Filter bank based multicarrier for cognitive radio

Maurice Bellanger, Didier Le Ruyet, Daniel Roviras, Michel Terré, Haijian Zhang, Yahia Medjahdi
Conservatoire National des Arts et Métiers
Paris, France.

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Outline

- FBMC system.
- PHYDYAS project overview
- Interference and spectrum efficiency
- Spectrum Sensing
- Ressource allocation for CR
- Conclusion
**FBMC system**

**Advantage:**
- FBMC time-frequency response is well localized.
- No need to insert Cyclic Prefix.

**Disadvantage:**
- Higher implementation complexity due to the PPN

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FBMC system

Normalized PSD (dB)

OFDM
Filter Bank

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FBMC system

- In FBMC, each subchannel overlaps only with its neighbours.
- We can separate two bands only by deactivating one subcarrier.
- In FBMC, we use OQAM modulation.
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We can separate two bands only by deactivating one subcarrier.

In FBMC, we use OQAM modulation.

At the receiver side, we have:

\[ y_i(n) = d_i(n) + ju_i(n) \]

\[ u_i(n) = \sum_{l=-1}^{1} \sum_{k=-(2K-1)}^{2K-1} c_{lk} d_{i+l}(n-k) \quad k, l \neq 0 \]

The coefficients \( c_{lk} \) represent the system impulse response.
PHYDYAS project

PHYDYAS : Physical layer for dynamic spectrum access and cognitive radio

• Duration 3 years (sept 2007 – dec 2010)

• List of the 13 members
  – Conservatoire National des Arts et Métiers (CNAM), France
  – Technische Universität München (TUM), Germany
  – Tampere University of Technology (TUT), Finland
  – Université Catholique de Louvain (UCL), Belgium
  – SINTEF - Trondheim, Norway
  – Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Spain
  – Research Academic Computer Technology Institute (RA-CTI), Greece
  – University of Napoli Federico II (UNINA), Italy
  – CEA-LETI Grenoble, France
  – Agilent-Belgium, Belgium
  – Alcatel-Lucent Swindon, UK
  – Alcatel-Lucent Deutschland, Germany
  – COMSIS-Paris, France

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PHYDYAS project

- SIGNAL PROCESSING CLUSTER
  - WP2 – fast scalable synchronization and initialization,
  - WP3 – transmit and receive processing (single antenna)
  - WP4 – MIMO transmit and receive processing
  - WP5 – prototype filter and filter bank structure

- COMMUNICATION CLUSTER
  - WP6 – dynamic access and cross layer aspects
  - WP7 – backward compatibility with OFDM
  - WP8 – radio scene spectrum analysis and cognitive radio

- DEMONSTRATOR CLUSTER
  - WP9 – includes the development and integration of a simulation package, the implementation of a laboratory setup with real-time channel emulation
cognitive radio

- **Aim**: improve the exploitation of the spectrum thanks to dynamic access (opportunistic)

- Public space (open sharing model)
  - users compete for the resource
  - high spectral density
  - protection of other users

- White space in a licensed band (spectrum overlay)
  - protection of primary users
  - priority of primary users
• Centralized spectrum access
  – cognitive pilot channel (primary+secondary users / databases)
  – cognitive control channel (between CRS-coexistence of secondary systems / collaborative)
  – service discovery using a geolocation data base (FCC 10-174 doc., rules for using TV white spaces)

• Decentralized dynamic spectrum access (DDSA)
  – local decision based on spectrum sensing
  – no coordination with other systems

=> opportunistic unsynchronized networks
Opportunistic terminal

- Detection of an unoccupied frequency band (spectrum sensing and monitoring)
- Local access decision and building of the capacities requested by the users
- Capability to handle unsynchronized users with minimal loss in spectral use
- Guaranteed protection of other users (coexistence)
- Exploitation of fragmented spectrum (broadband)
Interference Calculation

Hypothesis
- Frequency reuse 1
- Timing offset $\tau$ between the Cell B and the user
Determination of the set of interfering slots associated to the corresponding interference power for OFDM and FBMC systems
Interference Calculation

CP-OFDM

\[ y_m(\tau) = x_{m',0} e^{-j \frac{2\pi}{T} m' \tau} \times \begin{cases} \delta(l) & \tau \in [0, \Delta] \\ e^{j \frac{\pi l}{T} (T+\tau+\Delta)} \frac{\sin(\pi l (T+\Delta-\tau)/T)}{\pi l} & \tau \in [\Delta, T + \Delta] \end{cases} \]

- \( \tau \) is the timing offset
- \( l = m' - m \) and \( \delta(l) \) is the Kronecker delta function
- \( T \) is the OFDM symbol duration
- \( \Delta \) is the cyclic prefix duration

\[ I(\tau, l) = \begin{cases} \delta(l) & \tau \in [0, \Delta] \\ \left| \frac{\sin(\pi l (T+\Delta-\tau)/T)}{\pi l} \right|^2 + \left| \frac{\sin(\pi l (\tau-\Delta)/T)}{\pi l} \right|^2 & \tau \in [\Delta, T + \Delta] \end{cases} \]
Interference Calculation

CP-OFDM

Tab. 1 – CP-OFDM mean interference power table

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<th>( n )</th>
<th>( n+1 )</th>
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<td>9.19E-04</td>
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<td>5.00E-03</td>
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</tbody>
</table>
Interference Calculation

FBMC

\[ y_{m,n}(\tau) = a_{m',n'} e^{i(\varphi_{m',n'} - \varphi_{m,n})} e^{-j \frac{2\pi}{T} m} \int_{t_1}^{t_2} g(t - n'T/2 - \tau) g(t - n'T/2) e^{i \frac{2\pi}{T} m'} \Psi(t, \tau, l) \bigg|_{t=t_1}^{t=t_2} dt \]

**case 1:** \((-DT < (n - n') \frac{T}{2} < \tau)\)

\[ I(\tau, l) = \sum_{n' = \lfloor \frac{\tau}{T/2} \rfloor + n + 1}^{2D+n-1} a_{m',n'} \mathcal{R} \left\{ e^{i(\varphi_{m',n'} - \varphi_{m,n})} e^{-j \frac{2\pi}{T} m'} \Psi(t, \tau, l) \bigg|_{t-\tau}^{DT+(n-n')\frac{T}{2}} \right\}^2 \]

**case 2:** \((\tau < (n - n') \frac{T}{2} < DT)\)

\[ I(\tau, l) = \sum_{n' = -2D+n+1}^{n+\lfloor \frac{\tau}{T/2} \rfloor - 1} a_{m',n'} \mathcal{R} \left\{ e^{i(\varphi_{m',n'} - \varphi_{m,n})} e^{-j \frac{2\pi}{T} m'} \Psi(t, \tau, l) \bigg|_{t=(n-n')\frac{T}{2}}^{DT+\tau} \right\}^2 \]
FBMC case, PHYDYAS prototype filter

Interference level vs. Subcarrier offset ($l=k-k'$)
The number of interfering slots is reduced in FBMC with respect to OFDM.

The interference tables can easily be used for the derivation of the mean interference power due to a set of active slots in the interfering cell.
Interference Calculation


Spectrum efficiency comparison

Cognitive radio network with one primary system and one secondary cell
Spectrum efficiency comparison

OFDM

FBMC

Primary User

Secondary User

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Spectrum efficiency comparison

- distribution of the primary users and the spectrum holes (802.16)
- power allocation using the gradient projection method (GPM)
Spectrum efficiency comparison

36 PUs, 6 SUs, 12 free clusters, $P_{th} = 36$ mWatt, $D = 0.2$ km

Averaged spectral efficiency (bis/s/Hz) vs. Interference level (Watt)
• Different spectrum sensing methods have been explored (cyclostationary method, using candidate spectral estimation, ...)
• Within Phydyas, special focus on spectrum monitoring, i.e, detecting rapidly reappearing primary users (PUs) during on-going secondary user (SU) transmissions.
• FBMC enables spectrally efficient utilization of quiet sensing subbands in SU transmissions.
• Frequency-domain sensing subband approach is proposed
The Analysis Filter Bank of an FBMC system provides high-resolution, high dynamic range spectrum analysis, which can be utilized for very flexible, multiband spectrum sensing for different PU waveforms.

Pd versus SNR level for Pfa=5%
Spectrum Monitoring

- Secondary data
- Sensing window
- Guardband
- Guard interval

Continuous sensing subband

Guard subband

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• 2 approaches:
  • Heuristic resource allocation approach (good neighbor) decentralized dynamic spectrum access strategies (Kusminskiy)
  • Game theory approach
Game theory approach

Utility function

\[
\max : \quad u_n = \sum_{f=1}^{F} \log_2 \left( 1 + \frac{\sum_{m=1}^{M} G_m^{\text{norm}} p_f^{\text{norm}}}{\sigma^2 + I_f^n} \right)
\]

s.t.
\[
\begin{cases}
\sum_{f=1}^{F} p_f^{\text{norm}} = P, \quad \forall n, m \\
p_f^{\text{norm}} \geq 0
\end{cases}
\]


special issue on filter bank for wireless communication, EURASIP journal on advances in signal processing, 2010

http://www.ict-phydyas.org

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Conclusion

- Filter bank based multicarriers system is a good candidate for cognitive radio
- Multiband spectrum sensing is available thanks to the filter bank structure
- Simplified resource allocation solutions due to the absence of interference
- Future works:
  - Demonstration of the proposed system in real conditions
  - Contribution to standardization
  - Research on multiband spectrum sensing
  - Theoretical/practical research on resource allocation for non-cooperative multicell