Waveform Design for 5G Air Interface: An Overview

Hao Lin (Orange Labs), Malte Schellmann (Huawei ERC), Xitao Gong (Huawei ERC)

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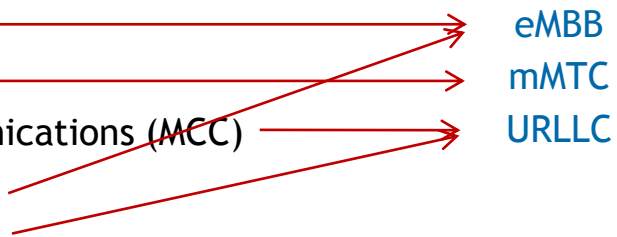
Outline

- Motivation
- Requirements for 5G waveform design
- Waveform proposals
- Some exemplary results
- Conclusion and outlook

Motivation

- 5G will support a large variety of services, posing heterogeneous requirements to the system design.
- **FANTASTIC-5G** considers 5 core services

  - Enhanced mobile broadband (MBB)
  - Massive machine-type communications (MMC)
  - Mission-critical/Ultra-reliable and low-latency communications (MCC)
  - Broad- and multicast services (BMS)
  - Vehicular to anything (V2X)



→ Air interface needs to provide more flexibility to meet the diverse requirements.

→ Key component of a flexible air interface design is an adaptive waveform.

- **FANTASTIC-5G** investigates and compares a set of promising waveform candidates.

Use cases and target KPIs for 5G system below 6 GHz

- **Fantastic-5G** defined 7 use cases (UC)
  - UC1: 50 Mbps everywhere
    MBB for rural and sub-urban areas
  - UC2: High speed train
    MBB and V2X at high vehicular speeds
  - UC3: Sensor networks
    MMC with low-cost, low-energy devices and sensors
  - UC4: Tactile Internet
    MCC in combination with high data rates
  - UC5: Automatic traffic control / driving
    MCC in combination with V2X
  - UC6: Broadcast like services: Local, Regional, National
    BMS
  - UC7: Dense Urban Society below 6GHz
    MBB in densely populated urban areas

and 9 KPIs for system evaluation

1. User experienced data rate
2. Traffic density
3. Latency
4. Coverage
5. Mobility
6. Connection density
7. Reliability / Availability
8. Complexity reduction
9. Energy efficiency

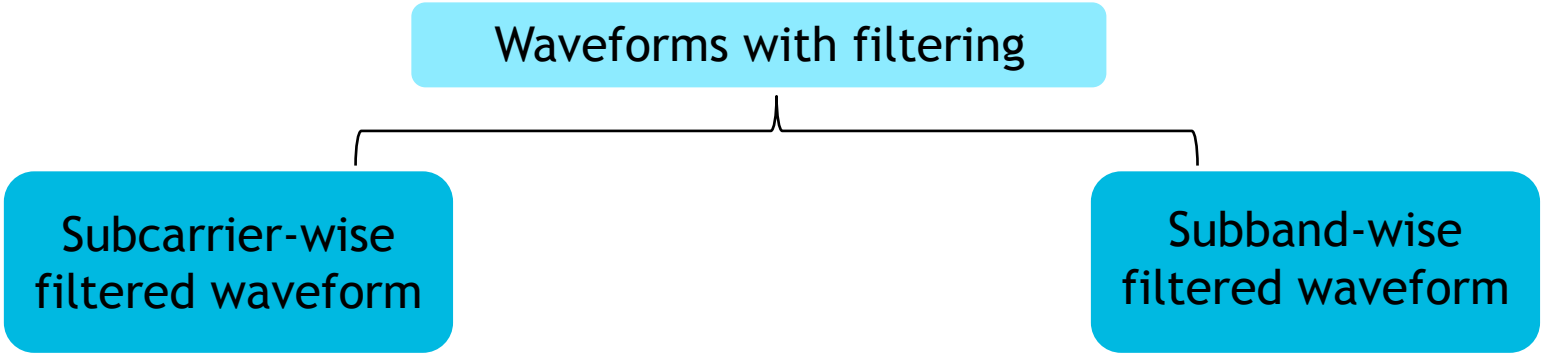
Primary target KPIs per UC

	MBB	MBB & V2X	MMC	MCC	MCC & V2X	BMS	MBB
	UC1	UC2	UC3	UC4	UC5	UC6	UC7
User experienced data rate	50 / 25 Mbps	50 / 25 Mbps					50 / 25 Mbps
Traffic density	5-20 / 2.5-10 Gbps/km²	100 / 50 Gps/km²					125 / 62.5 Gpbs/km²
Latency	10 ms	10 ms		≤1 ms	1-10 ms		10 ms
Coverage	99.999%	99.5%	20 dB more than legacy	99.999%	99.999%	99.999%	99.999%
Mobility	0-120 km/h	0-500 km/h			up to 500 km/h		0-100 km/h
Connection density			600,000 devices/km²				
Reliability / Availability				99.999%	99.999%		
Complexity reduction			90% for devices				
Energy efficiency			10 years battery life				

Requirements for 5G waveform design

- Holistic air interface design
  - Adaptive supporting service-specific configurations instead of a „one–fits-all“ solution
- Waveform design requirements
  - Support of flexible numerology
  - Support of asynchronous transmission
  - Support of high mobility
- Criteria for waveform evaluation
  - Out-of-band emission
  - Robustness against time and frequency offsets (→ asynchronous transmission)
  - Flexibility in the waveform configuration

Waveform candidates in FANTASTIC-5G



I. Frequency-spreading filter-bank multi-carrier (FS-FBMC)

II. Quadrature amplitude modulation FBMC (QAM-FBMC)

III. Pulse shaped OFDM (P-OFDM)

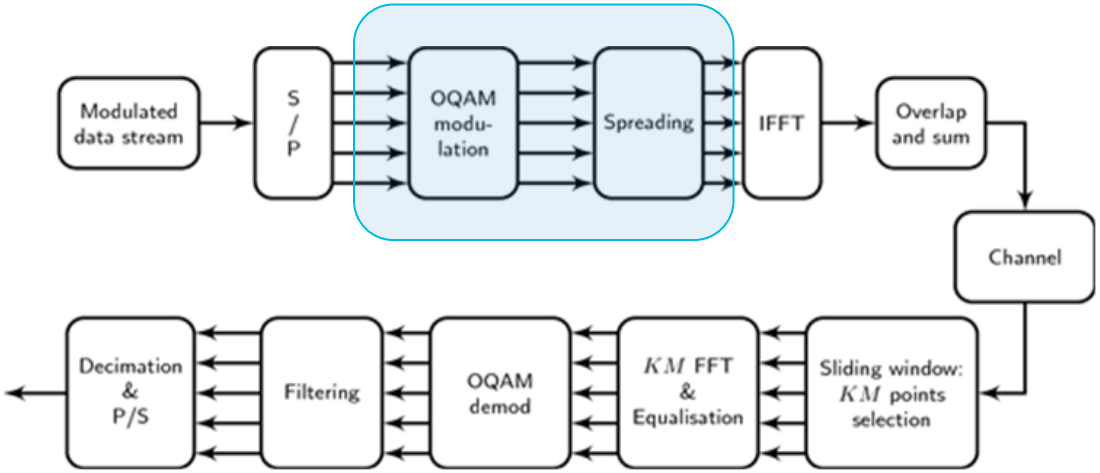
IV. Zero-tail DFT-spread-OFDM (ZT-DFT-s-OFDM)[1]

V. Flexible configured OFDM (FC-OFDM)

VI. Universal-Filtered OFDM (UF-OFDM)

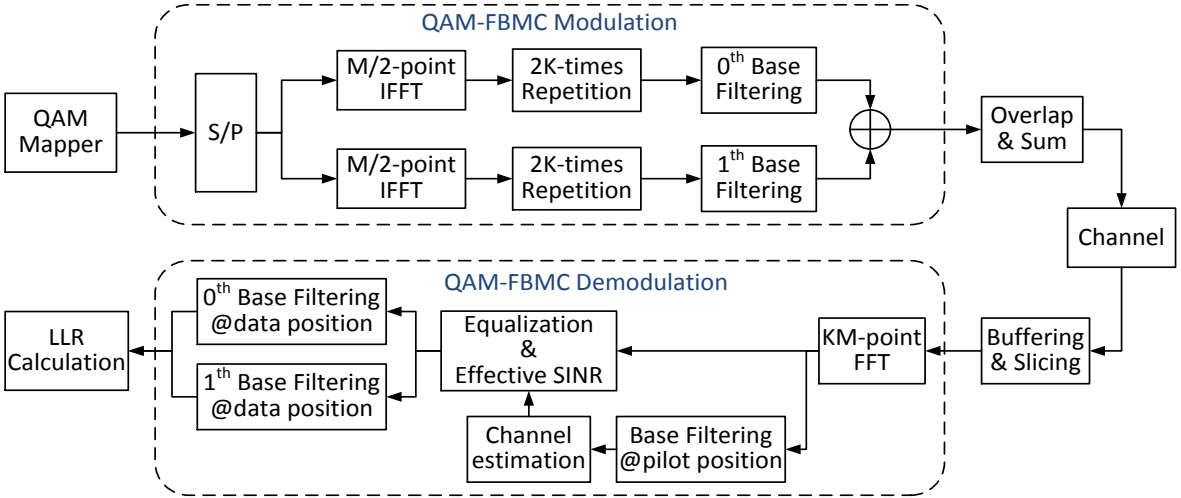
[1] Single-carrier waveform

Waveform Proposal (I): FS-FBMC



- Feature: Prototype filter for good frequency localization, combined with offset QAM
- High stop band attenuation, long pulses → Excellent frequency localization
- Support for channels with very large delay spread or synchronization mismatch
- Not fully OFDM compatible (real-field orthogonality), long tails of pulse

Waveform Proposal (II): QAM-FBMC

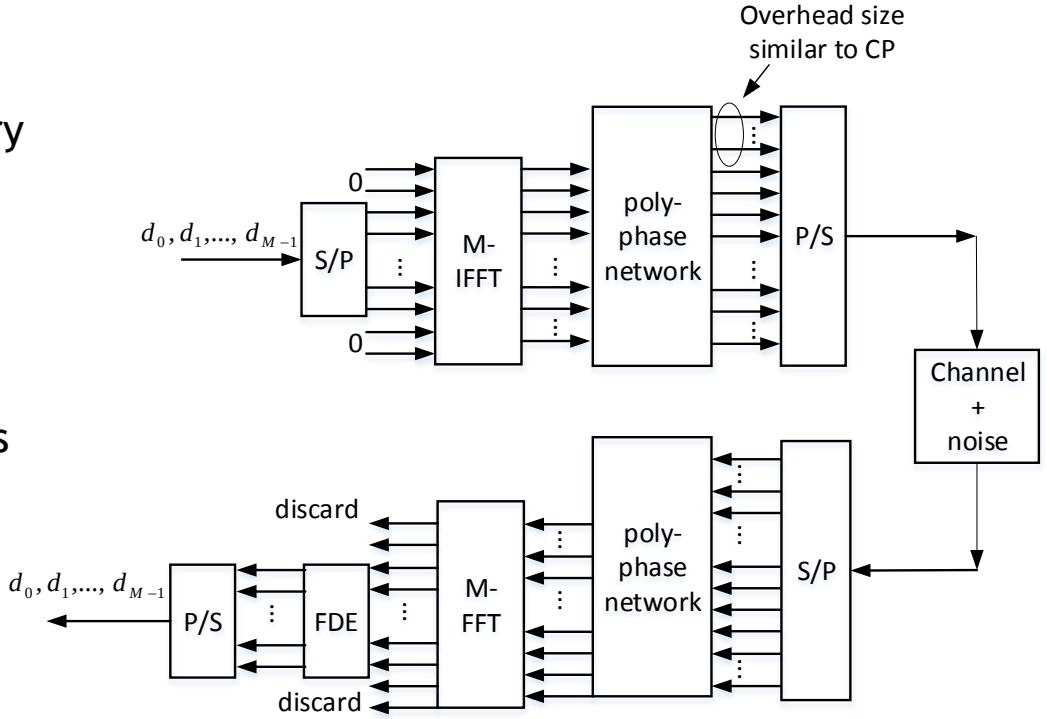


- Feature: Support QAM signaling based on two filter-banks (for even and odd subc.)
- Compromised frequency localization compared to FS-FBMC, but better than CP-OFDM
- Support for asynchronous transmissions (FDMA)
- Orthogonality constraints are relaxed

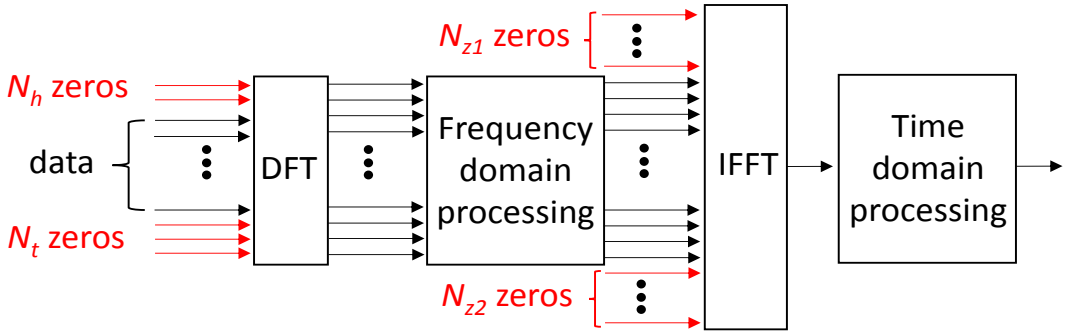
Waveform Proposal (III): P-OFDM

- Features: Uses pulse shapes of arbitrary length as a free design parameter, CP-like overhead
- Improved frequency localization compared to CP-OFDM and SC-FDMA
- Support for asynchronous transmissions (FDMA & SDMA)
- Improved robustness against time/frequency distortions

- Pulse length may be limited by delay constraints



Waveform Proposal (IV): ZT-DFT-s-OFDM

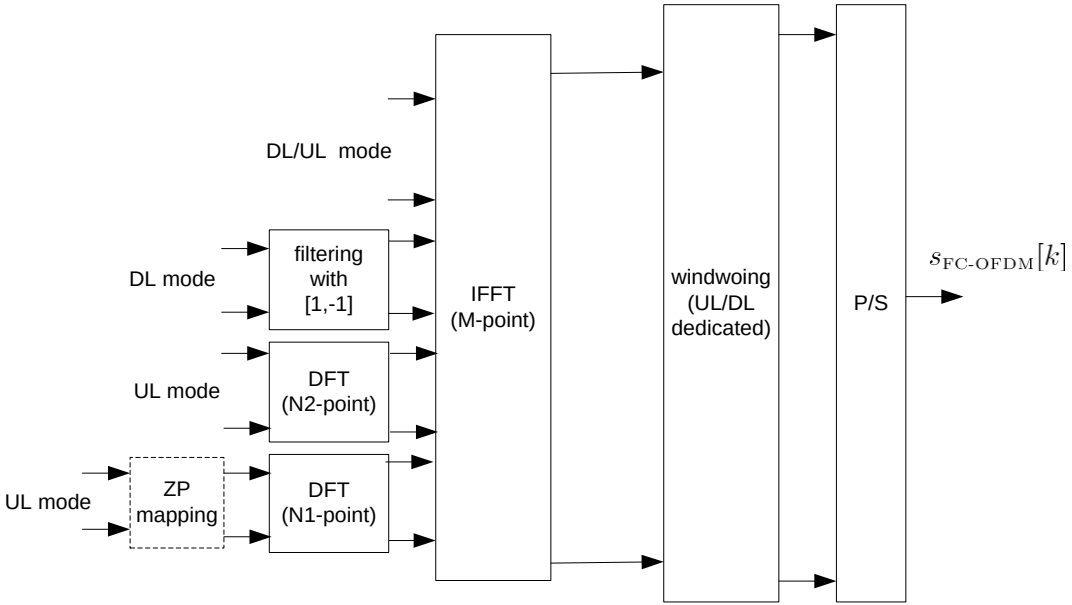


- Feature: zero-head and zero-tail added to the DFT block
- Improved frequency localization compared to CP-OFDM and SC-FDMA
- Support for asynchronous transmissions (FDMA)
- Zero-tail adjustable for variable delay spreads

- Error floor in the high SNR region with high-order modulation (not problematic for MTC)
- Non-ideal reference sequence design (not problematic for low SNR region)

Waveform Proposal (V): FC-OFDM

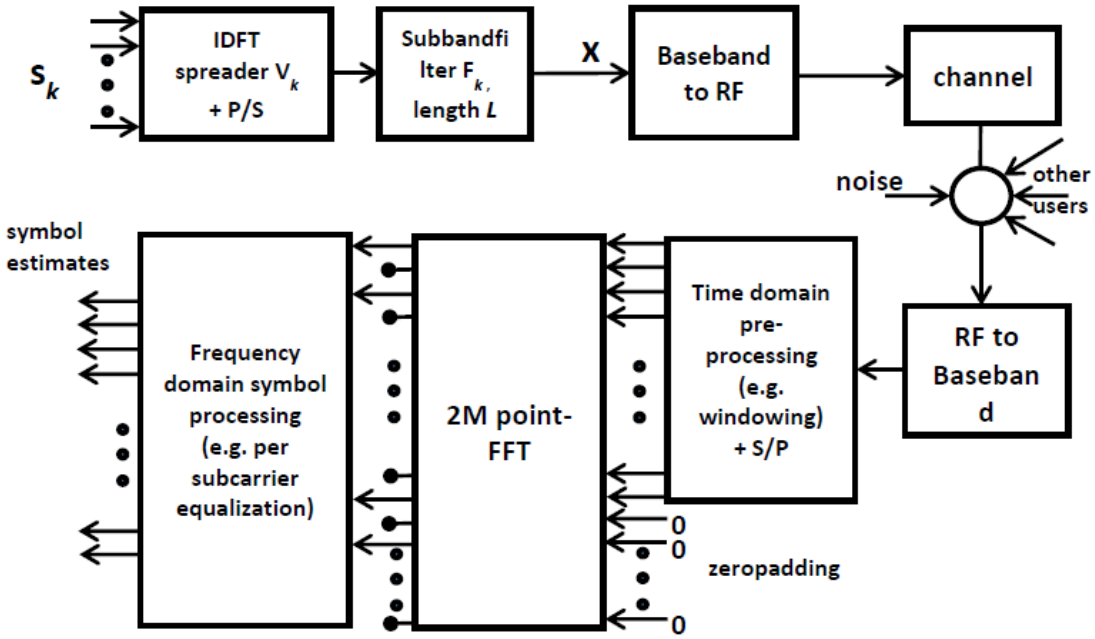
- Feature: multiplexing different waveforms tailored to desired service requirements in the same band
- Each multiplexed waveforms can provide its unique advantages, e.g.,
  - OOB emission
  - Support for asynchronous transmissions
  - Enhanced robustness to mobility
- Support coexistence of hybrid open-loop/closed-loop synchronization
- Not all native features of waveform candidates can be maintained



Waveform Proposal (VI): UF-OFDM

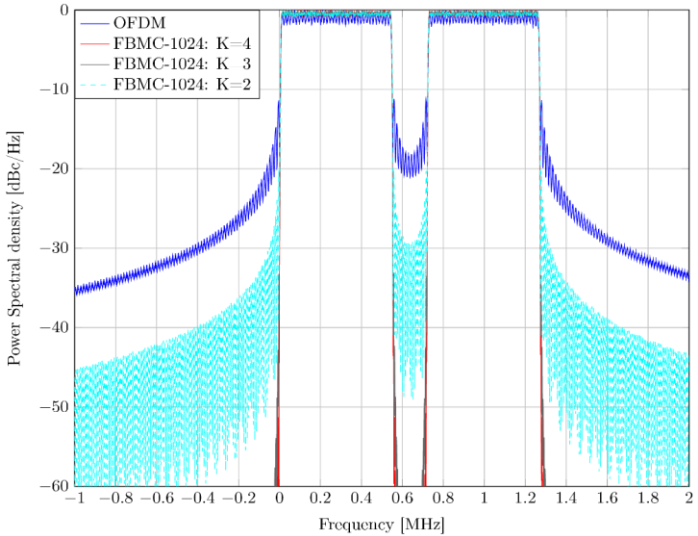
- Feature: subband filtering of a group of subcarriers, short time-domain filter length (~ CP length)
- Improved frequency localization compared to CP-OFDM
- Support for asynchronous transmissions (FDMA)

- Slightly higher sensitivity to channel delay spreads

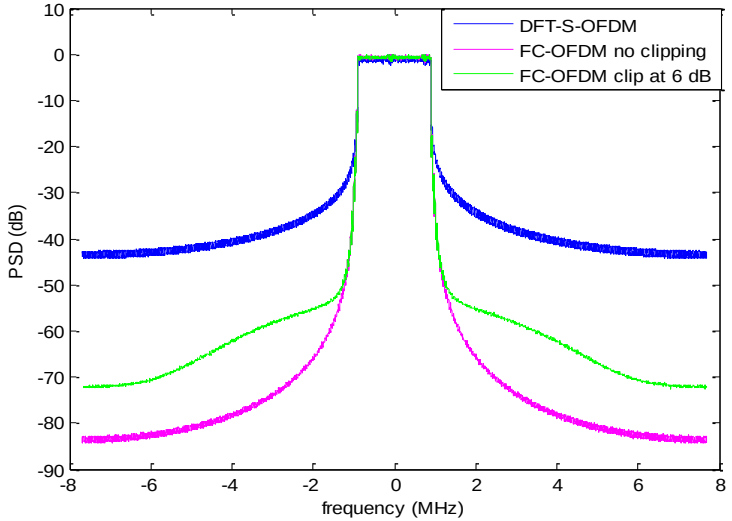


Exemplary results on spectral confinement

FS-FBMC

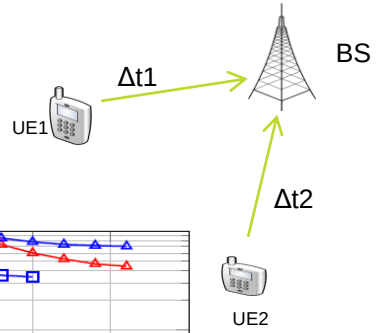


FC-OFDM

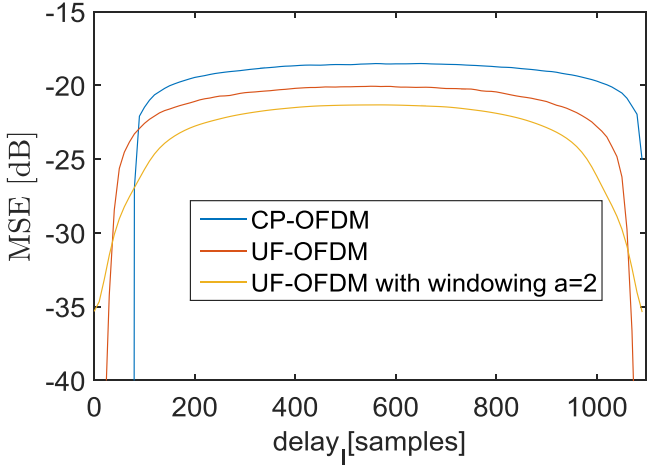


Better spectral containment than CP-OFDM/DFT-S-OFDM, even with short filter length and non-linearity PA effects.

Exemplary results on robustness to time offsets



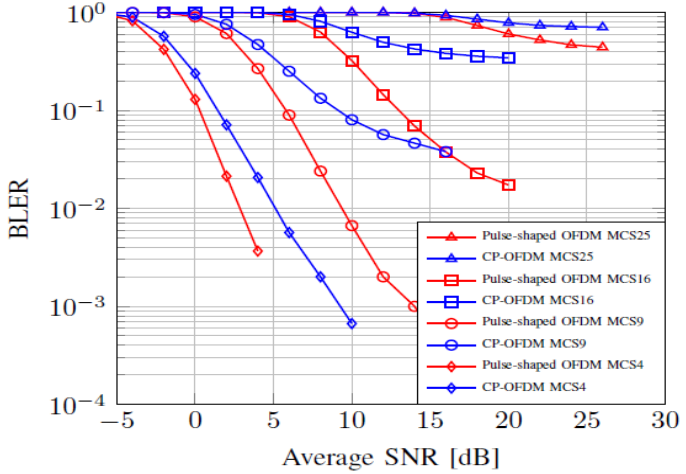
UF-OFDM



Interference power (MSE) caused by a neighboring allocation with temporal delay (3RBs/user)

Leads to lower interference power thanks to lower side lobe levels of UF-OFDM.

P-OFDM



BLER performance for asynchronous transmission (2UEs, 1BS, ETU channels with uniformly distributed timing offset within [0, 13] μs

High robustness against time distortions underpins support for async. SDMA transmission.

Waveform Comparison (I)

Waveform	Features	Pros	Cons	Targeted service
FS-FBMC	FBMC-OQAM with large FFT for mod. /demod., simple parameterization	Like FBMC-OQAM + support for large delay spreads & enlarged time offsets for async. access	Not fully OFDM compatible, long filter tails increase delay for short bursts	Multi-service
QAM-FBMC	Different filters for even and odd subcarriers enable the use of QAM →OFDM compatible	Sub-band wise configurability, async. FDMA access support	Not fully orthogonal	Multi-service
ZT-DFT-s-OFDM	DFT spread OFDM like, good coexistence capabilities thanks to low OOB emission	Coexistence with OFDM, zero-tail adjustable	Overhead of the zero-tail increases for small bandwidth allocation	MMC

Table and more details in project Deliverable D3.1 – Available @ http://fantastic5g.eu/

Waveform Comparison (II)

Waveform	Features	Pros	Cons	Targeted service
P-OFDM	Pulse shaping as free design parameter, OFDM compatible, low OoBE, Cyclic prefix (CP)-like overhead	Sub-band wise configurability, robustness to time/freq. distortions, async. access support	Filter length may be limited by delay constraints	Multi-service
FC-OFDM	Multiplexing of diff. waveforms in the transmission band	Coexistence of different waveforms in the same band, inheriting the pros of multiplexed waveforms	Not all the native features of the waveform candidates can be maintained once multiplexed	Multi-service
UF-OFDM / F-OFDM	OFDM compatible, low out of band emissions (OoBE) between sub-bands	Sub-band wise configurability, async. FDMA access support coexistence with CP-OFDM	Slightly more prone to delay-spread channels	Multi-service

Table and more details in project Deliverable D3.1 – Available @ http://fantastic5g.eu/

Conclusion and Outlook

- 5G has to support a variety of services, thus air interface needs to be more flexible.
- Filtered waveforms are a key component for a flexible air interface design, enabling
  - flexible numerology settings
  - asynchronous transmission
  - low out-of-band emission.
- Two waveform categories: Subband-wise filtering & Subcarrier-wise filtering
- High-level waveform comparisons
  - General advantages: Better spectrum confinement, robustness to time or frequency distortions
  - Subband-wise filtering: suitable for fixed bandwidth and wideband scenarios
  - Subcarrier-wise filtering: suitable for flexible bandwidth and narrowband scenarios
- Outlook: Quantitative comparison of waveforms

For Future updates and deliverables check out

http://fantastic5g.eu/