
ALTERA
UNIVERSITY
PROGRAM
5G
5G第一届移动通信算法创新大赛
赛题及要求
F-OFDM
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
intel
SPREADTRUM

F-OFDM for InnovateAsia Competition

Task	Description	Requirements
F-OFDM – 下一代无线通信的基础波形	波形是无线通信物理层最基础的技术。CP-OFDM以其传输效率高，实现简单，易于与MIMO结合等诸多优点，目前已经被广泛用于4G LTE，以及Wifi等无线通信系统中。但是传统的CP-OFDM系统存在带外泄露高，同步要求严格，以及整个带宽只支持一种波形参数等缺点。 5G支持丰富的业务场景，每种业务场景对波形参数的需求各不相同，能够根据业务场景来动态地选择和配置波形参数，同时又能兼顾传统CP-OFDM的优点，是对5G基础波形的必然要求。 Filtered-OFDM，基于子带滤波的OFDM，就是能够满足5G需求的波形技术。将系统带宽划分若干子带，子带之间只存在极低的保护带开销，每种子带根据实际业务场景需求配置不同的波形参数。各子带通过filter进行滤波，从而实现各子带波形的解耦。支持5G按业务需求的动态软空口参数配置。 请根据材料中对F-OFDM基本原理的介绍，设计实现基本的下行F-OFDM通信系统，并验证性能。	**要求：** 根据培训资料中对F-OFDM的介绍，实现简化的F-OFDM下行多用户通信链路，重点在于子带滤波器的实现以及与OFDM的性能对比验证。 **作品格式：** 1. 完成简化F-OFDM下行多用户链路设计文档，尤其是子带滤波器的设计。 2. 完成简化F-OFDM下行多用户链路的仿真，并给出发射机OOB带外性能，以及接收机BLER(或PER） v.s Eb/No的瀑布曲线。 3. 完成简化F-OFDM下行多用户链路FPGA实现，测试其性能（发射机OOB带外性能，以及接收机瀑布曲线（与OFDM对比））并报告处理时延及使用的FPGA资源。 交付材料： 1. F-OFDM下行多用户链路设计文档，仿真代码（C/C++、Matlab等）和仿真结果。 2. FPGA设计说明书，FPGA代码、比特文件及测试结果。 **评选标准：** 初赛： 1. 完成简化的F-OFDM下行多用户通信链路系统设计文档，正确理解F-OFDM系统。 2. Matlab仿真输出发射机OOB带外性能，以及接收机BLER(或PER） v.s Eb/No的瀑布曲线， 测试F-OFDM与OFDM的链路仿真性能差异：瀑布曲线在BLER10%条件下，SNR差异小于0.3dB结果。 3. 提供以参赛 FPGA 平台来进行F-OFDM系统设计的框架和方法。 复赛： 1. 完成FPGA逻辑设计，在FPGA系统中成功完成简化F-OFDM下行多用户链路，译码正确率超过90%。 2. 在FPGA系统上测试性能曲线（F-OFDM和OFDM），并与仿真（允许刷新优化）比对，差别小于0.5dB。 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。

Reference to Read

OFDM Fundamental :

- R. Nee and R. Prasad, “OFDM for Wireless Multimedia Communications”. Artech House, Inc., 2000.
- A. Bahai, B. R. Saltzberg, and M. Ergen, “Multi-Carrier Digital Communications: Theory and Applications of OFDM”. Springer Science & Business Media, 2004.
- 3GPP, “Overview of 3GPP release 8 v0.3.3,” Tech. Rep., Sep. 2014.

Filter Design and Fast Filtering Implementation

- A. Antoniou, “Digital Filters: Analysis, Design, and Applications”, New York, NY: McGraw-Hill, 1993.
- Douglas L. Jones, "Fast Convolution", available online: https://inst.eecs.berkeley.edu/~ee123/sp15/docs/FastConv.pdf

Algorithm Design of F-OFDM

- “F-OFDM algorithm design”，attached in this document

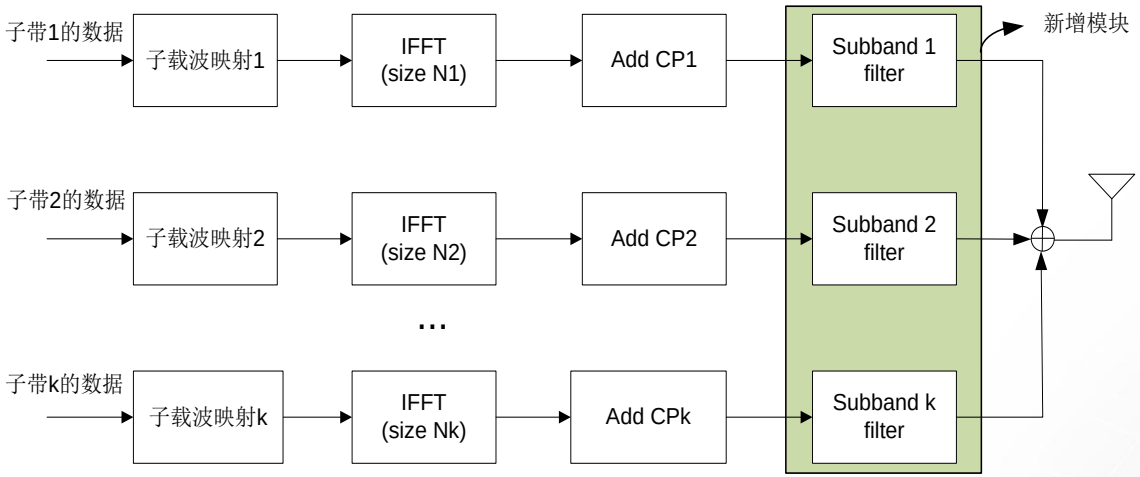
Outline

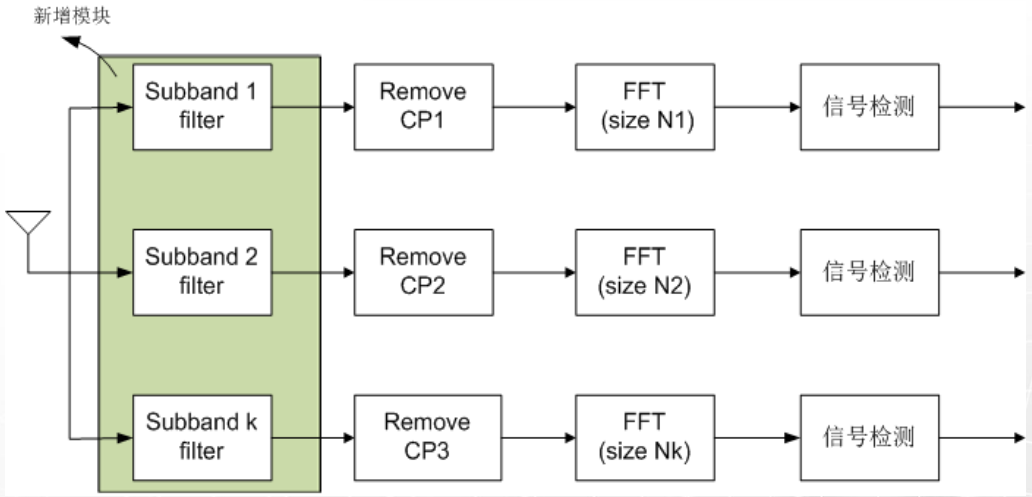
- What is F-OFDM?
- Why we need F-OFDM in 5G?
- How does F-OFDM work?
- What will you implement?

To have a gut feeling what is filtered OFDM

WHAT IS F-OFDM?

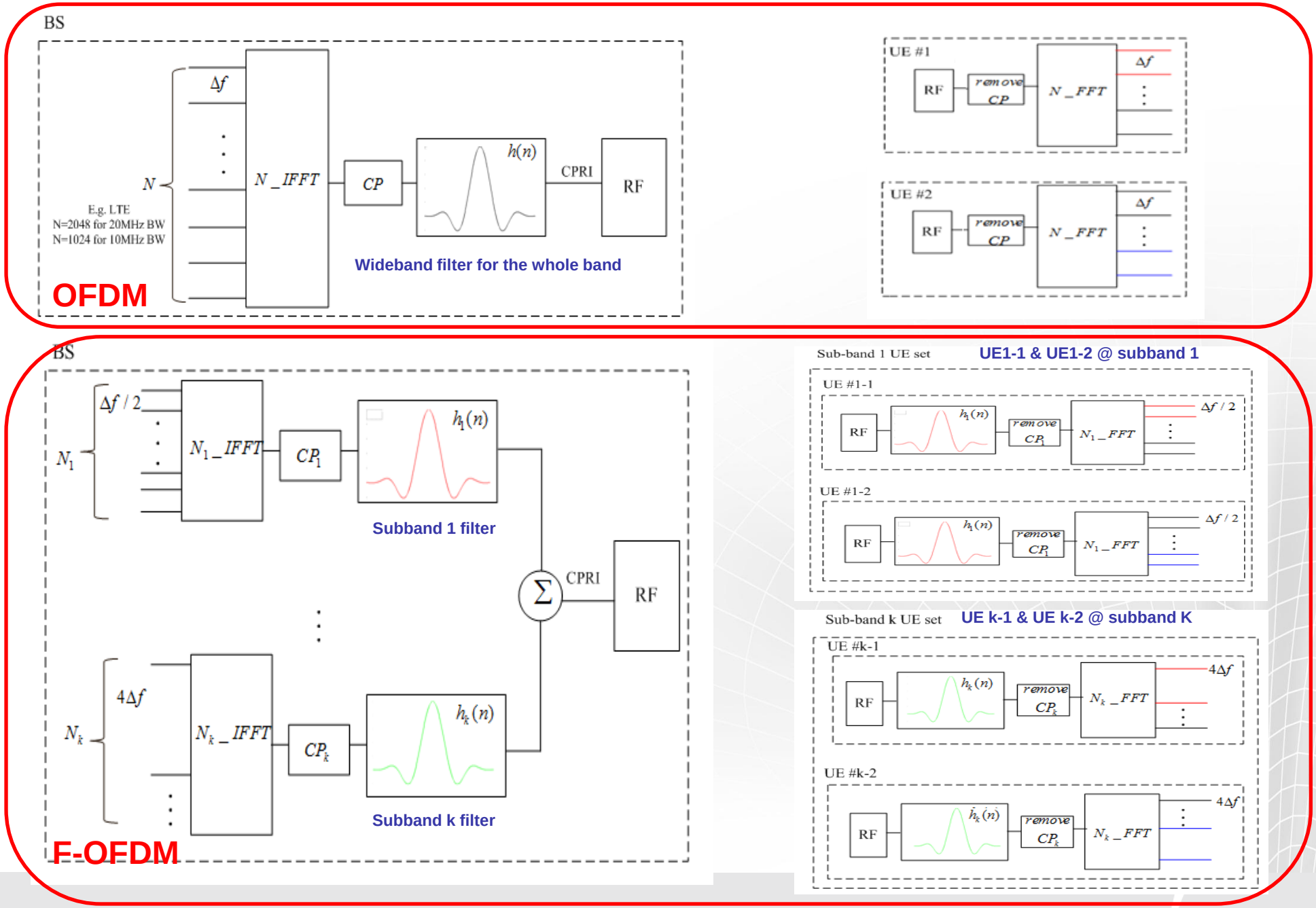
F-OFDM System Diagram





Key message

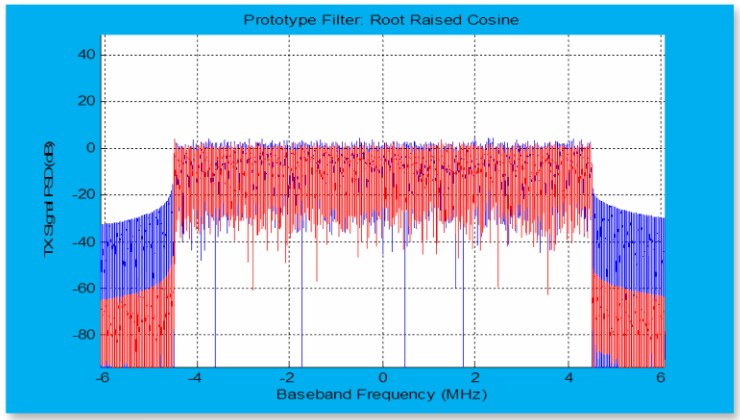
1. **Subband filter is added on top of CP-OFDM, without any change on existing CP-OFDM**
2. **Filtering for each subband (subband BW >= 1RB)**
3. **Independent Subcarrier spacing/ CP length/ TTI configuration for each subband**
4. **Rather low guard tone overhead between neighboring subband**
5. **Support asynchronous inter-band transmission due to perfect OOB performance**

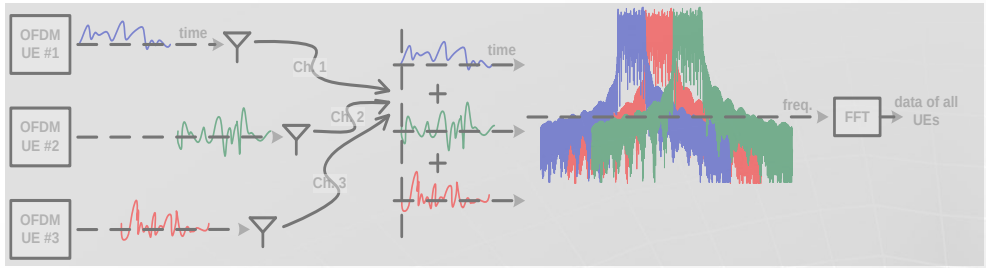

BS
Δf
N
N _IFFT
CP
h(n)
CPRI
RF
E.g. LTE
N=2048 for 20MHz BW
N=1024 for 10MHz BW
Wideband filter for the whole band
OFDM
UE #1
RF
remove CP
N _FFT
Δf
UE #2
RF
remove CP
N _FFT
Δf
BS
Δf / 2
N1
N1 _IFFT
CP1
h1(n)
Subband 1 filter
Σ
CPRI
RF
4Δf
Nk
Nk _IFFT
CPk
hk(n)
Subband k filter
F-OFDM
Sub-band 1 UE set
UE1-1 & UE1-2 @ subband 1
UE #1-1
RF
h1(n)
remove CP1
N1 _FFT
Δf / 2
UE #1-2
RF
h1(n)
remove CP1
N1 _FFT
Δf / 2
Sub-band k UE set
UE k-1 & UE k-2 @ subband K
UE #k-1
RF
hk(n)
remove CPk
Nk _FFT
4Δf
UE #k-2
RF
hk(n)
remove CPk
Nk _FFT
4Δf

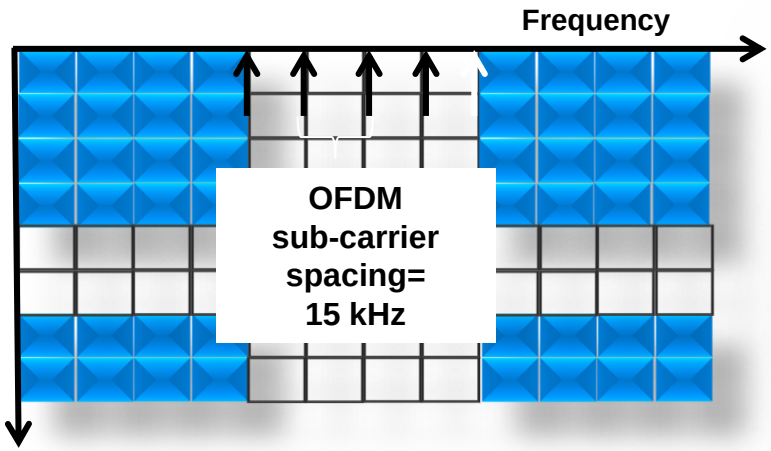
To know what role F-OFDM plays in 5G and what benefit it brings along

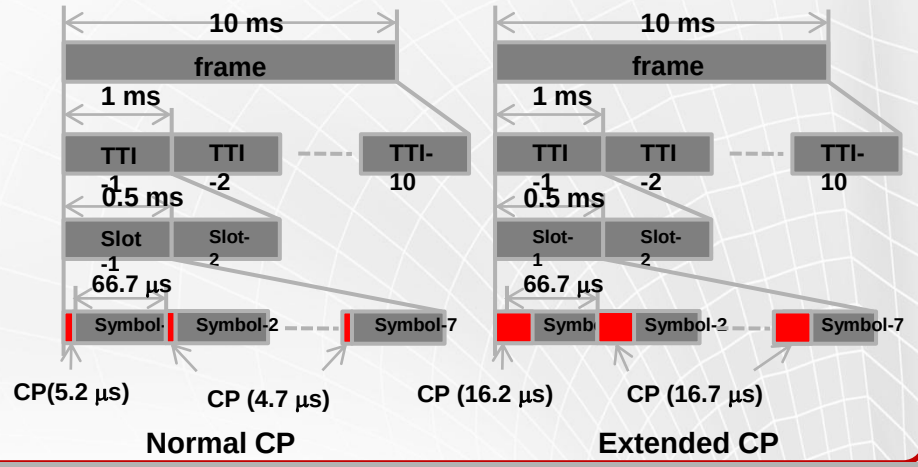
WHY WE NEED F-OFDM IN 5G?

Issues of Existing OFDM Waveform



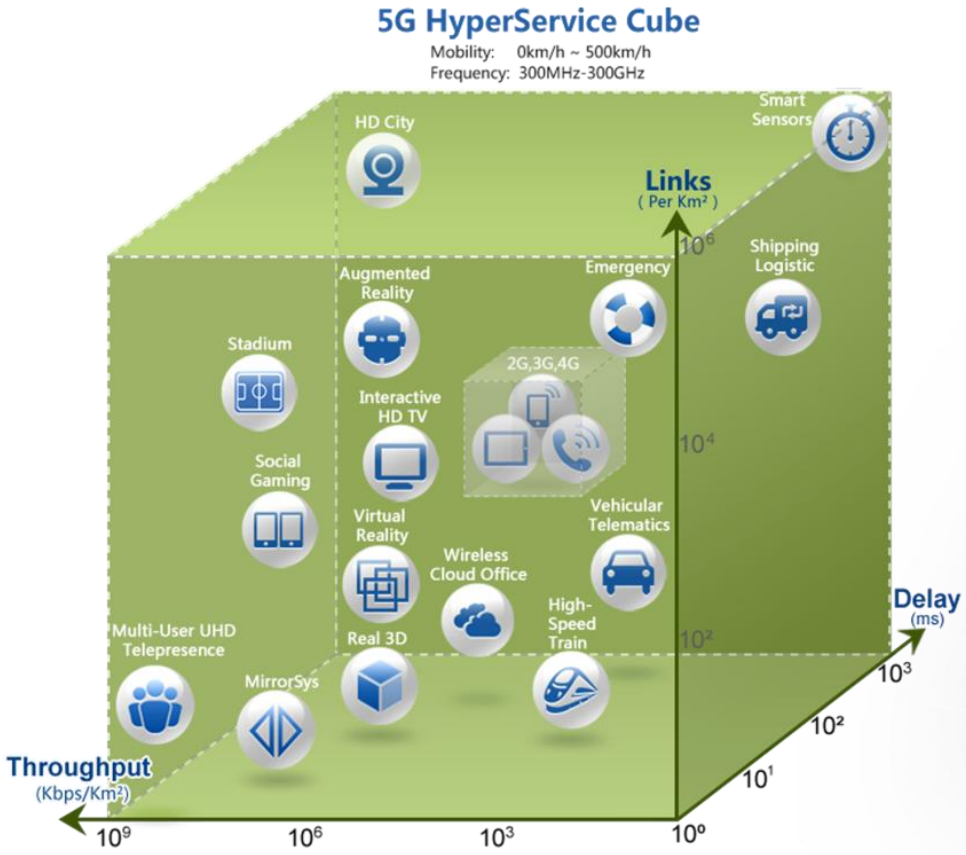






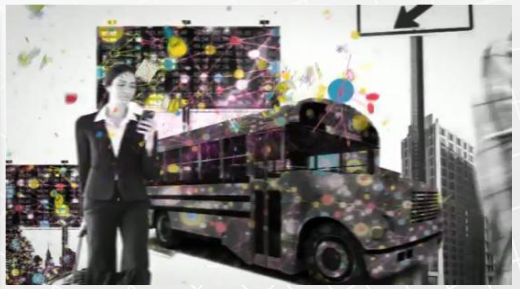
- OFDM waveform is not spectrum localized
  - 10% Guard band is needed in order to meet out-of-band leakage rejection requirement.
- OFDM waveform is not flexible
  - Fixed subcarrier spacing & limited number of cyclic CP
- OFDM waveform cannot support asynchronous operation
  - Timing adjustment is needed

5G Vision: Zero Distance Communications



Massive Capacity

Massive Connectivity



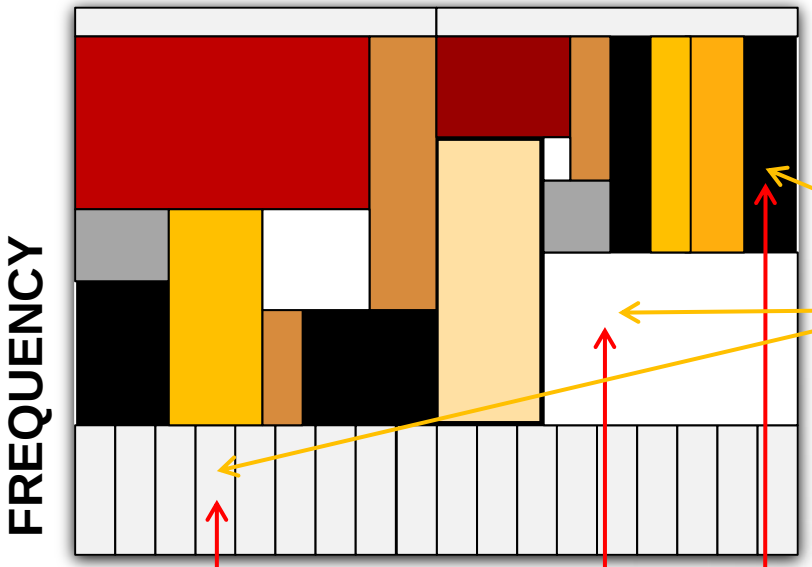
Zero Waiting

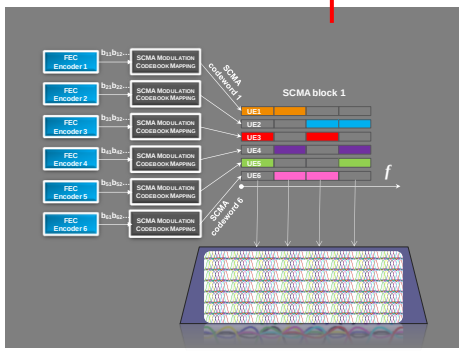
10^3 Times Traffic Flooding

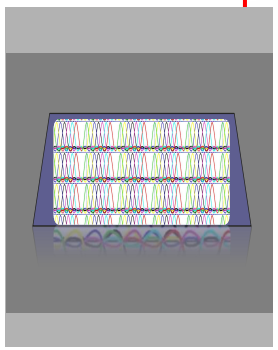
10^2 Billion Connections

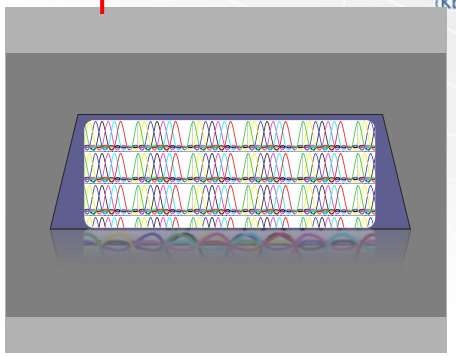
10^0 ms Delay Experience

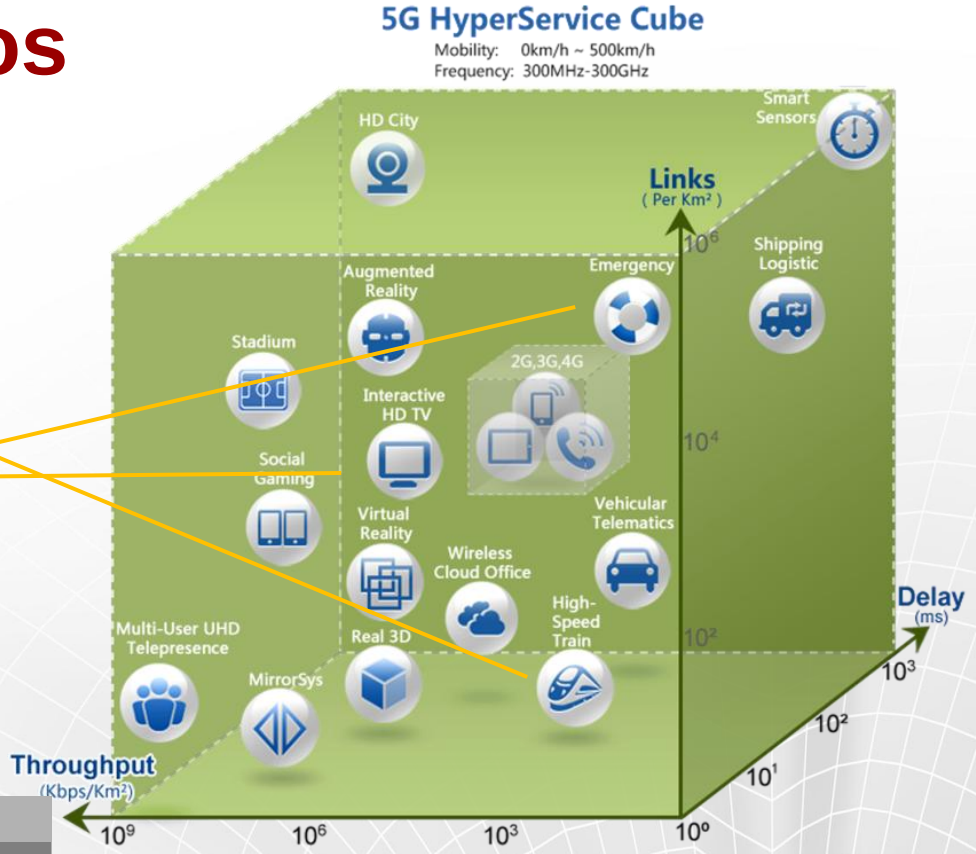
F-OFDM Application Scenarios





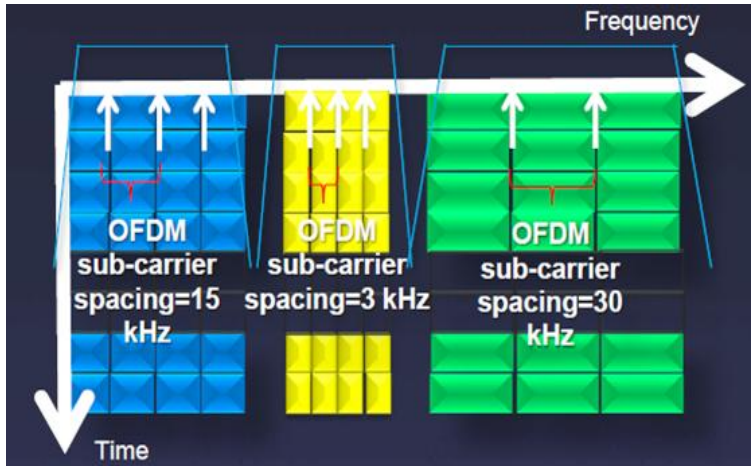




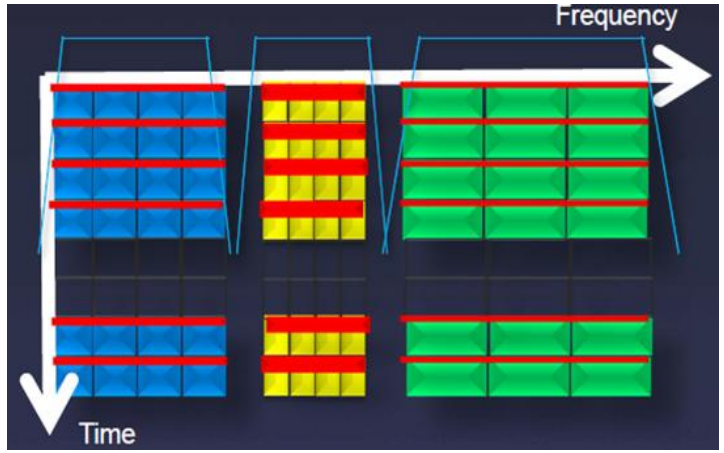


- F-OFDM as the basic 5G waveform, enables the flexible air interface to support co-existence of different waveform / multiple access schemes / flexible TTI configurations
- F-OFDM enables straightforward backward compatible & forward compatible

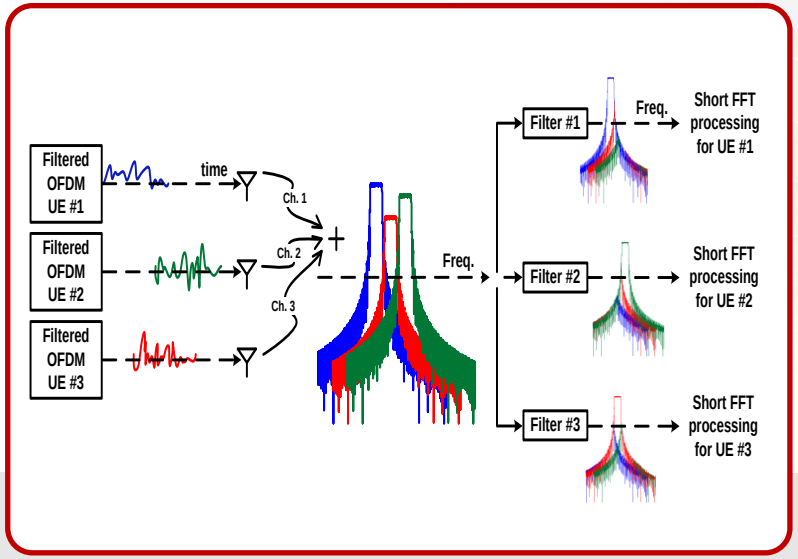
F-OFDM: advantages



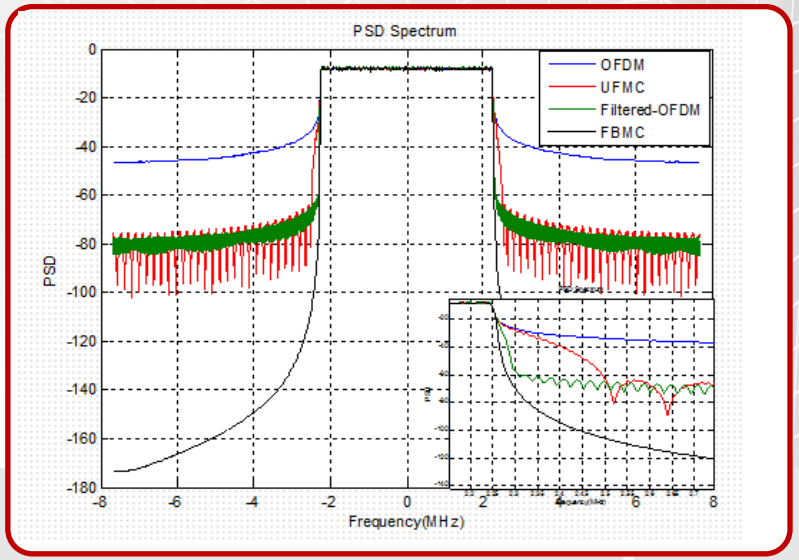
Co-existence of waveform with different OFDM primitive



Different Cyclic prefix for each specific sub-band

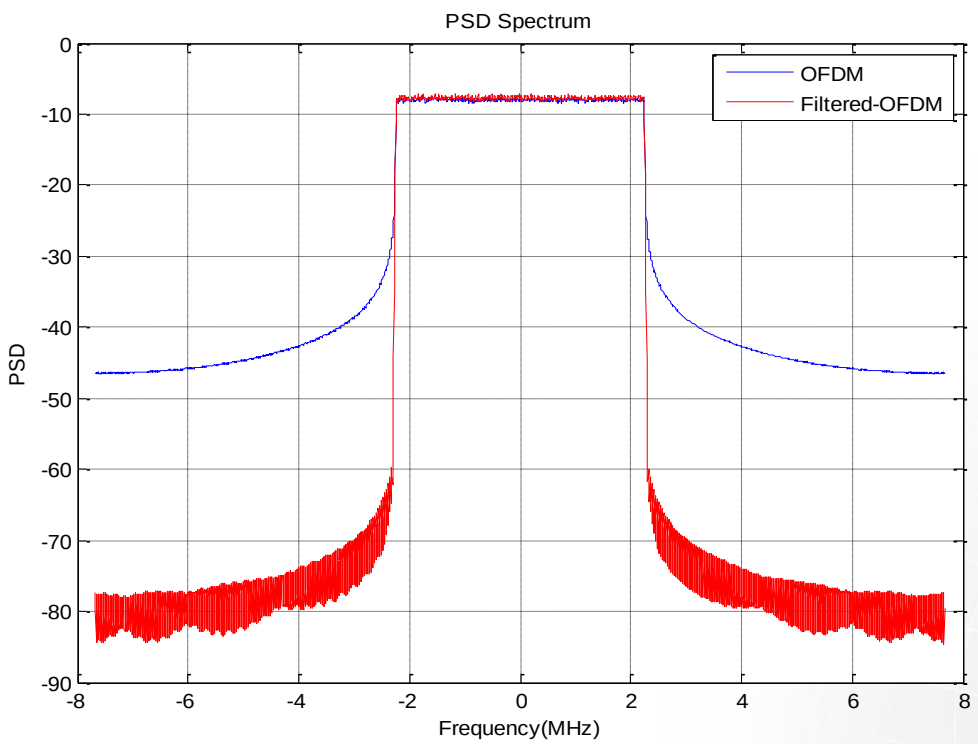


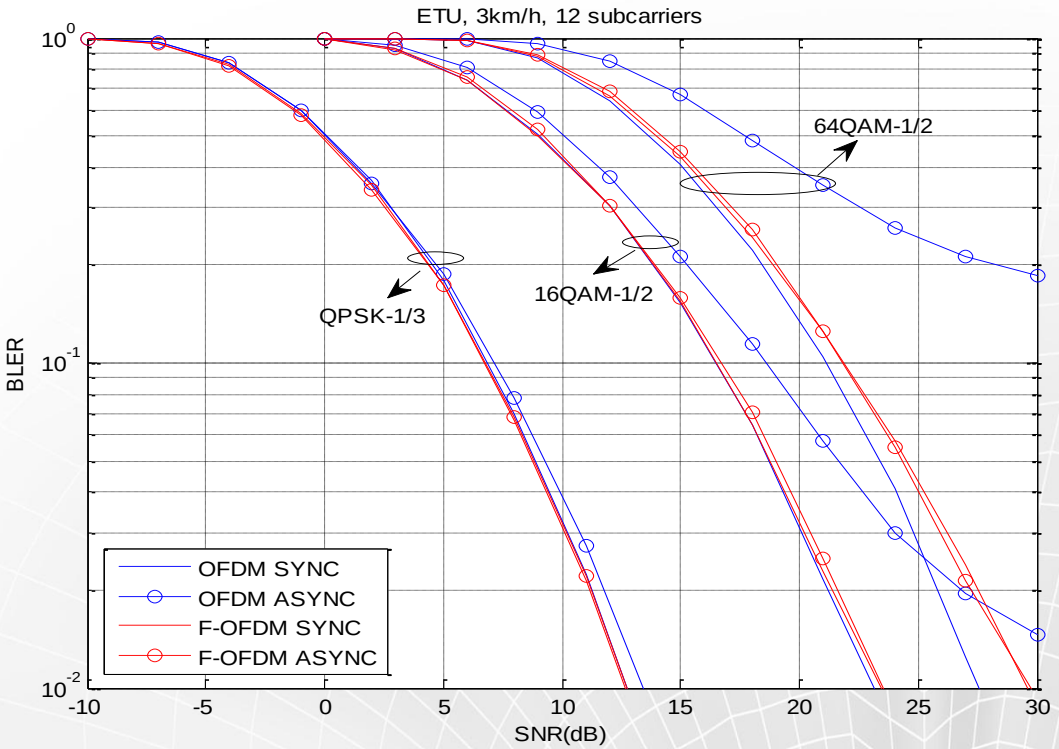
Support asynchronous OFDMA transmission



Good Out-of-band leakage rejection

F-OFDM: simulations(SISO)

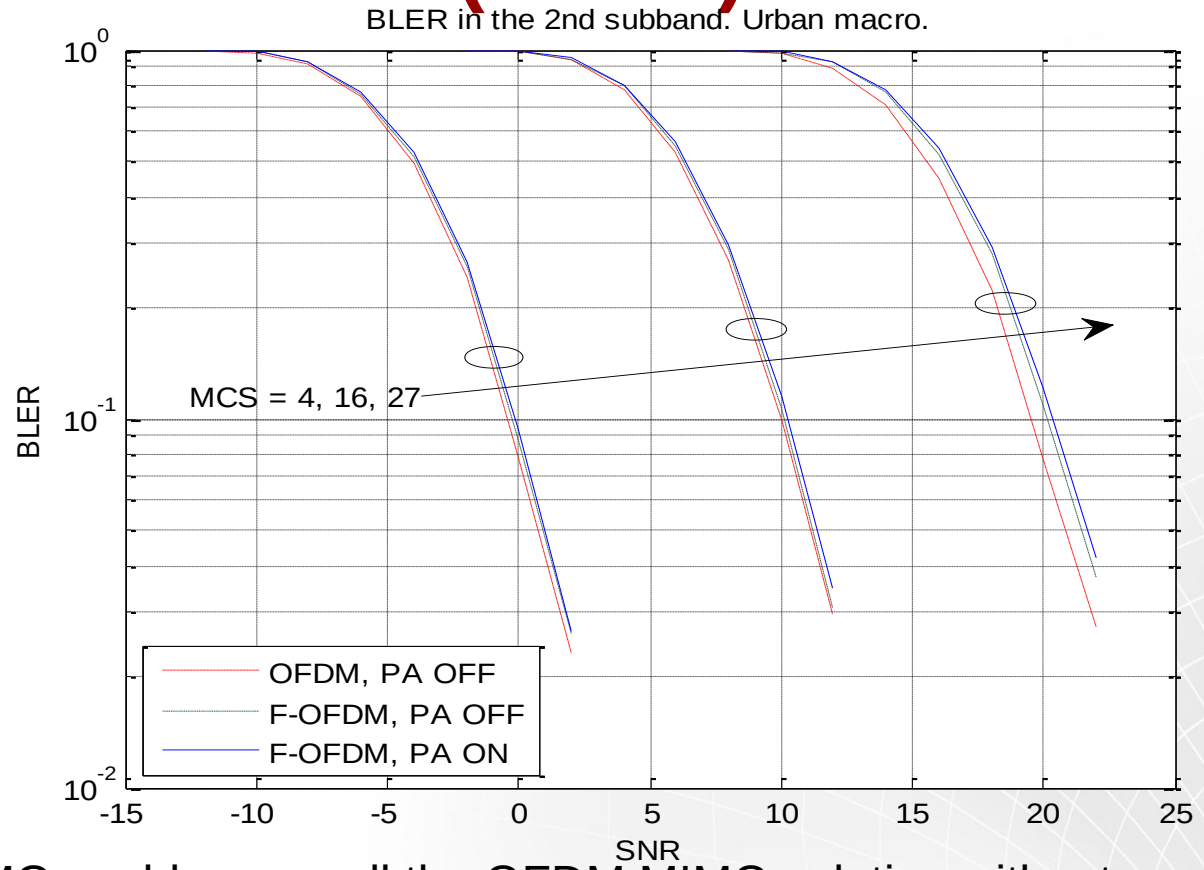




1. F-OFDM has rather low OOB leakage

2. With only 1 guard tone, F-OFDM could achieve the same performance as OFDM with neighbor band interference

F-OFDM: simulations(MIMO)



1. F-OFDM MIMO could re-use all the OFDM MIMO solution without any change

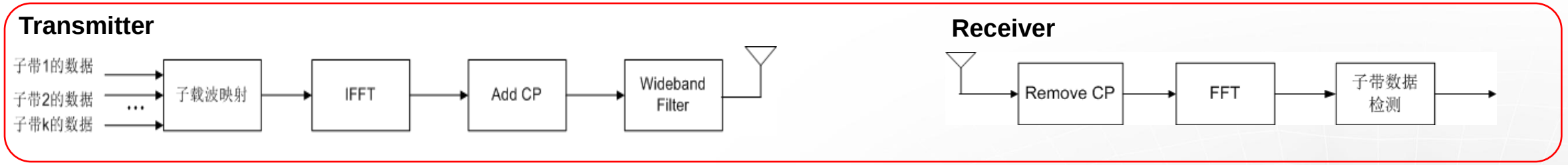
2. With only 1 guard tone, F-OFDM MIMO could achieve the same performance as OFDM MIMO with neighbor band interference

To have a gut feeling how F-OFDM will be implemented in the 5G wireless systems

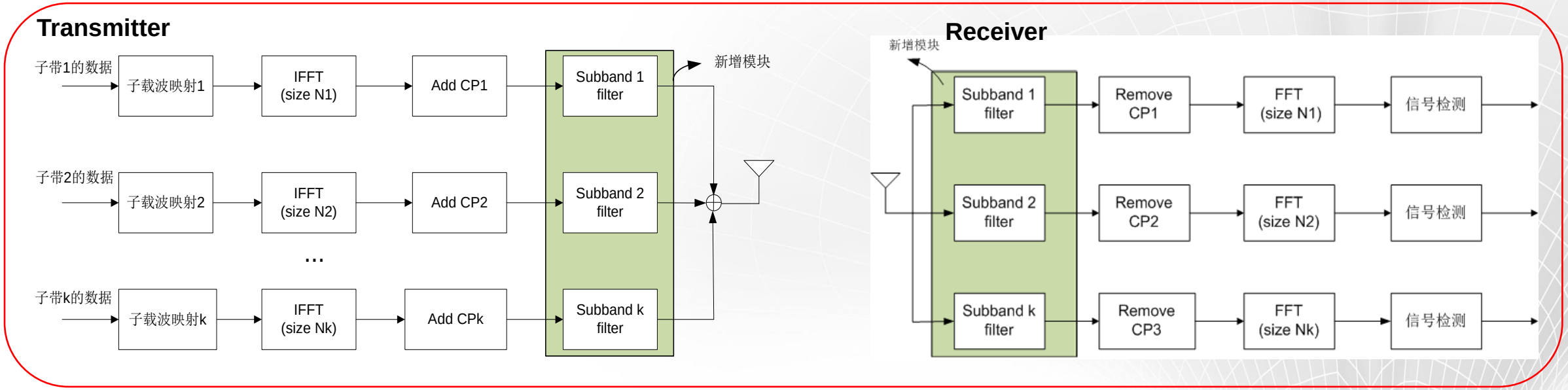
HOW DOES F-OFDM WORK?

F-OFDM System Diagram

OFDM



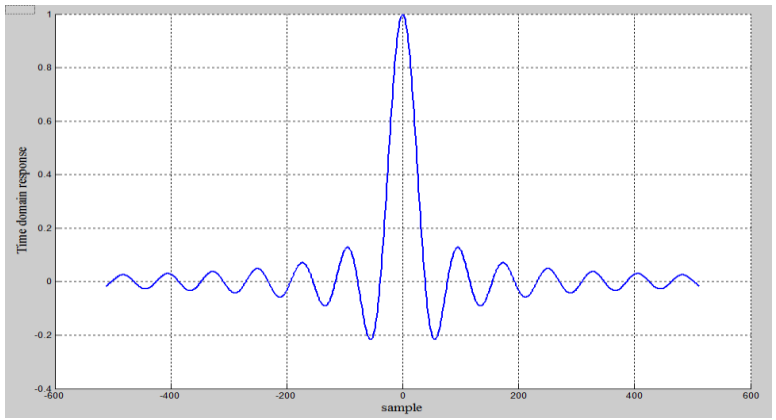
F-OFDM



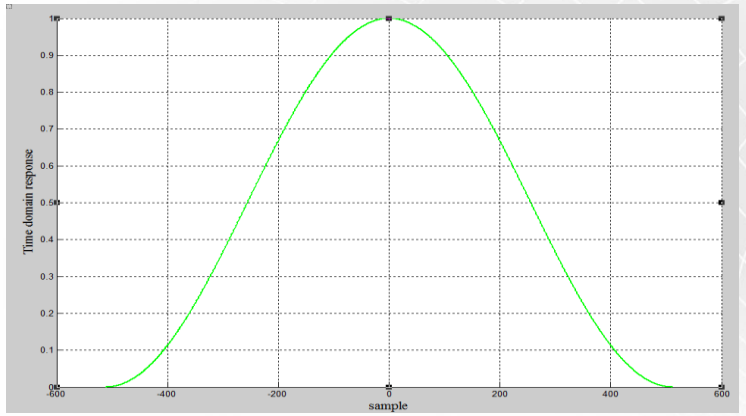
Filter design

- 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

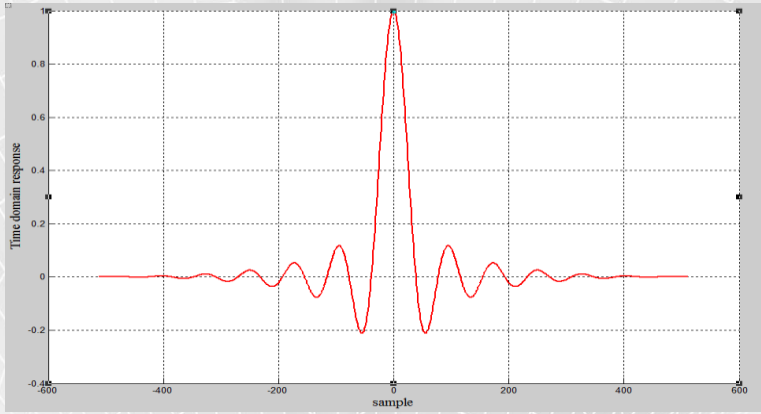
Time domain Sinc function:
Ideal filter with BW = subband BW + some guard tone



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



Final filter



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

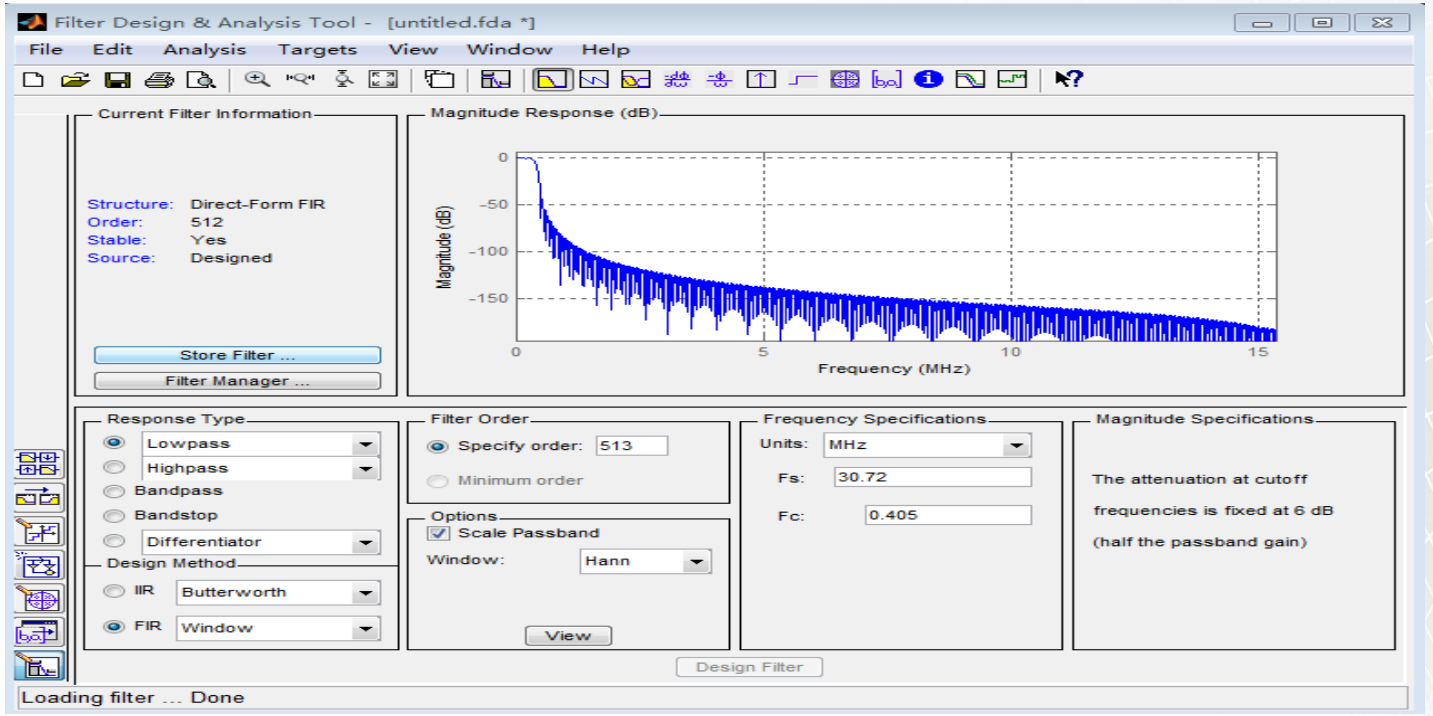
Example of filter

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

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

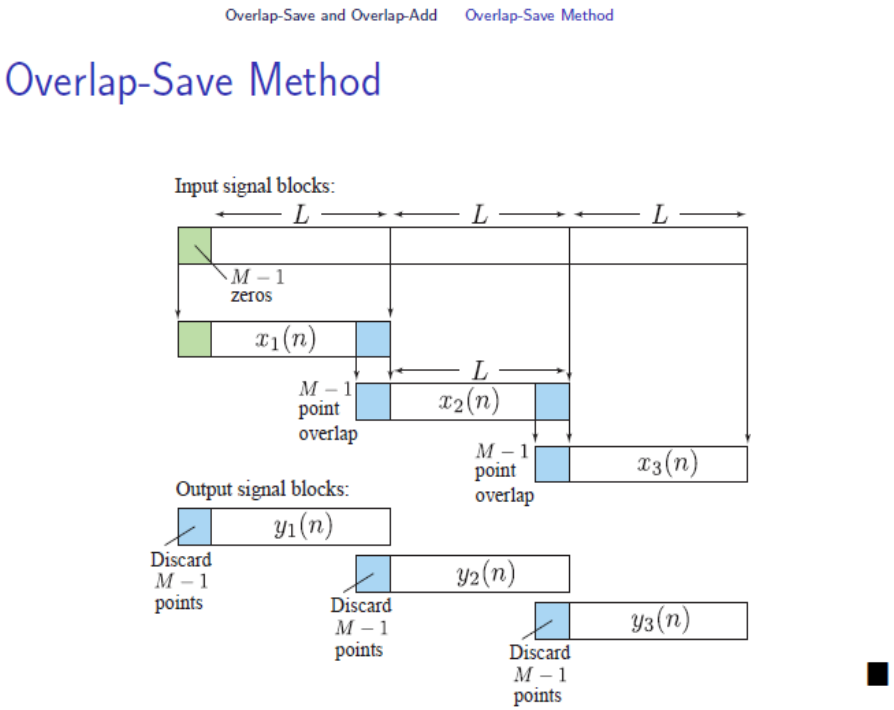
$$W_{Hanning}(n) = 0.5\left(1 - \cos\left(\frac{2\pi n}{N-1}\right)\right)$$

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



Filter implementation

1. Conceptually, F-OFDM filtering operation is continuous filtering in time domain
2. However, frequency domain filtering operation is preferred for simple implementation[1]

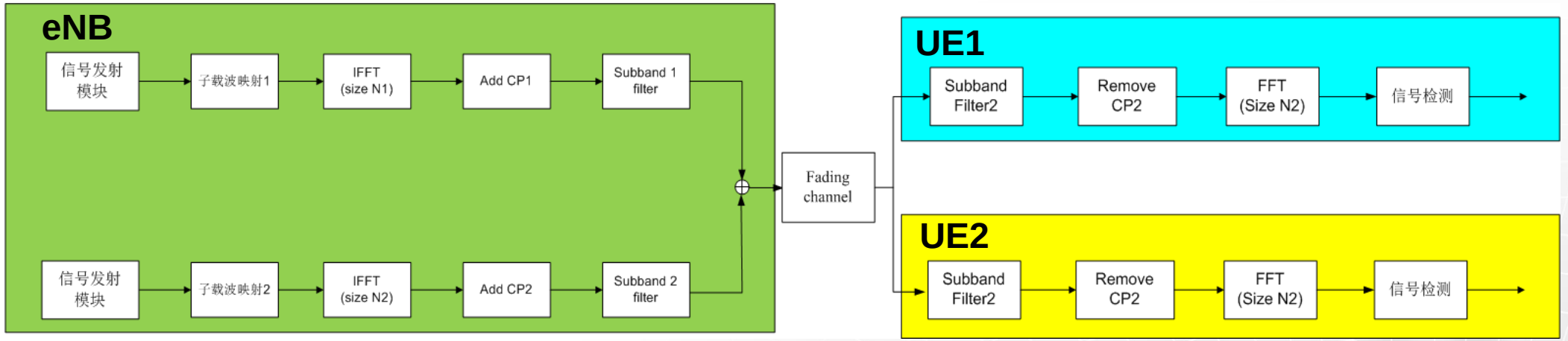


- For each FFT/IFFT based block filtering, we can filter a data block of size L.
- Filter time domain length is of size M.
- FFT size N = L + M – 1.
- Complexity is much less sensitive to the filter length.

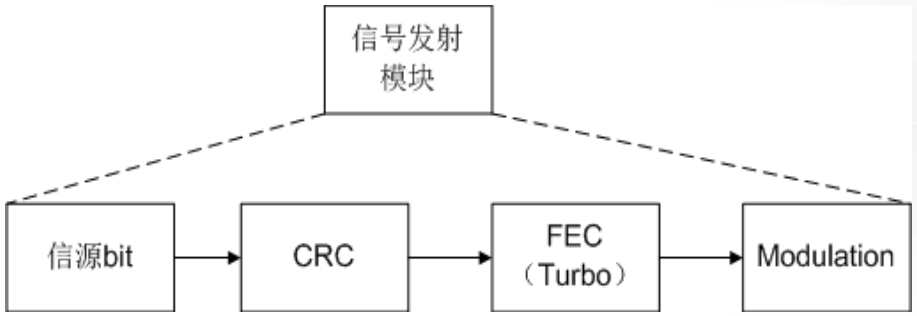
[1] *reference:* Douglas L. Jones, "Fast Convolution", available online: https://inst.eecs.berkeley.edu/~ee123/sp15/docs/FastConv.pdf

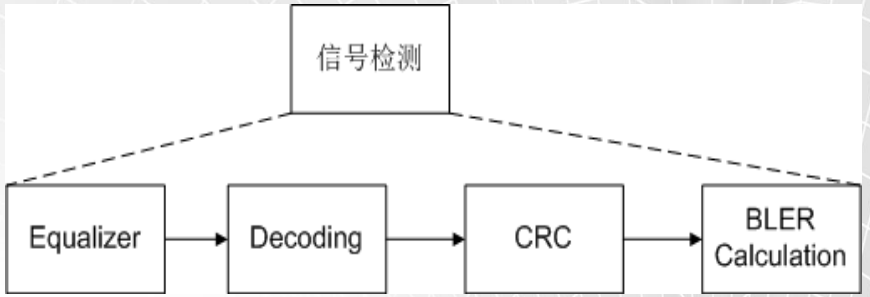
WHAT WILL YOU IMPLEMENT?

Simplified Downlink F-OFDM System to be Implemented



F-OFDM技术简介





Link Parameters

Parameters	F_OFDM @ subband1	F-OFDM @subband2	
Duplex	FDD		
Antenna config.	SISO		
Sampling rate	30.72Mbps		
Subband BW	720KHz	720KHz	可配置，两子带可以不同
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		可配置，两子带可以不同
Turbo coding rate	1/3,1/2, 3/4		可配置，两子带可以不用

How We Judge and Compete the Results

描述	要求	交付
建立2条Filtered-OFDM链路（filter功能作为可选开关，打开即为F-OFDM,关闭则为OFDM），每条链路具有不同的OFDM波形参数（包括子载波间隔，CP长度，TTI长度），2条链路使用相邻的频带，配置不同的保护子载波数量，比较F-OFDM和OFDM的性能。 1. 两条链路的发射OOB性能 2. 两条链路的BLER/PER性能	1、方案设计准确，链路仿真性能正确 2、性能达到预期指标：带外发射OOB性能远好于OFDM；带内BLER/PER性能与OFDM相同 信道模型包括： (1) ETU 3km/h (2) EPA 3km/h (3)AWGN 3、复杂度低，可实现性好 4、滤波器性能优化	1. F-OFDM下行多用户链路设计文档 2. F-OFDM下行多用户链路Matlab仿真，并给出2个子带发射机OOB带外性能，以及2个子带的接收机BLER(或PER） v.s Eb/No的瀑布曲线 3. F-OFDM下行多用户链路FPGA实现和性能测试结果，包括2个子带发射机OOB带外性能，以及2个子带的接收机BLER（或PER）v.s. Eb/No的瀑布曲线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