第一届5G算法创新大赛
——F-OFDM

现场宣讲&答疑会

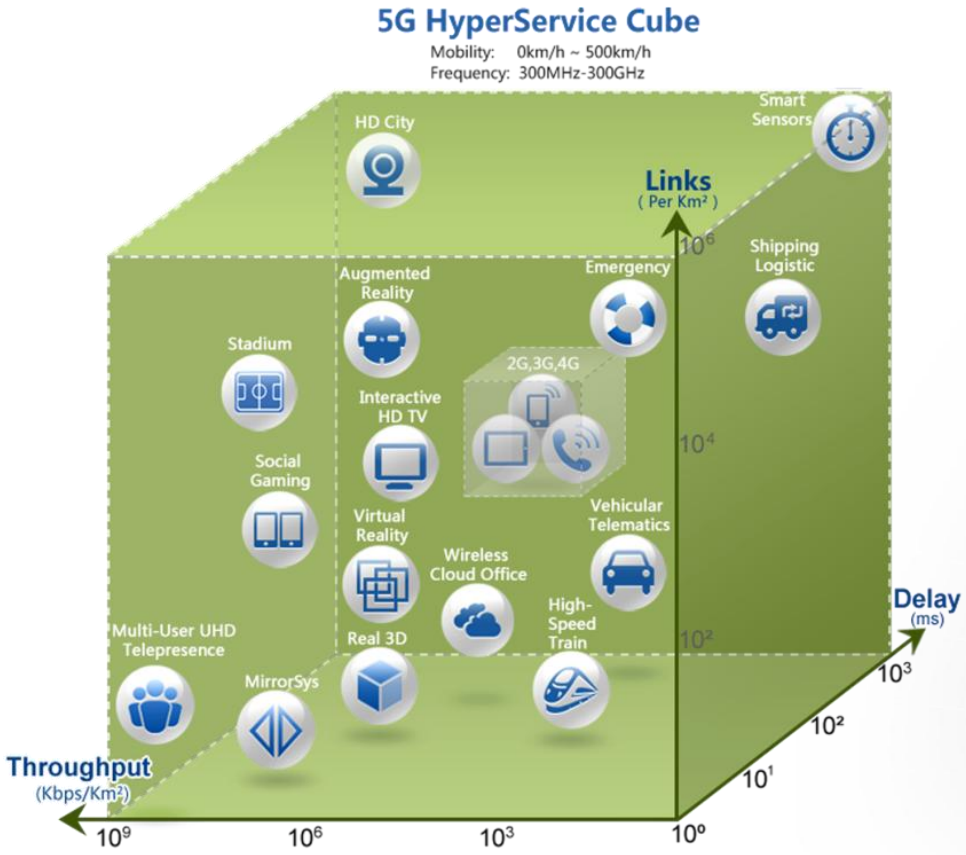
2015年7月16日

Outline

- Motivation of F-OFDM
- Introduction of simulation link
- Introduction of filter design
- MATLAB Demo

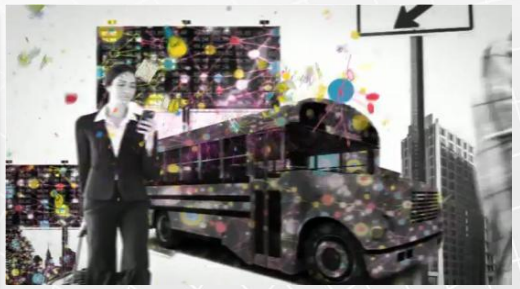
MOTIVATION OF F-OFDM

5G Vision: Zero Distance Communications



Massive Capacity

Massive Connectivity



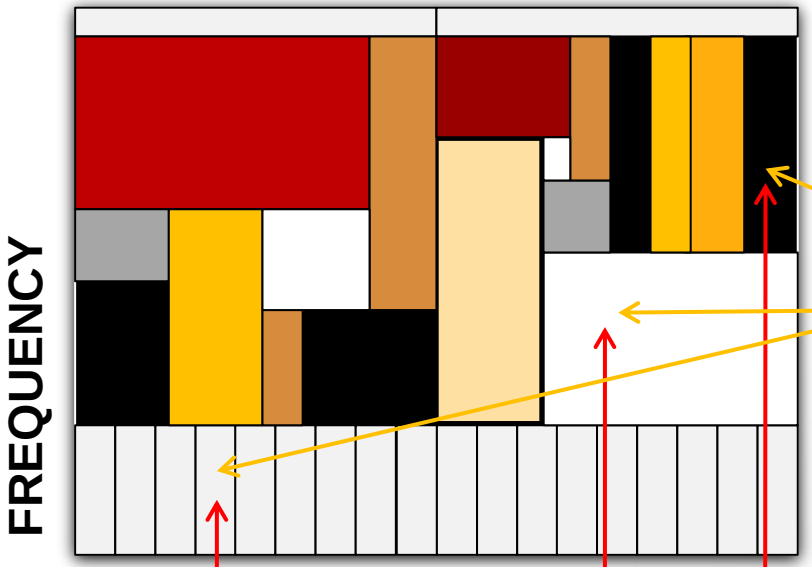
Zero Waiting

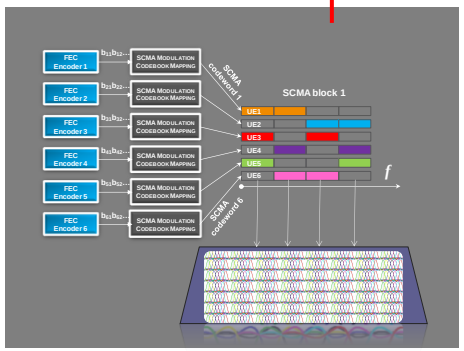
10^3 Times Traffic Flooding

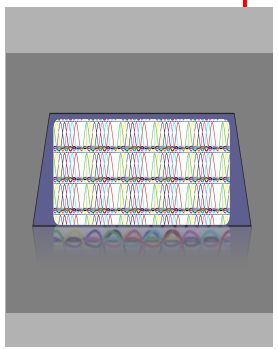
10^2 Billion Connections

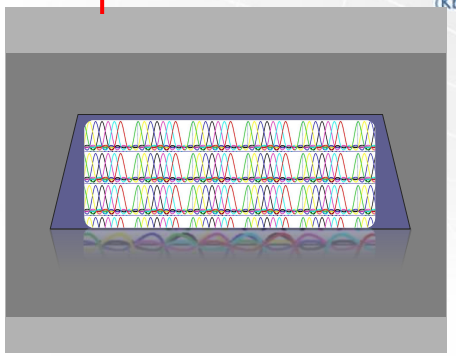
10^0 ms Delay Experience

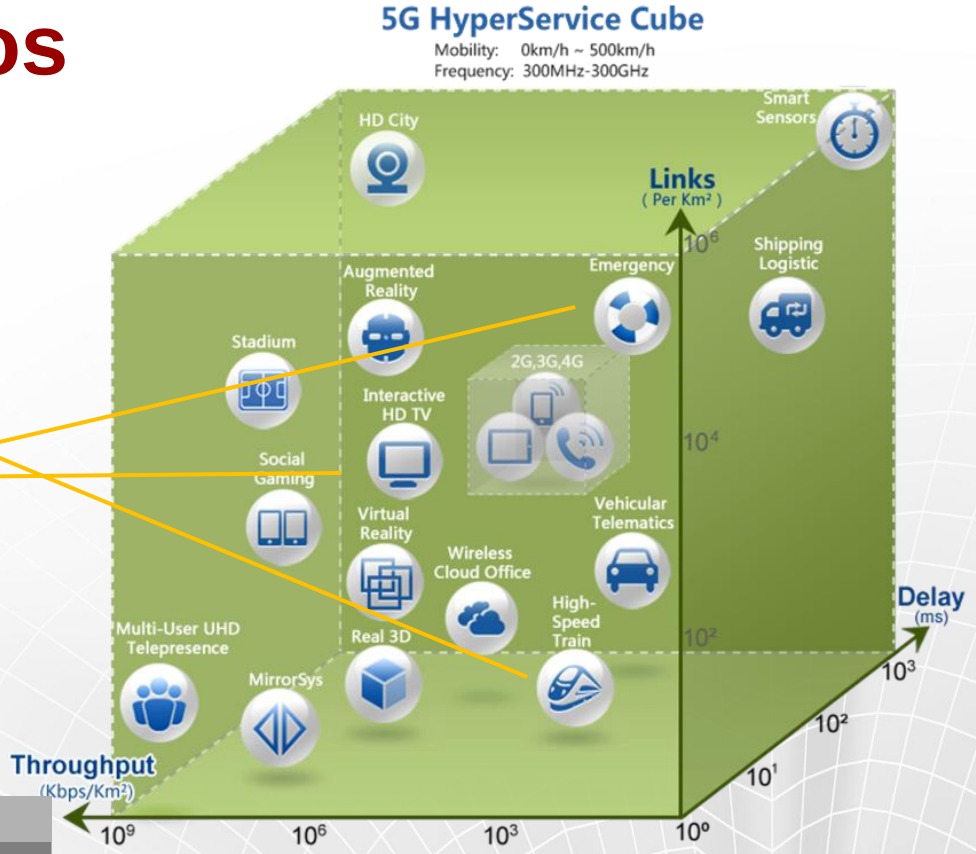
F-OFDM Application Scenarios







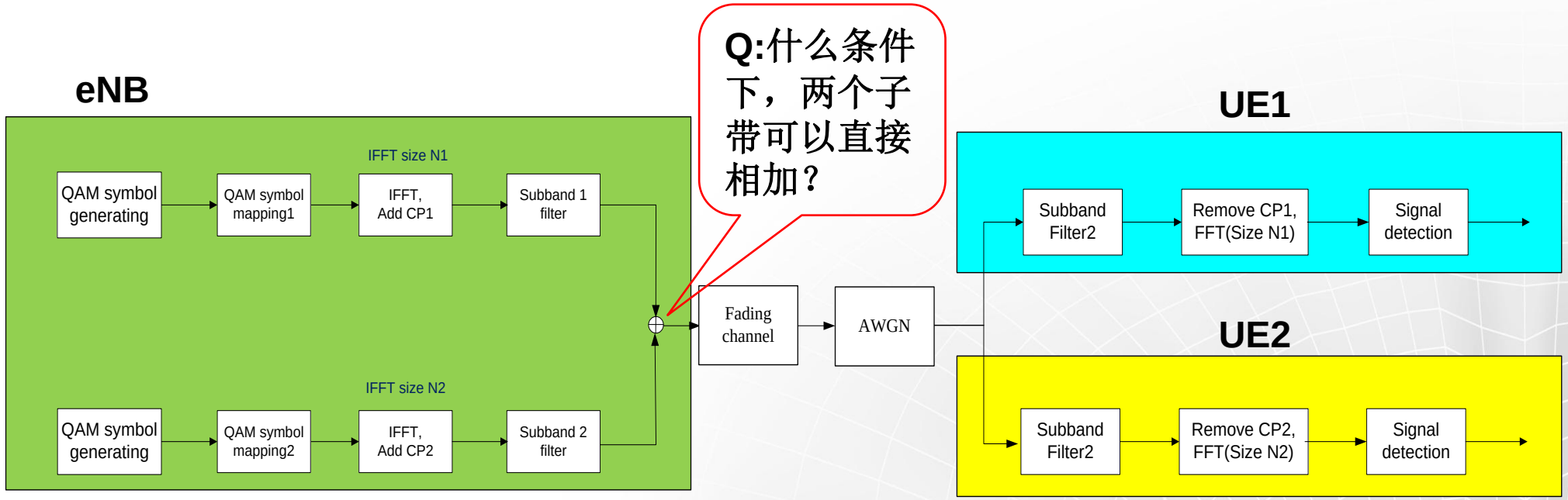




- F-OFDM as the basic 5G waveform, enables the flexible air interface to support co-existence of different waveform / multiple access schemes / flexible TTI configurations
- F-OFDM enables straightforward backward compatible & forward compatible

INTRODUCTION OF SIMULATION LINK

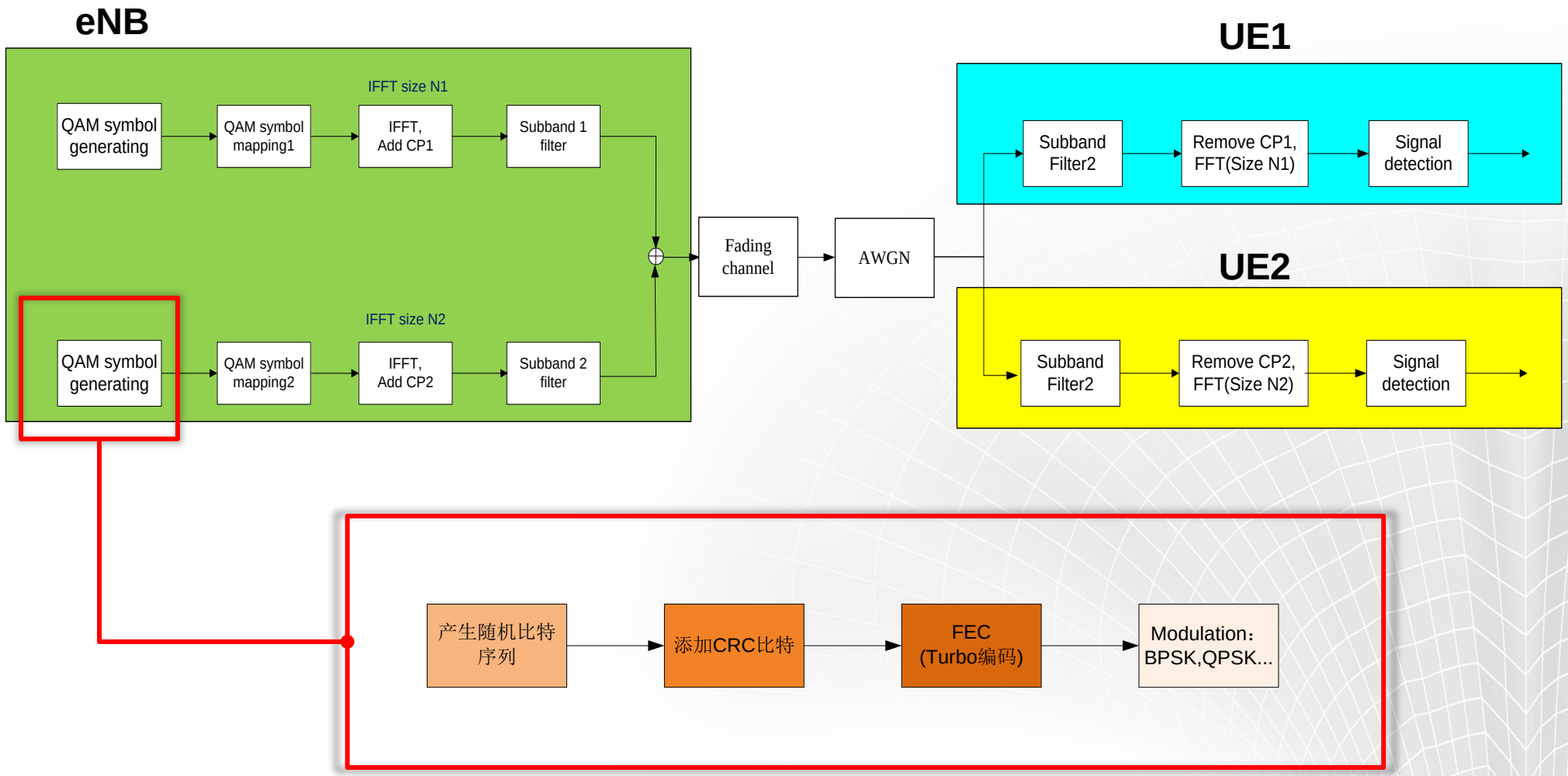
Simplified Downlink F-OFDM System to be Implemented



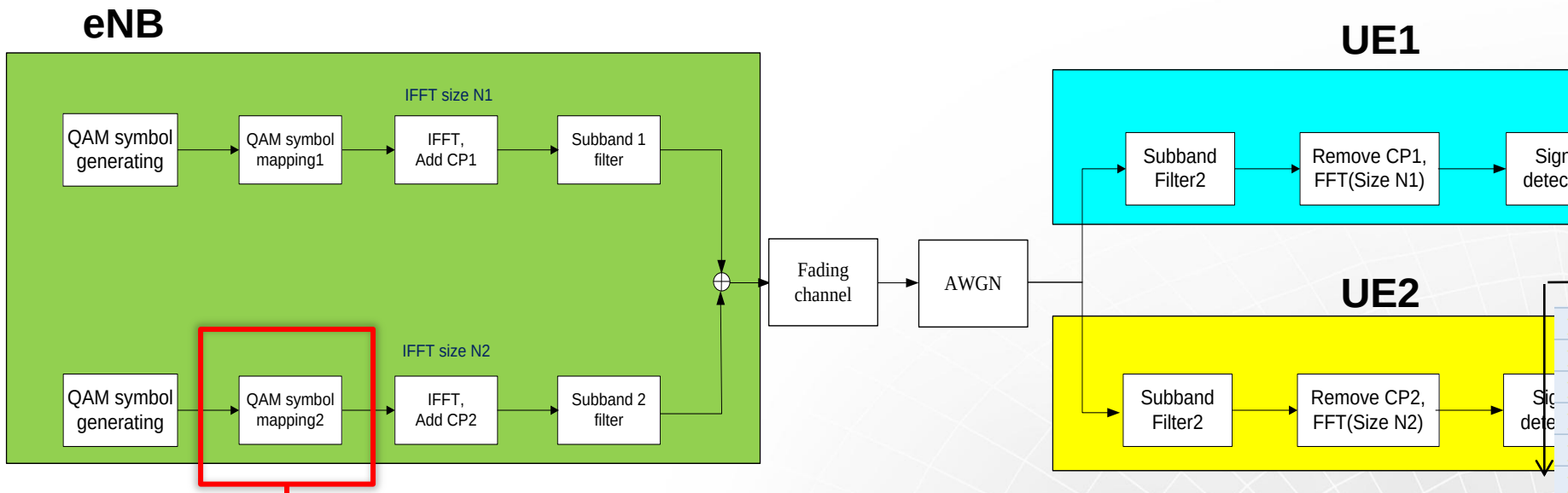
Link Parameters

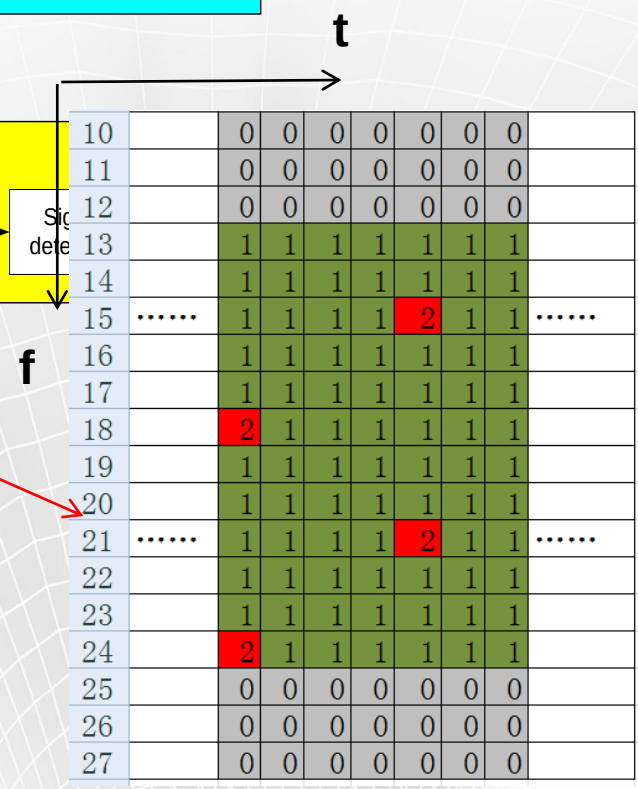
Parameters	F_OFDM @ subband1	F-OFDM @subband2	
Duplex	FDD		
Antenna config.	SISO		
Sampling rate	30.72Mbps		
Subband BW	720KHz	720KHz	Configurable, two sub-bands can be different.
Subcarrier spacing	15KHz	30KHz	
FFT size	2048	1024	
Symbol duration	1/15K=66.67us	1/30K=33.33us	
TTI	1ms	0.2ms	
# symbol per TTI	14	5	
CP length	160 samples(5.2us) for symbol 1 144 samples(4.7us) for symbol 2~7	224 samples for symbol 1 200 samples for symbol 2~5	
Guard tone number	0/1/2/3		
CRC	24 bit		
Modulation	QPSK/16QAM/64QAM		Configurable, two sub-bands can be different.
Turbo coding rate	1/3,1/2, 3/4		Configurable, two sub-bands can be different.

Simplified Downlink F-OFDM System to be Implemented



Simplified Downlink F-OFDM System to be Implemented

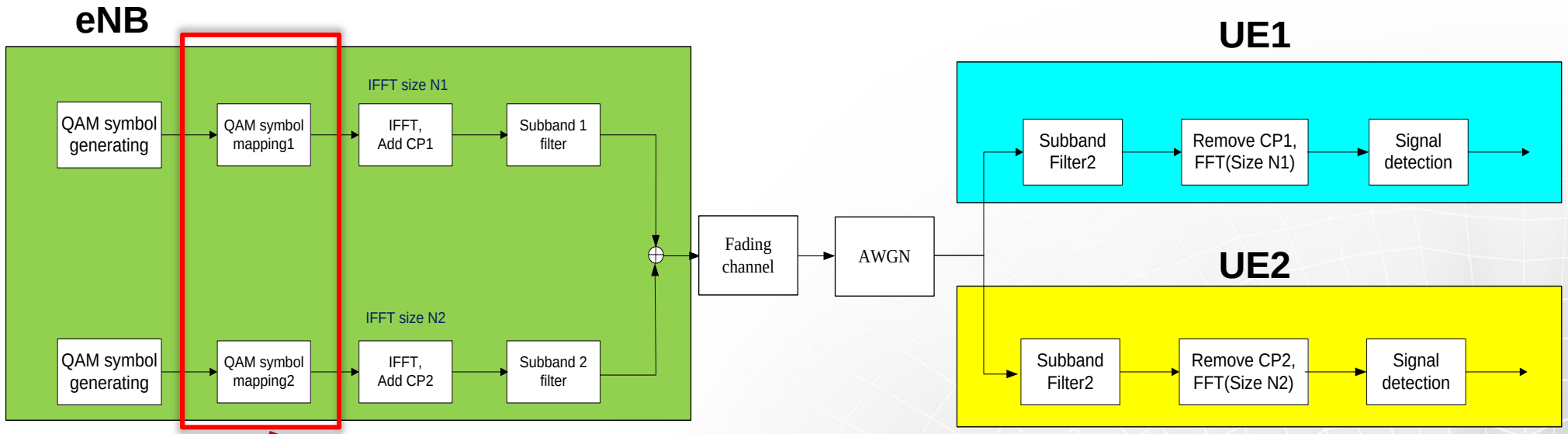


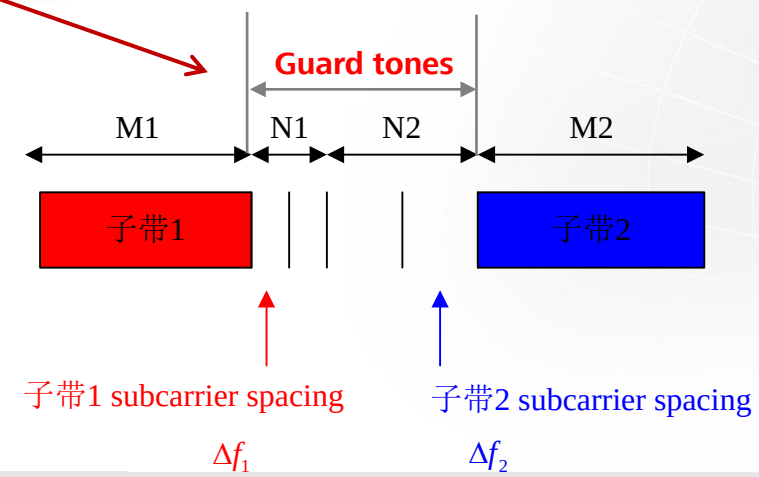


- **DataMapped = data_resource_mapping(QAMsymbol, TableResource)**
  - 功能：把QAM符号映射到时频资源上
  - 输入：
    - **QAMsymbol** – 复数星座点形式的QAM符号
    - **TableResource** – 指示QAM符号映射的时频位置
  - 输出： **DataMapped** – 映射到时频资源上的数据

0：该位置添0；
1：该位置映射数据符号；
2：该位置映射导频

Simplified Downlink F-OFDM System to be Implemented





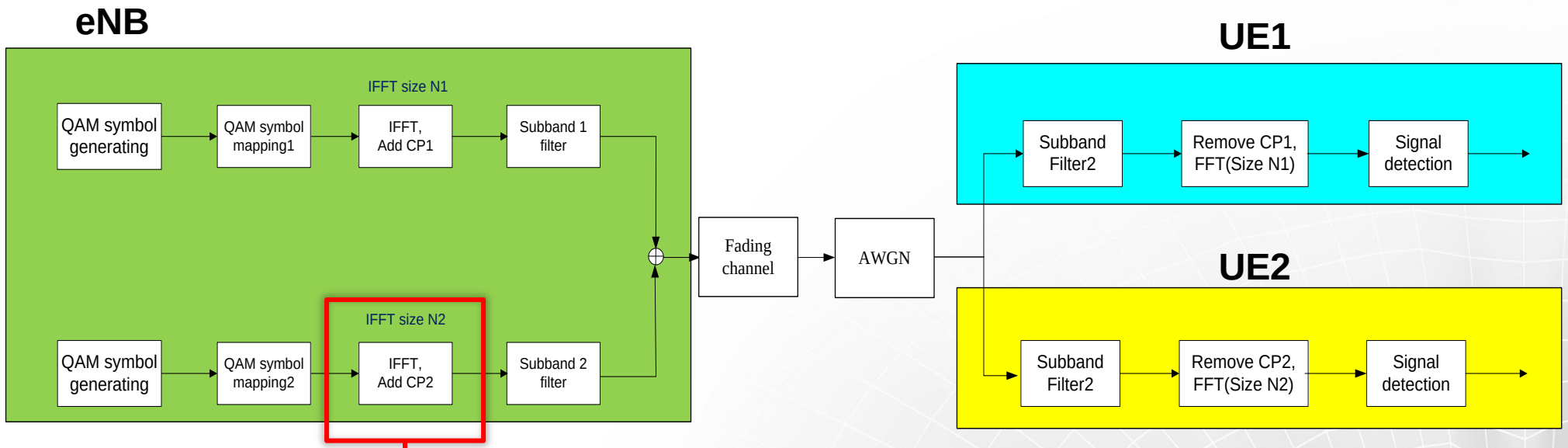
以两个子带均为720KHz带宽为例，则M1=48，M2=24。

假设子带1的子载波映射编号为[-24, -1] [1 24], 中间的0号子载波为直流分量，不做数据映射。

假设N1=0，N2=1，则子带2的子载波编号应为[14, 37]。

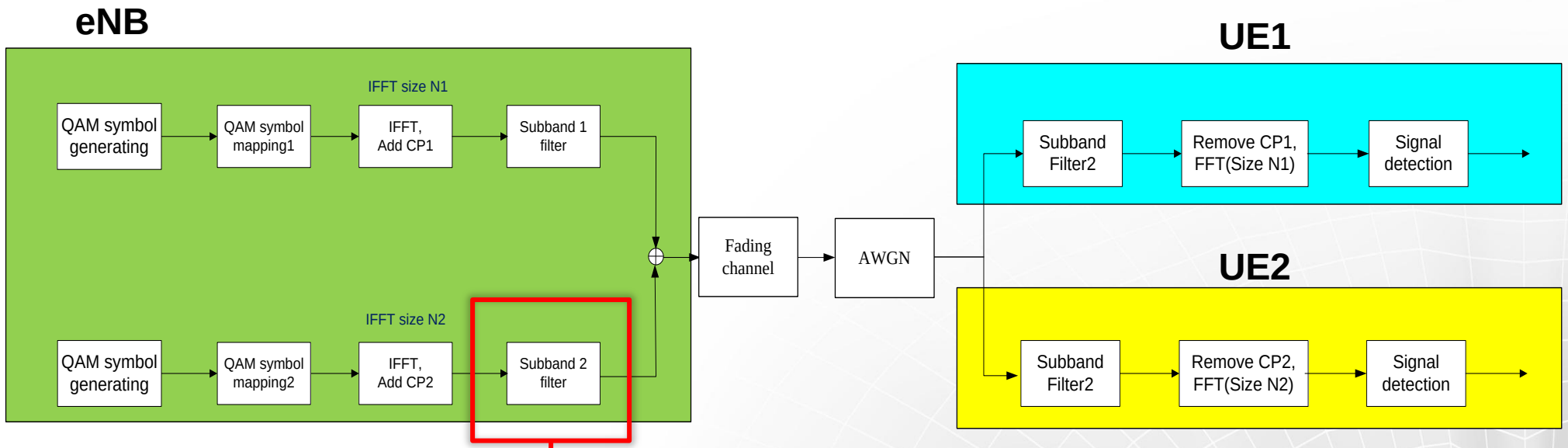
0：该位置添0；
1：该位置映射数据符号；
2：该位置映射导频

Simplified Downlink F-OFDM System to be Implemented



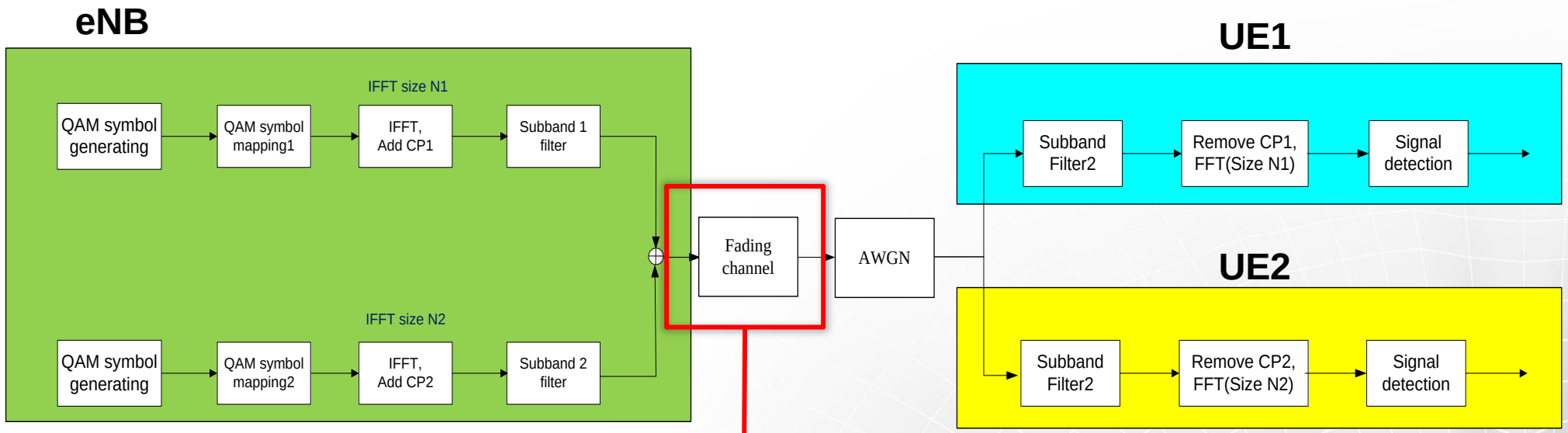
- **OFDMsignal = OFDM_modulation(DataMapped , FFTsize, CPlength)**
  - 功能：**OFDM调制并添加CP**
  - 输入：
    - **DataMapped –映射到时频资源上的数据**
    - **FFTsize – OFDM调制时的FFT点数**
    - **CPlength – OFDM调制后添加的循环前缀的长度**
  - 输出： **OFDMsignal – OFDM调制并添加CP后的时域信号**

Simplified Downlink F-OFDM System to be Implemented



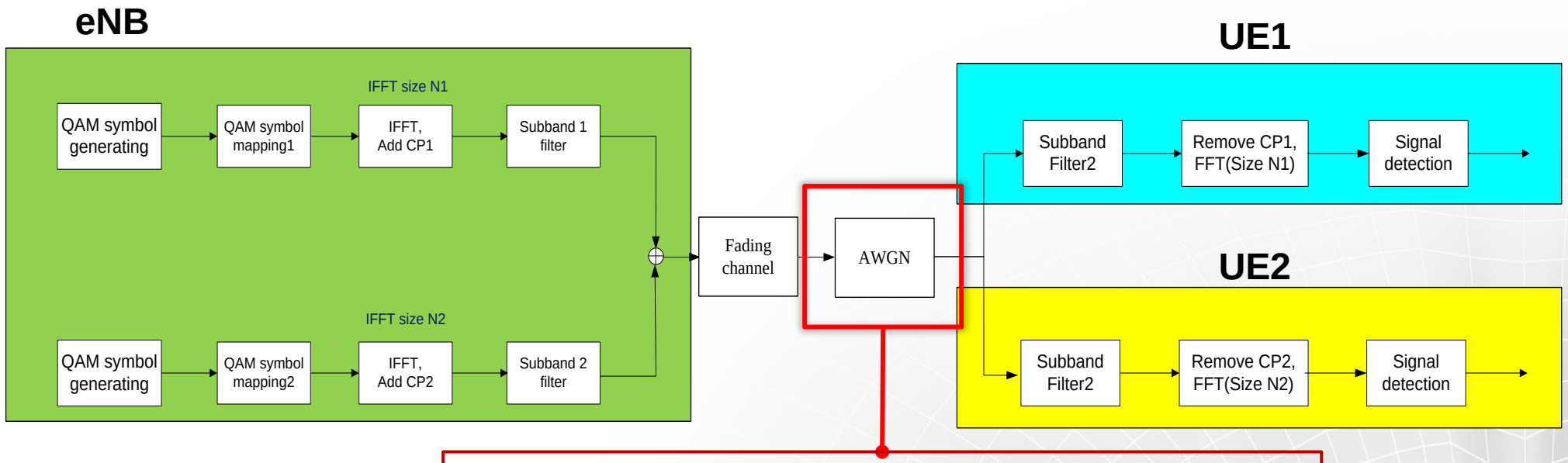
- **SubbandSignal = TX_filter(OFDMsignal, TXfilter)**
  - 功能：发送端时域信号子带滤波
  - 输入：
    - **OFDMsignal–OFDM调制并添加CP后的时域信号**
    - **TXfilter–** 发送端子带滤波器系数
  - 输出： **SubbandSignal –** 滤波后的子带信号

Simplified Downlink F-OFDM System to be Implemented



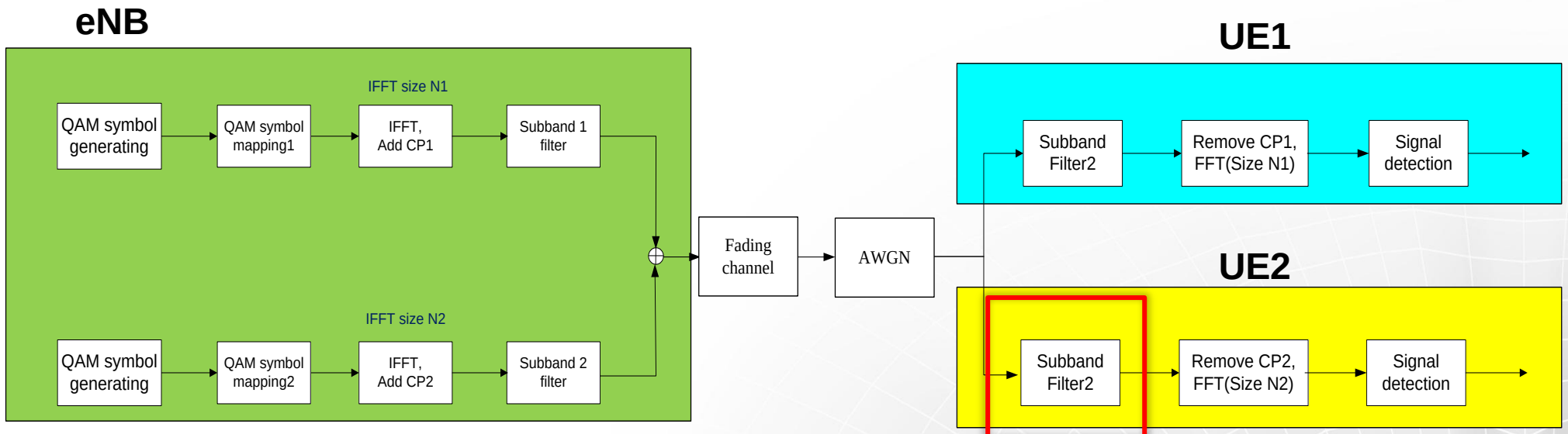
- **DataChannel = pass_fading_channel(Signal, CIR)**
  - 功能：信号通过衰落信道
  - 输入：
    - **Signal**–发送端使时域发送信号
    - **CIR**– 信道脉冲响应
  - 输出： **DataChannel**– 过衰落信道后的时域信号

Simplified Downlink F-OFDM System to be Implemented



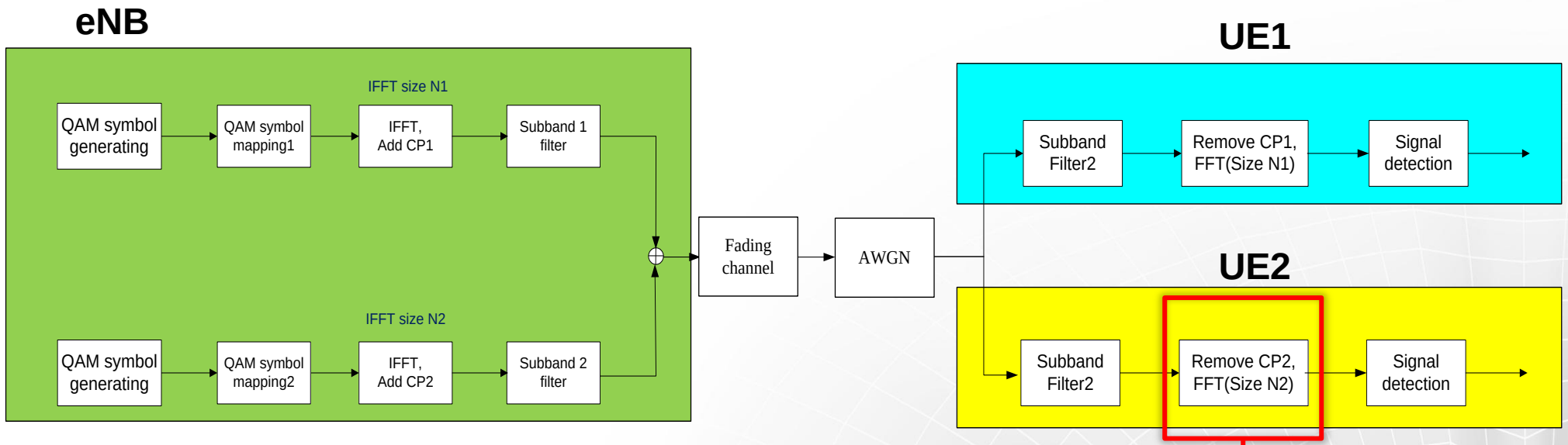
- **ReceivedData = AWGN(DataChannel, SNR)**
  - 功能：加高斯白噪声
  - 输入：
    - **DataChannel**–过衰落信道后的时域信号
    - **SNR**– Es/N0
  - 输出：**ReceivedData** –接收端的时域信号

Simplified Downlink F-OFDM System to be Implemented



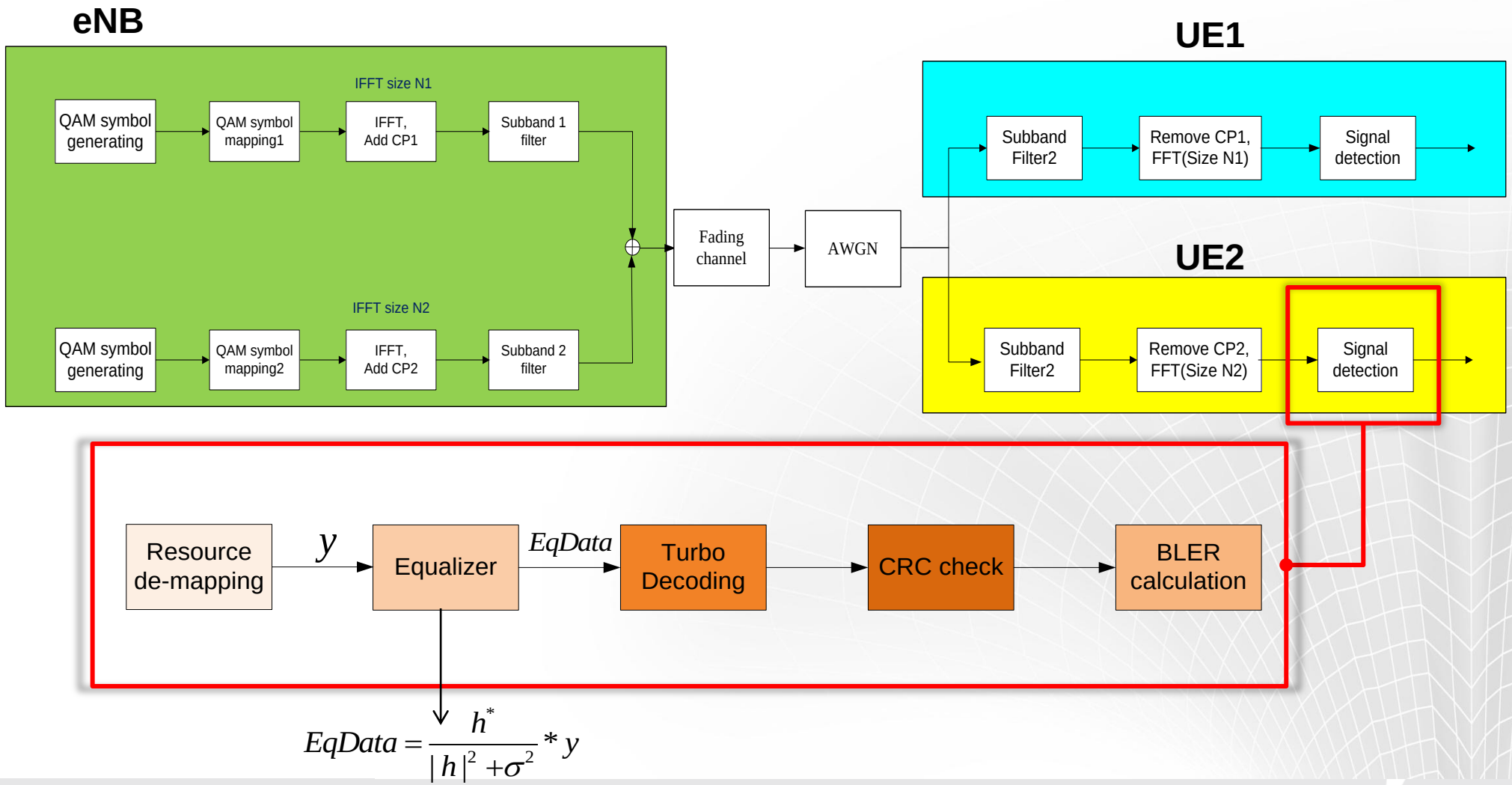
- **RecvdSubbandSignal = RX_filter(RecvdData, RXfilter)**
  - 功能：接收端时域信号子带滤波
  - 输入：
    - **RecvdData**–接收到的时域信号
    - **RXfilter**– 接收端子带滤波器系数
  - 输出： **RecvdSubbandSignal** – 滤波后的子带信号

Simplified Downlink F-OFDM System to be Implemented



- **Signal4Eq = OFDM_Recv(RecvdSubbandSignal , FFTsize, CPlength)**
  - **功能：去CP，OFDM解调**
  - **输入：**
    - **RecvdSubbandSignal –该UE子带上的接收信号**
    - **FFTsize – OFDM调制时的FFT点数**
    - **CPlength– OFDM调制后添加的循环前缀的长度**
  - **输出： Signal4Eq– 接收端待检测的时频信号**

Simplified Downlink F-OFDM System to be Implemented



Demo

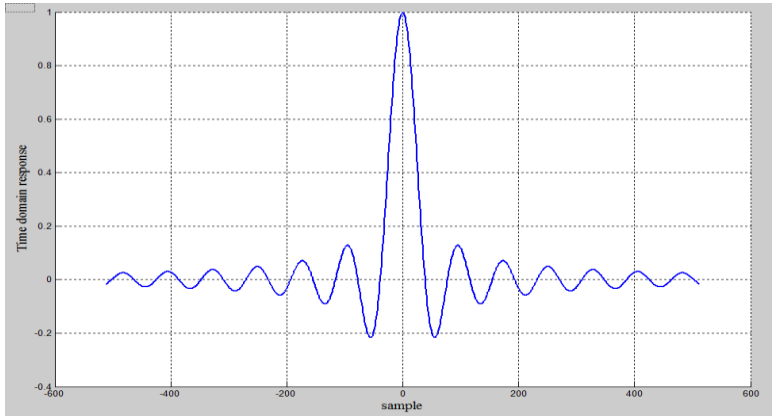
INTRODUCTION OF FILTER DESIGN

Filter design

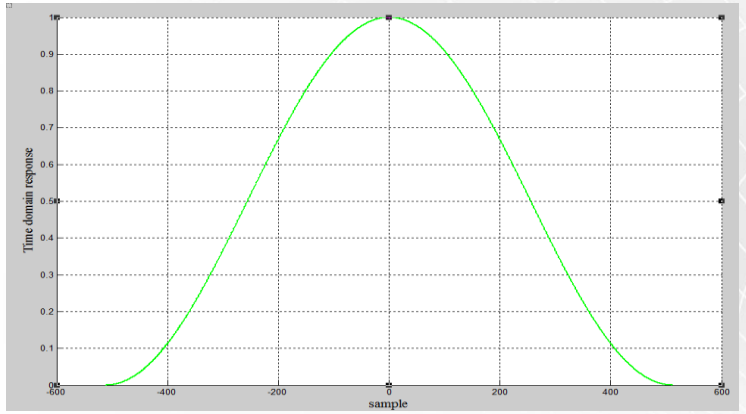
- Soft truncated filter with specific window is recommended to achieve
  - Trade-off between time and frequency localization (that is ISI and ICI)
  - Easy implementation for flexible subband configuration
  - Small round-up error due to frequency domain fixed point implementation

Q: 时域的软截断处理相当于频域的什么操作？

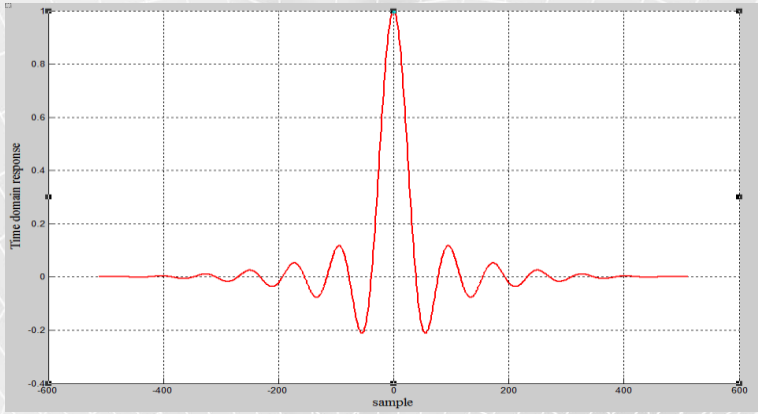
Time domain Sinc function:
Ideal filter with BW = subband BW + some guard tone



Time domain window (e.g. Hanning/Kaiser/RC…) :
to balance pass-band flatness & T/F localization



Final filter



$$W_{Sinc} \cdot W_{spec\_win} = W_{filter\_time}$$

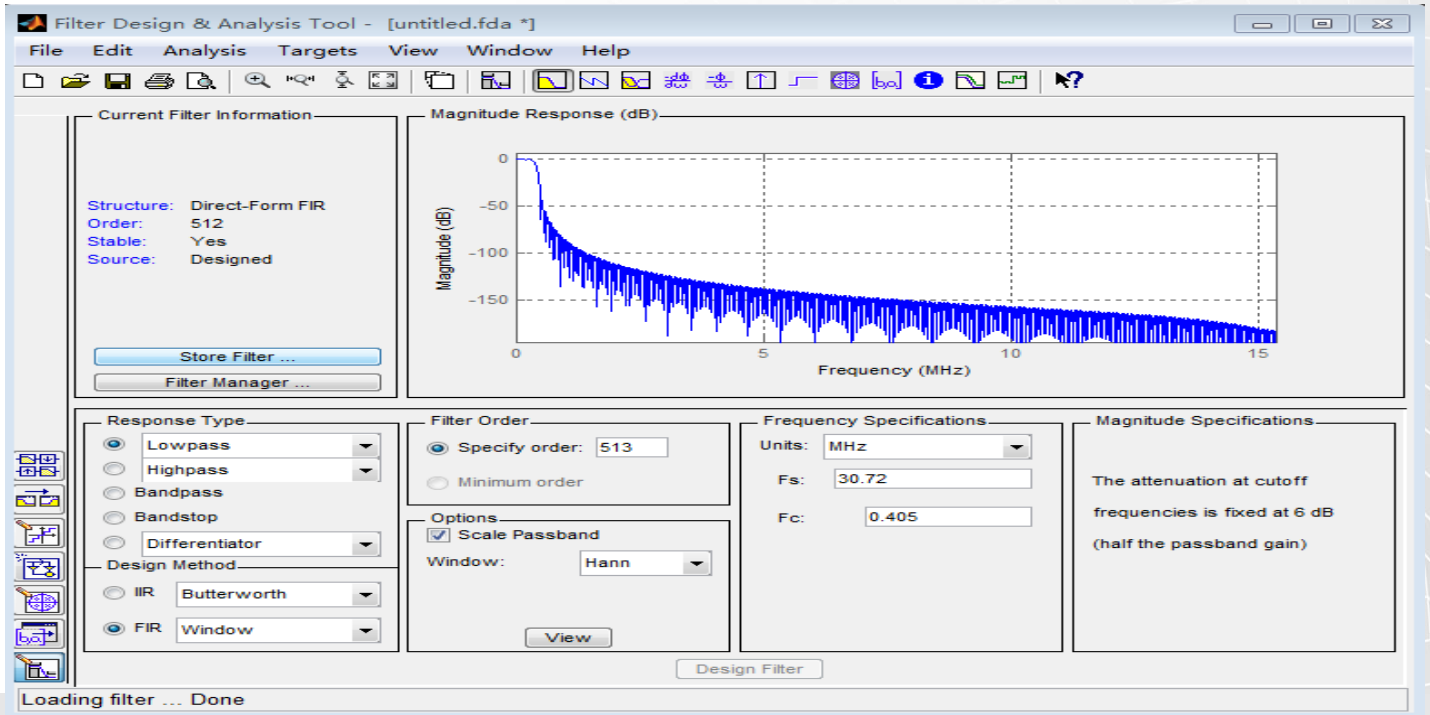
Example of filter

- **Example with Hanning window**
  - Subcarrier spacing = 15KHz
  - Subband = 720KHz
  - Fs = 30.72MHz (LTE baseband sampling rate)

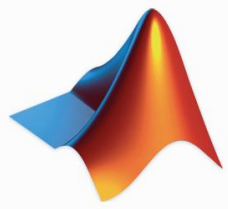
$$W_{filter\_time} = W_{Sinc} \cdot W_{Hanning}$$

$$W_{Hanning}(n) = 0.5\left(1-\cos\left(\frac{2\pi n}{N-1}\right)\right)$$

Matlab built-in filter tool to generate the soft truncated filter



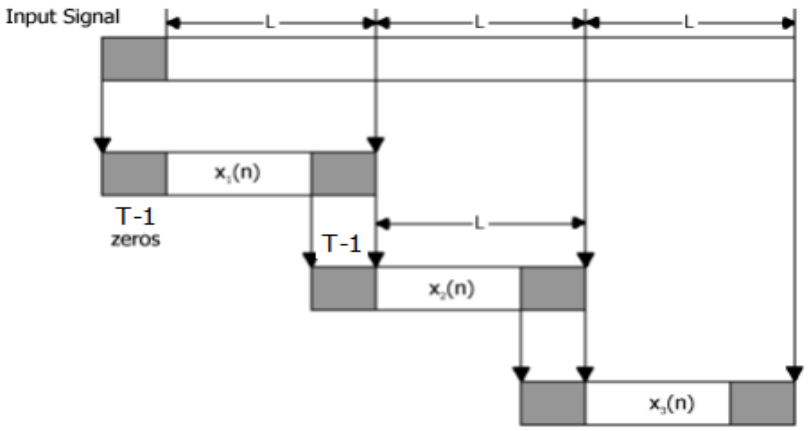
Q: 已知子带带宽，那么滤波器的通带宽度(6dB带宽)应该怎么设置？
是应该等于，小于还是大于子带带宽？



Demo

Low complexity filtering implementation

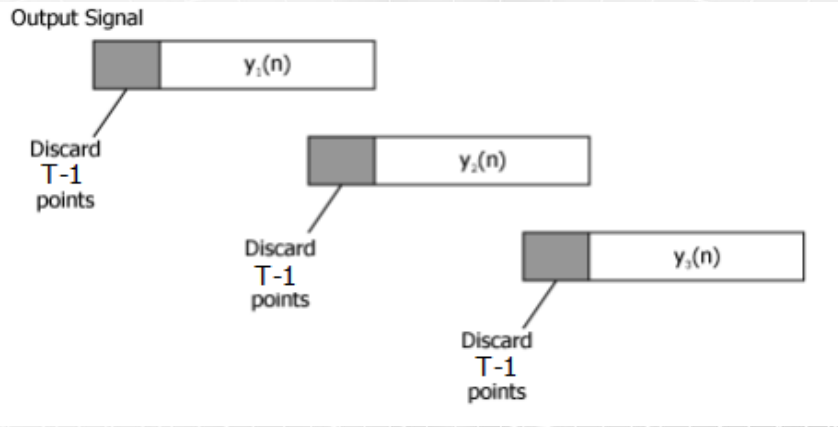
- In order to get better performance, long filter should be used, e.g., 512 or 1024. So low complexity filtering implementation should be considered



Step 1: segment

$$y_i[n] = \mathrm{IFFT}_{L+T-1}\left\{\mathrm{FFT}_{L+T-1}\left\{x_i[n]\right\}\mathrm{FFT}_{L+T-1}\left\{h[n]\right\}\right\}$$

Step 2: frequency domain filtering



Step 3: concatenation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SPREADTRUM

How We Judge and Compete the Results

Description	Requirement	Deliverables
Implement two Filtered-OFDM links, wherein the subband filtering functions are switchable, i.e., when the filter functions are switched off, the links will be OFDM, otherwise they will be F-OFDM. The two links should have different OFDM parameters, including subcarrier spacing, CP length and TTI length. Moreover, adjacent frequency subbands should be used by the two links, and guard tones should be reserved between the two subbands. The performance gap between F-OFDM and OFDM should be observed by setting different number of guard tones, the performance metrics include: 1. The out-of-band emission of each link 2. The BLER/PER curves of each link	1. Design correctly, simulation results are right 2. The performance of F-OFDM meets requirement, includes: a. The OOBE is much better than OFDM b. The BLER/PER are similar to OFDM under the channel models of (a) ETU 3km/h, (b) EPA 3km/h, (c) AWGN 3. Low complexity, fine reliability 4. Optimized filter design	1. The design document of F-OFDM links 2. The maltab simulation program of F-OFDM links, and simulation report which should include the OOBE simulation results, the BLER/PER curves. 3. The FPGA implementation of F-OFDM links and test report which should include the OOBE and BLER performance.