Cooperation: Brno University of Technology

5G Simulator: FBMC

Ronald Nissel

11.02.2016

The 5G Simulator is under development, expected release date is 2017. Our FBMC Matlab code, however, can be downloaded at: https://www.nt.tuwien.ac.at/downloads/ and corresponds to our published papers
LTE Simulator

Matlab functions and classes

Main Simulation Files

LTE_load_parameters

LTE_sim_main
5G Simulator – Design Paradigm

Matlab functions and classes

- Signal constellation class
- FBMC class
- Turbo coder class

...should have a simple input output relation

Main Simulation Files

- Single-user BER
- Single-user throughput
- Multi-user throughput
- ...

Ronald Nissel, TU Wien
11.02.2016
Currently Implemented Classes

• Modulation:
  – FBMC
  – OFDM
  – Signal Constellation (QAM, PAM)

• Coding
  – TurboCoding

• Channel Estimation
  – ImaginaryInterferenceCancellationAtPilotPosition
  – PilotSymbolAidedChannelEstimation
Turbo Coding Class

TurboCoding = Coding.TurboCoding(...
    2700,...
    206 ...
);

CodedBits = TurboCoding.TurboEncoder(DataBits); % Code binary stream
EstimatedDataBits = TurboCoding.TurboDecoder(LLR); % Decode bits

• To DO: Rewrite class
  Currently, the Communications System Toolbox is used for the turbo coder
  • Slow
  • Not included in all MATLAB versions
FBMC Class

FBMC = Modulation.FBMC(... % Class constructor
  90,... % Number of subcarriers
  30,... % Number of FBMC symbols
  15e3,... % Subcarrier spacing
  15e3*90,... % Sampling frequency
  0,... % Intermediate frequency
  false,... % Transmit real valued signal
  'Hermite-OQAM',... % Prototype filter and OQAM or QAM
  8, ... % Overlapping factor
  0, ... % Initial phase shift
  true ... % Polyphase implementation
);

s = FBMC.Modulation(x); % Modulate data stream
y = FBMC.Demodulation(s); % Demodulate received signal

Some additional methods (small subset):

FBMC.PlotTransmitPower(R_x); % Plot average transmit power over
FBMC.PlotPowerSpectralDensity; % Plot the power spectral density
Throughput: infinitely many transmission blocks assumed!

- OFDM: $O\{L \log_2(L)\}$
- FBMC: $O\{2(L \log_2(L) + OL)\}$
Overlapping Factor 8

- Average transmit signal in dB

![Graph showing signal comparison between PHYDYAS, Root-raised-cosine, and Hermite methods over time.](image)
Overlapping Factor 8

- Power spectral density
Overlapping Factor 4

- Power spectral density
Overlapping Factor

- Signal-to-Interference Ratio
FBMC vs. OFDM

- 1.4MHz LTE
- Doubly-flat Rayleigh fading

<table>
<thead>
<tr>
<th></th>
<th>OFDM</th>
<th>FBMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subcarriers</td>
<td>72</td>
<td>90</td>
</tr>
<tr>
<td>Number of time symbols</td>
<td>14</td>
<td>30 (real) (equivalent to 15 complex symbols)</td>
</tr>
</tbody>
</table>
Achievable Ergodic Capacity
Achievable BICM Capacity
Simulated Throughput
OFDM

Achievable Ergodic Capacity
Achievable BICM Capacity
Simulated Throughput
Simulated Throughput: FBMC vs OFDM
Channel Estimation

• Doubly-flat Rayleigh fading

• Cancel imaginary interference at pilot position
  – Auxiliary pilot symbols
  – Coding

• Channel estimation (interpolation)
  – Linear
  – MMSE

• LLR assumes perfect channel knowledge
1 Auxiliary Symbol per Pilot

- Power offset 4.3, High PAPR
2 Auxiliary Symbol per Pilot

- Power offset 0.8
Coding

- Power offset 0
FBMC: MMSE vs Linear for Coding

- FBMC throughput

![Graph showing throughput comparison between MMSE and Linear channel estimation. The graph plots capacity throughput against SNR_{OFDM} for both MMSE and Linear channel estimation, with MMSE achieving higher throughput at higher SNR values. The Achievable BICM Capacity (perfect CSI) is also indicated.]
FBMC vs OFDM for **MMSE Channel Estimation**

- **BICM Capacity (perfect CSI)**

![Graph showing the improvement of FBMC compared to OFDM](image)
FBMC vs OFDM for MMSE Channel Estimation

- Throughput simulations

![Graph showing the comparison between FBMC and OFDM for different SNR values and coding schemes.](image)
FBMC vs OFDM for Linear Channel Estimation

- Throughput simulations

![Graph showing improvement of FBMC compared to OFDM (%)](image)

- Coding
  - 2 Auxiliary pilots
  - 1 Auxiliary pilot

Ronald Nissel, TU Wien

Seite 26
Recent Results – Measurements

- Interference from the LTE Uplink

Use only these measurement points (just for testing)
Recent Results – Measurements

- FBMC and OFDM perform similar (as theory suggest)

![Graph showing Bit Error Ratio vs. estimated SNR for different modulation schemes]

- 64QAM, 8PAM
- 16QAM, 4PAM
- 4QAM, 2PAM
Outlook

• Throughput measurements for 2,3,4… auxiliary pilot symbols, submit to SAM 2016 in Rio de Janeiro

• Performance of FBMC in doubly-selective channels
  – Signal to interference ratio
  – Effects on channel estimation

• (Massive) MIMO in FBMC