FBMC for TVWS

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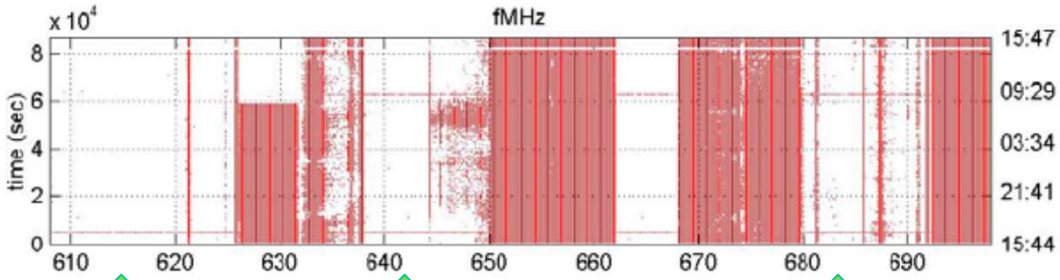
Summary / motivation

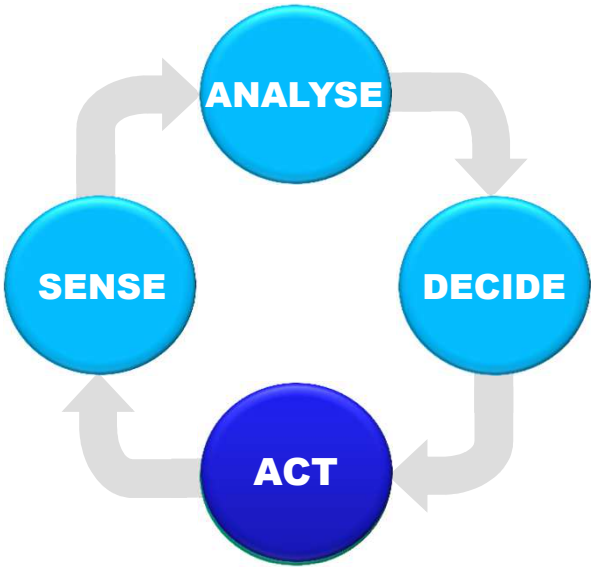
- **Regulators demand very low adjacent channel leakage for secondary TVWS usage**
- **FBMC is a multi-carrier PHY, which allows mitigating ACL though maintaining good spectrum efficiency**
- **CEA-LETI has worked on how to apply this PHY to the TVWS context**
- **This was presented at the White Space Summit in Paris in Dec. 2013.**
- **The 802.22 chair invited CEA-LETI to present this work in order for the WG to appreciate the potential interest of this technology for its work.**
- **This presentation stresses why we think FBMC is very suitable to White Space communication**

Cognitive Radio for White Spaces

Incumbent protection

Need to control interference





Dynamic Spectrum Usage

Need a flexible radio

Key parameters from regulation

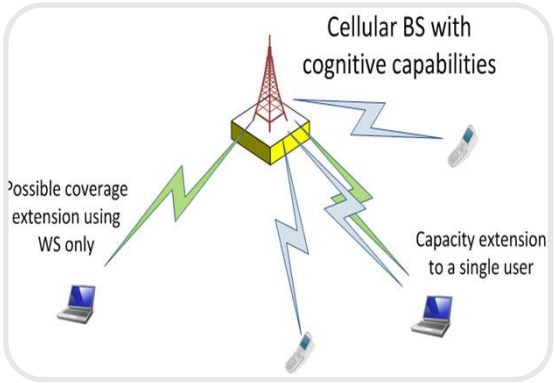
FCC has approved communication parameters in the TVWS in 2009 [1]

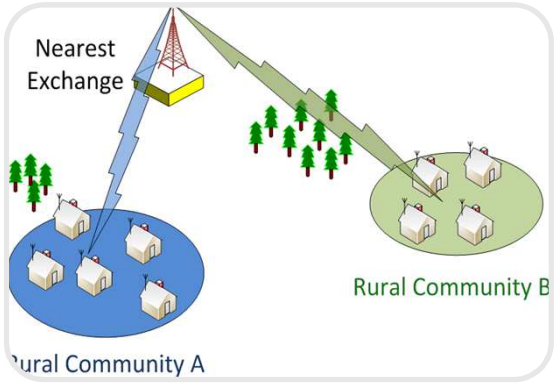
Parameter	FCC [1]	Note
Power for FD in adjacent band	Not allowed	
Power for FD in non-adjacent band with geo-location capability	30dBm (1W)	FCC: 36dBm EIRP with a gain antenna
Power for PPD in adjacent band	16dBm (40mW)	Gain antenna not allowed
Power for PPD in non-adjacent band with geo-location capability	20dBm (100mW)	Gain antenna not allowed
Power for PPD in non-adjacent band without geo-location capability	17dBm (50mW)	
Out-of-band performance	<55dB	Relative to in-band power

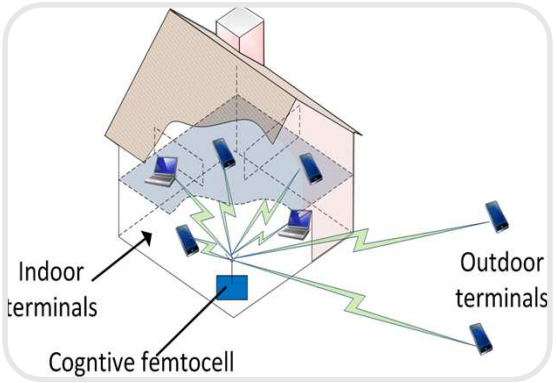
FD: Fixed Device
PPD: Personal Portable Device

[1] FCC final rule, “Unlicensed Operation in the TV Broadcast Bands”, US Federal Register Vol. 74, No.30, pp 7314-7332, Feb. 17 2009

What kind of radio?







Broadband scenarios

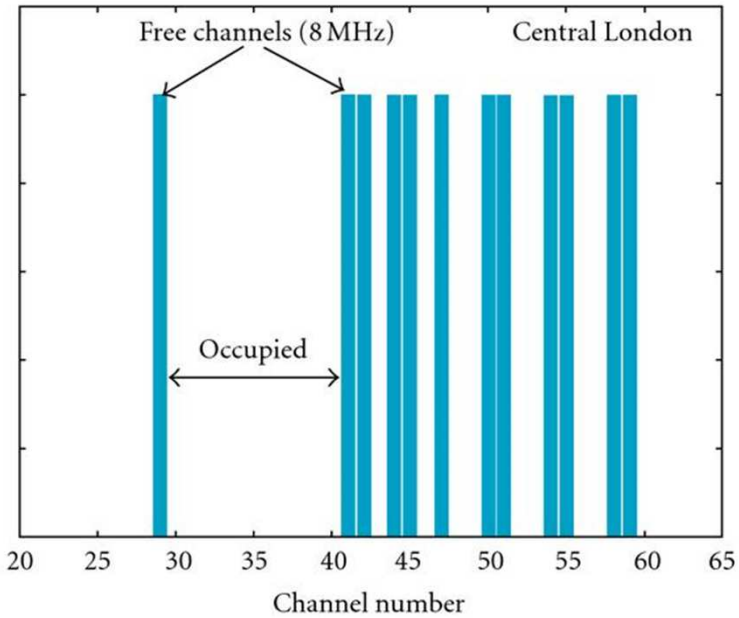
➔ **Few Mpbs to 10s Mbps**

Regulators require high rejection for adjacent incumbent protection in TVWS - e.g., 55dB requires by the FCC

➔**Low adjacent channel leakage (= high ACLR)**

Is it enough?

- UHF band is already fragmented
- Dynamic Spectrum Access may increase fragmentation



- Example Central London
- 96 MHz of spectrum available, 16 MHz of contiguous spectrum maximum

- Maximizing spectrum usage implies the use of non contiguous spectrum

Source: Nekovee, M., "A Survey of Cognitive Radio Access to TVWhite Spaces", International Journal of Digital Multimedia Broadcasting, Volume 2010, Hindawi

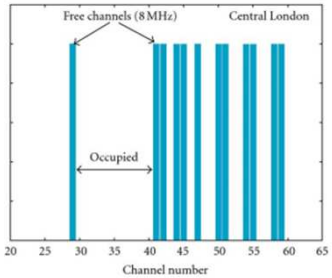
Guidelines

Broadband scenarios

➔ **Few Mpbs to 10s Mbps**

Regulators require high rejection for adjacent incumbent protection, eg 55dB required by the FCC

➔**Low adjacent channel leakage (high ACLR)**



Adapt spectrum allocation to occupancy changes

➔ **Flexibility**

Exploit potentialy fragmented spectrum (spectrum asset may not be contiguous)

➔ **Spectrum pooling**

What can we do?

Flexible PHY which can adapt its spectrum profile to allowed and / or available spectral resource

Multi-Carrier approaches have such a flexibility, thanks to the possibility to adjust each subcarrier transmit power in order to shape the overall spectrum profile

OFDM is the initial choice for CR PHY for the following reasons:

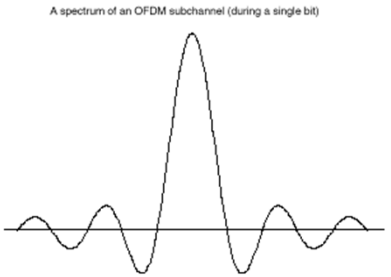
- OFDM is deployed in broadcast applications, as well as WLAN and in mobile wireless communication
- Simple equalization over frequency selective channels leads to simple receiver implementation
- High spectrum efficiency

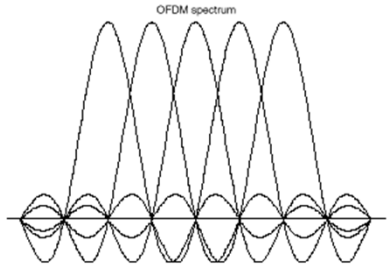
Is OFDM fulfilling our expectations?

In the frequency domain, the sum of *sinc* functions result in adjacent leakage power

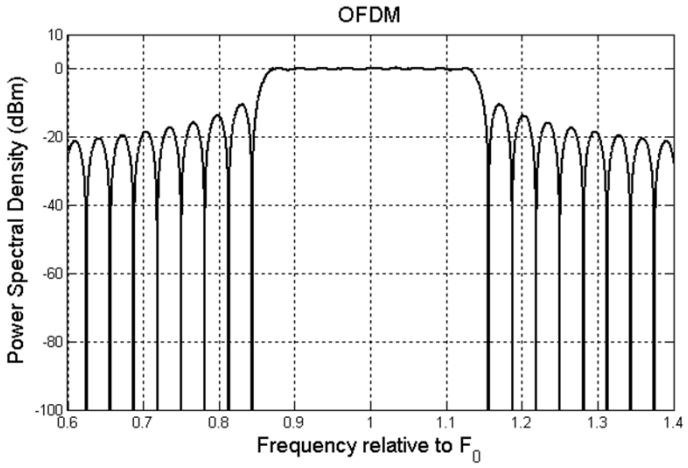
$$d[n,i] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} s[n,k] e^{j 2\pi i \frac{k}{N} \Delta f . T_s}$$

$$\frac{1}{T_s} = \Delta f$$





- Typically, first side-lobe of an OFDM spectrum is at -13dB compared to the main lobe
- Classical turnarounds are:
  - ➔ to add filtering
  - ➔ to decrease signal bandwidth



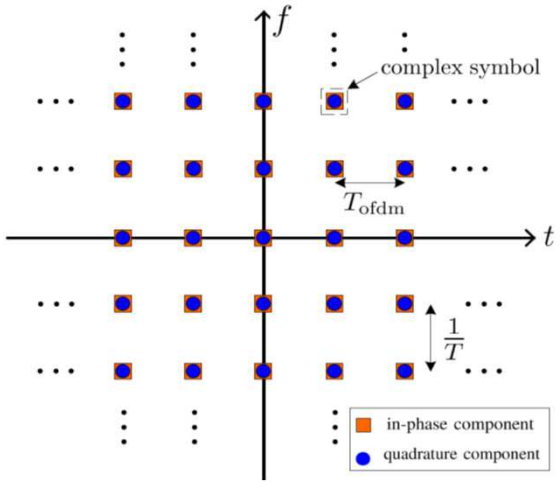
What can be done?

Balian-Low theorem states that we cannot have simultaneously:

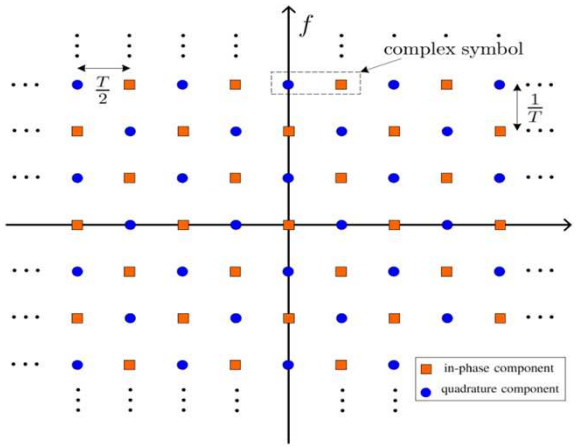
- A prototype filter well localized in time and frequency
- A maximal spectrum efficiency
- Complex orthogonality

Change prototype filter

CP-OFDM

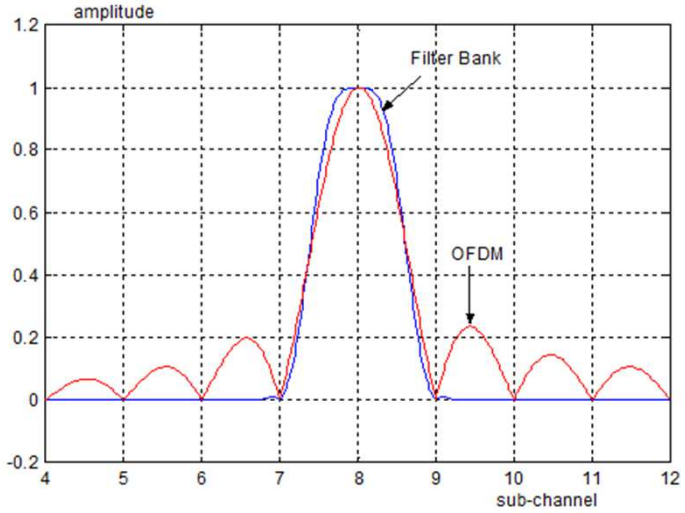


FBMC-OQAM



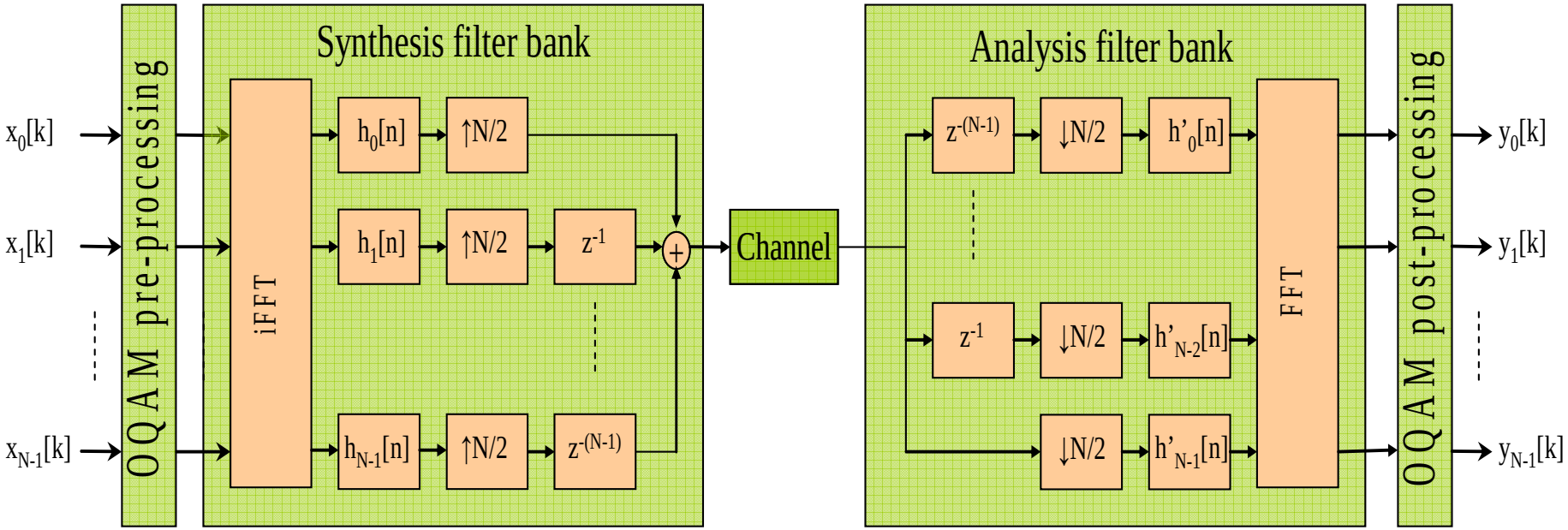
Filter Bank Multi Carrier (FBMC)

- **Keep the flexibility of Multi-Carrier modulation**
- **Control frequency response of each carrier by introducing a filter bank centered on every active carrier and based on the same prototype response**
- This prototype filter can be selected to minimize (null) adjacent channel interference
- The filtering is embedded in the digital modulation scheme
  - No additional filter is required
  - More flexibility



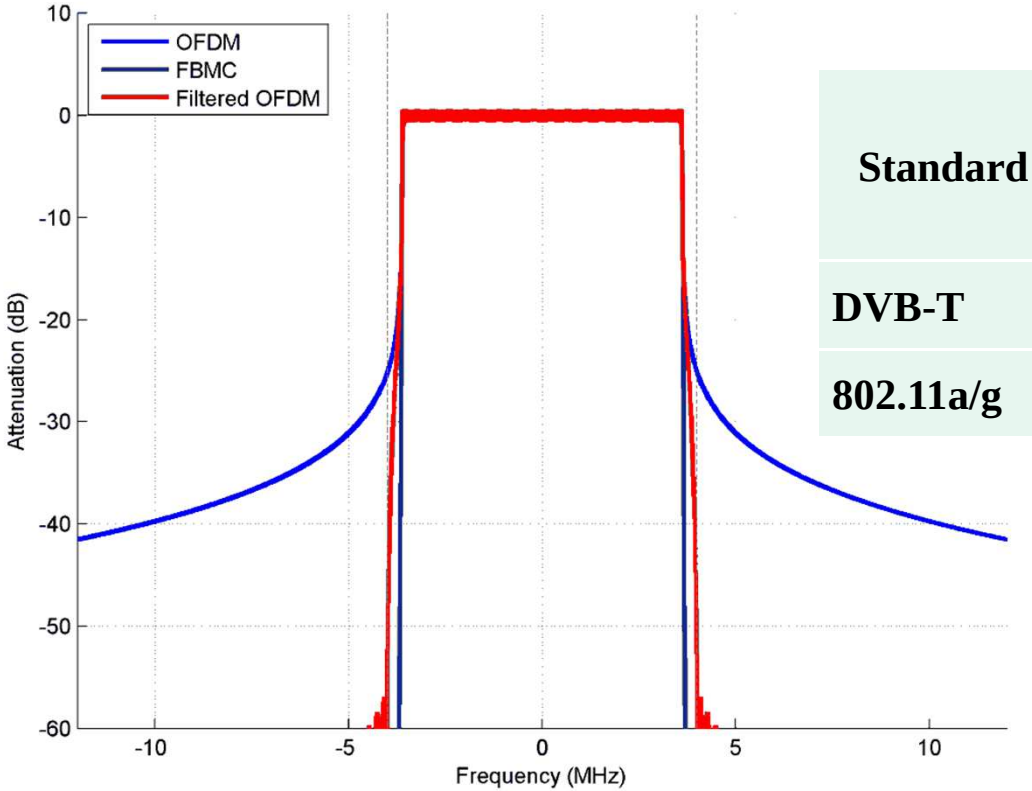
FBMC architecture

Can be implemented through usual iFFT / FFT for time/frequency domain conversion



FBMC in the TVWS context

ACLR and spectrum efficiency comparison: OFDM vs FBMC



Standard	Spectral Efficiency Gain relative to filtered OFDM		
	Frequency Domain	Time Domain	Total Gain
DVB-T	10 %	3 %	13 %
802.11a/g	3.8 %	15.8 %	19.6 %

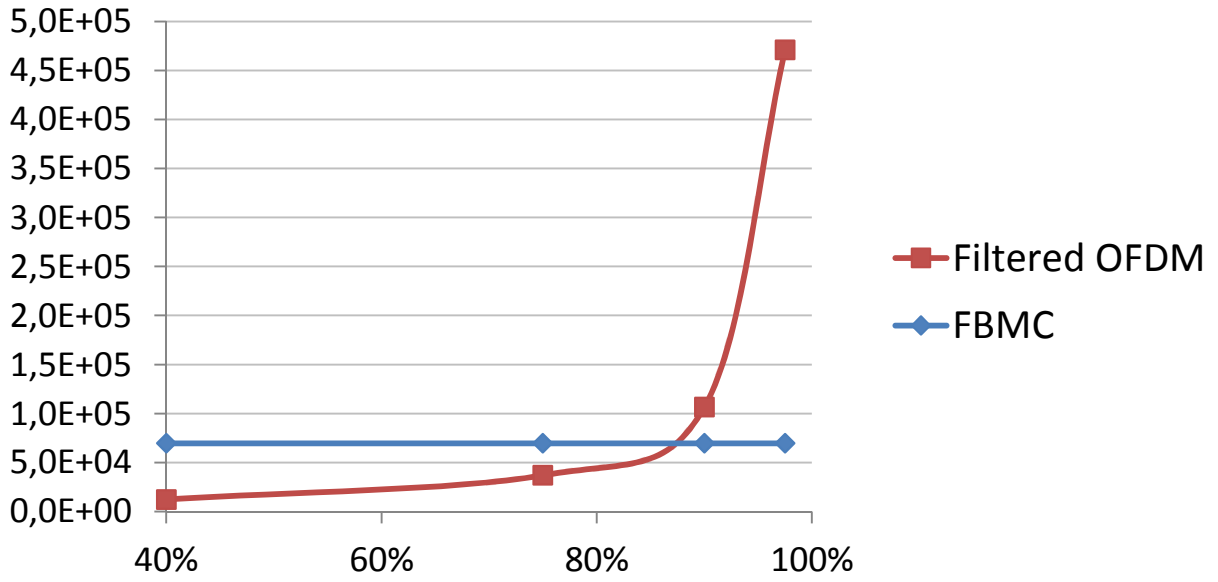
FBMC modulation complexity

Filtered OFDM vs FBMC

$$C_{FBMC} = 4 \cdot \left(N \cdot 2 + \left(N\left(\log_2(N) - 3\right) + 4 \right) + KN \cdot 2 \right)$$

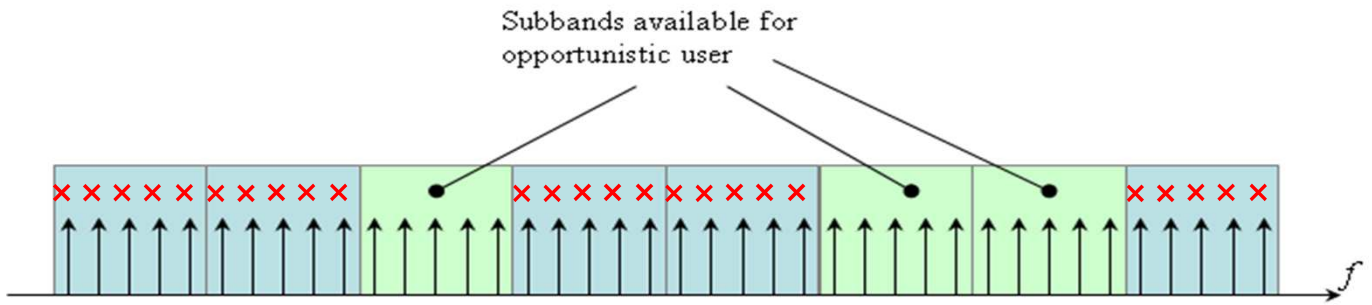
$$C_{CP-OFDM} = 2 \cdot \underbrace{\left(N\left(\log_2(N) - 3\right) + 4 \right)}_{\text{FFT and IFFT}} + \underbrace{2.N.N_{TxFilter}}_{\text{filter}}$$

N is the number of FFT carriers The FBMC prototype filter spans over K OFDM symbols



Spectrum pooling

- Concept of spectrum pooling where sub carriers are switched ‘on’ or ‘off’ according to available spectrum resource
- This shapes the spectrum to fill the available gaps, while avoiding interference in the band used by other systems (e.g. primary systems)



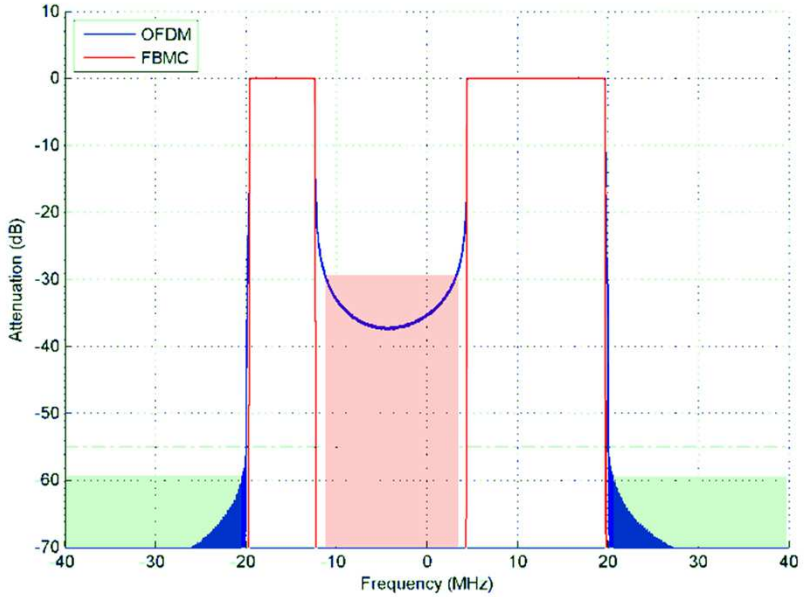
Source: T. A. Weiss, F. K. Jondral, "Spectrum pooling: an innovative strategy for the enhancement of spectrum efficiency", IEEE Communications Magazine, vol. 42, no. 3, pp.S8-S14, March 2004.

Spectrum pooling with FBMC

Since OFDM does not meet ACLR performance, only filtered OFDM is considered for comparison

In the example hereunder, 15kHz subcarrier spacing is considered in both cases

- ➡ The benefit of filtering on top of OFDM mitigates interference on both sides of the overall band
- ➡ It does not reject the signal inside the notch channels
- ➡ With FBMC, ACLR requirement is met both on adjacents and in the notch



Conclusion

- **TVWS is a context where spectrum efficiency, incumbent protection and flexibility are required**
- **CEA-LETI has investigated options to tackle these issues**
- **Multi-Carrier approaches were favored due to good spectrum efficiency and easy equalization at the RX (not presented herein)**
- **FBMC was considered as a serious contender to OFDM**
- **High ACLR and flexible access to fragmented spectrum are possible with FBMC, which outperforms OFDM in this regard**
- **Feedback from the group is very welcome**

Acknowledgement

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