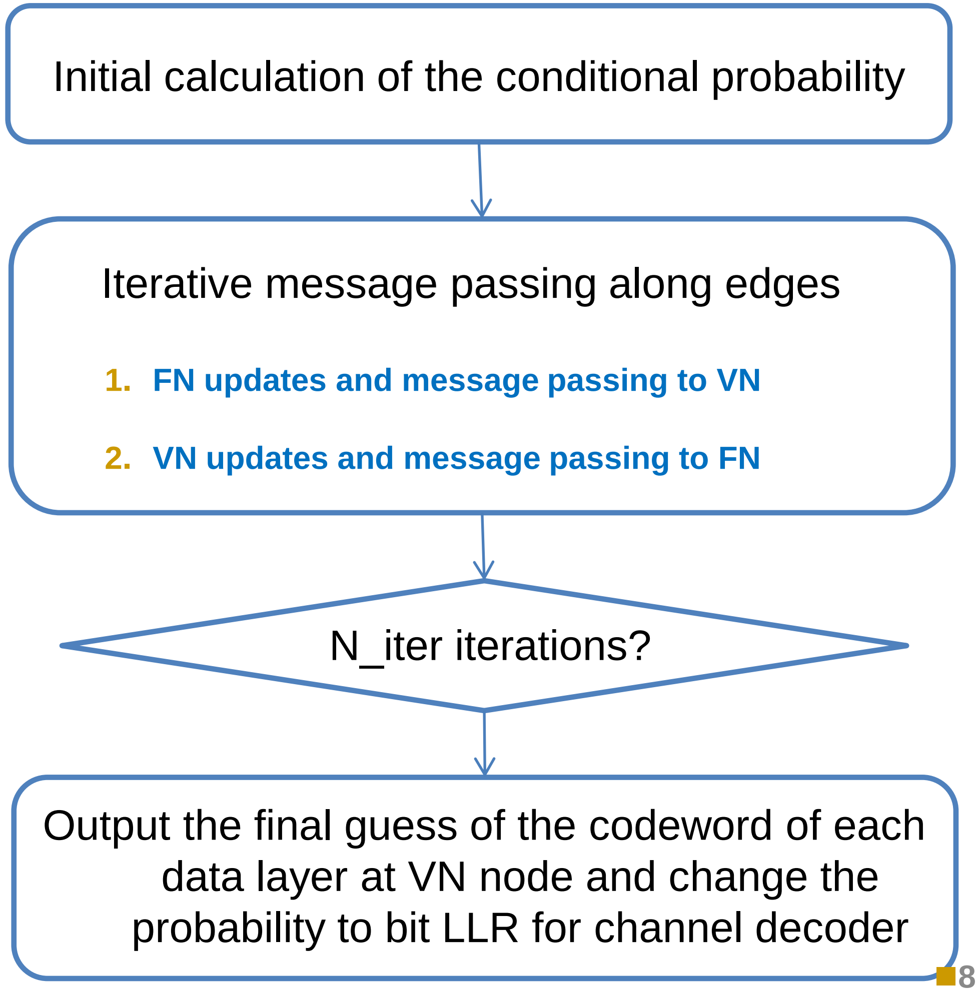
Selection of SCMA Decoder

- 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

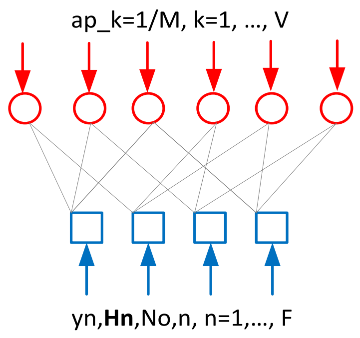


MPA Decoder (Performed for each SCMA block)



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

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

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

- 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

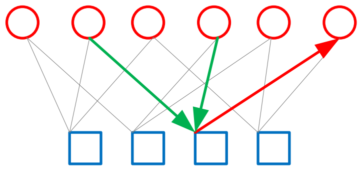
P(yn|x1, x2, x3) ----- $\Phi_n(y_n, m_1, m_2, m_3, N_{0,n}, H_n) = \exp\left(f_n(y_n, m_1, m_2, m_3, N_{0,n}, H_n) \right)$

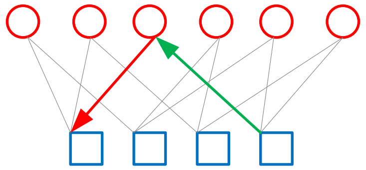
- To prepare for the iterations, we assign the a prior probability for each codeword, which is assumed to be equal

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

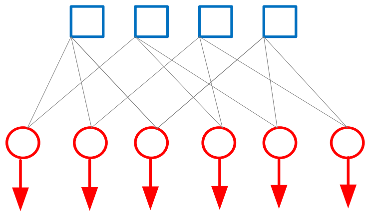
- VN node v passes updates obtained from extrinsic information to its neighboring FN nodes (v to g1, information from g2 is extrinsic)
- In the dv=2 case, it is actually a "guess" swap at VN node

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

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

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

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

- 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

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

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

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**

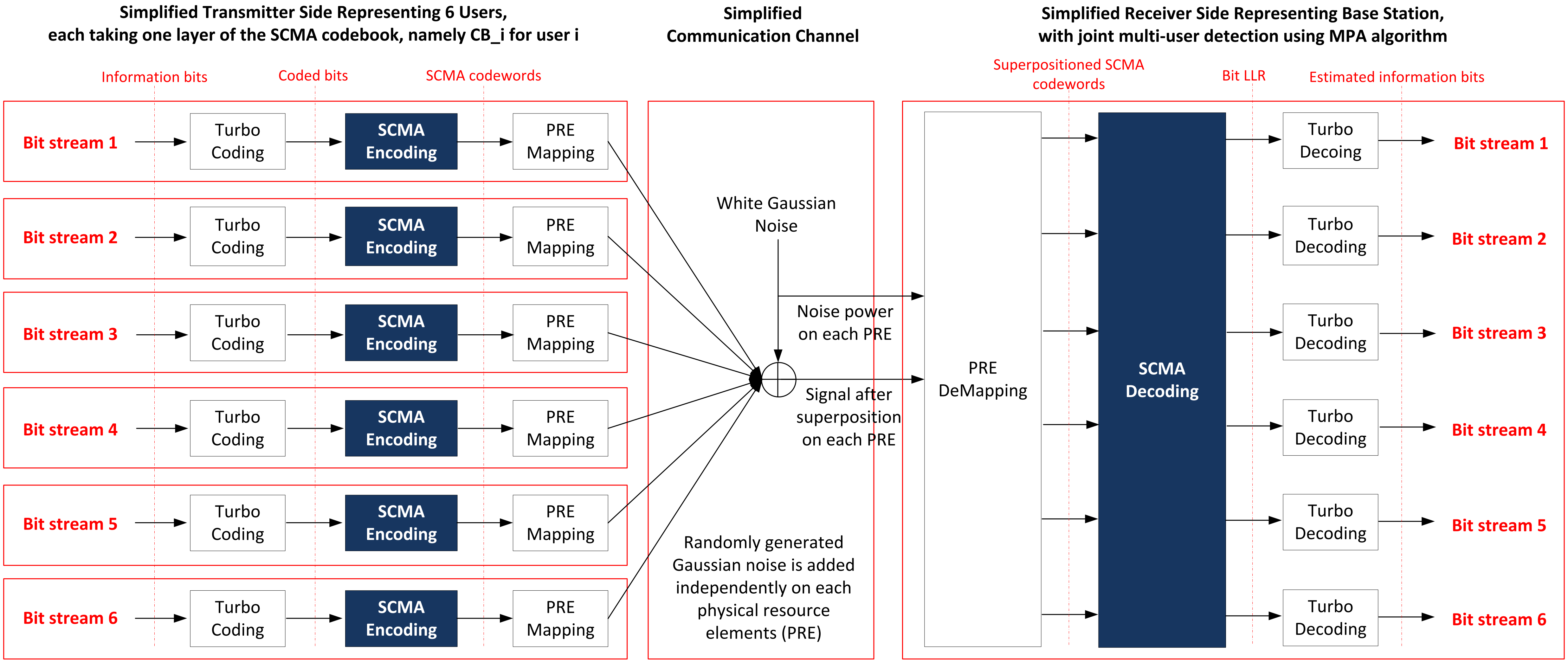
$$\log\left(\sum_{i=1}^{N}\exp(f_i)\right) \approx \max\{f_1, f_2, \ldots, f_N\}$$

- **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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