ON PILOT-SYMBOL AIDED CHANNEL ESTIMATION IN FBMC-OQAM

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Introduction

Filter Bank Multi-Carrier (FBMC) modulation is considered as a possible candidate for 5G. Compared to OFDM, channel estimation becomes more challenging in FBMC due to the **imaginary interference, which has to be canceled** at the pilot positions either by **auxiliary pilot symbols or coding.**

Novel Contribution

1. We formulate general conditions on the auxiliary pilot symbols, capturing also the interdependency of closely spaced pilots and an arbitrary number of auxiliary pilot symbols.
2. Previous authors consider only coding of up to $N = 8$ symbols. We propose an algorithm to design the coding matrix required for an arbitrary number of coded symbols.
3. We quantify the complexity difference between auxiliary pilot symbols and coding.

System Model

The data symbols $x_{l,k}$ at frequency position l and time position k are modulated by the basis pulses $g_{l,k}(t)$, so that the transmit signal $s(t)$ becomes:

$$s(t) = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} g_{l,k}(t)\, x_{l,k}, \qquad (1)$$

$$g_{l,k}(t) = p(t-kT)\, \mathrm{e}^{\mathrm{j}2\pi\, lF\,(t-kT)}\, \mathrm{e}^{\mathrm{j}\frac{\pi}{2}(l+k)}. \qquad (2)$$

Our prototype filter $p(t)$ is based on Hermite polynomials. Sampling the basis pulses $g_{l,k}(t)$:

$$[\mathbf{G}]_{i,l+kL} = \sqrt{\Delta t}\; g_{l,k}(t)\Big|_{t=\Delta t\, i - 3T_0}, \qquad (3)$$

allows us to rewrite the sampled signal in (1) by

$$\mathbf{s} = \mathbf{G}\mathbf{x}. \qquad (4)$$

The overall transmission system is then given by:

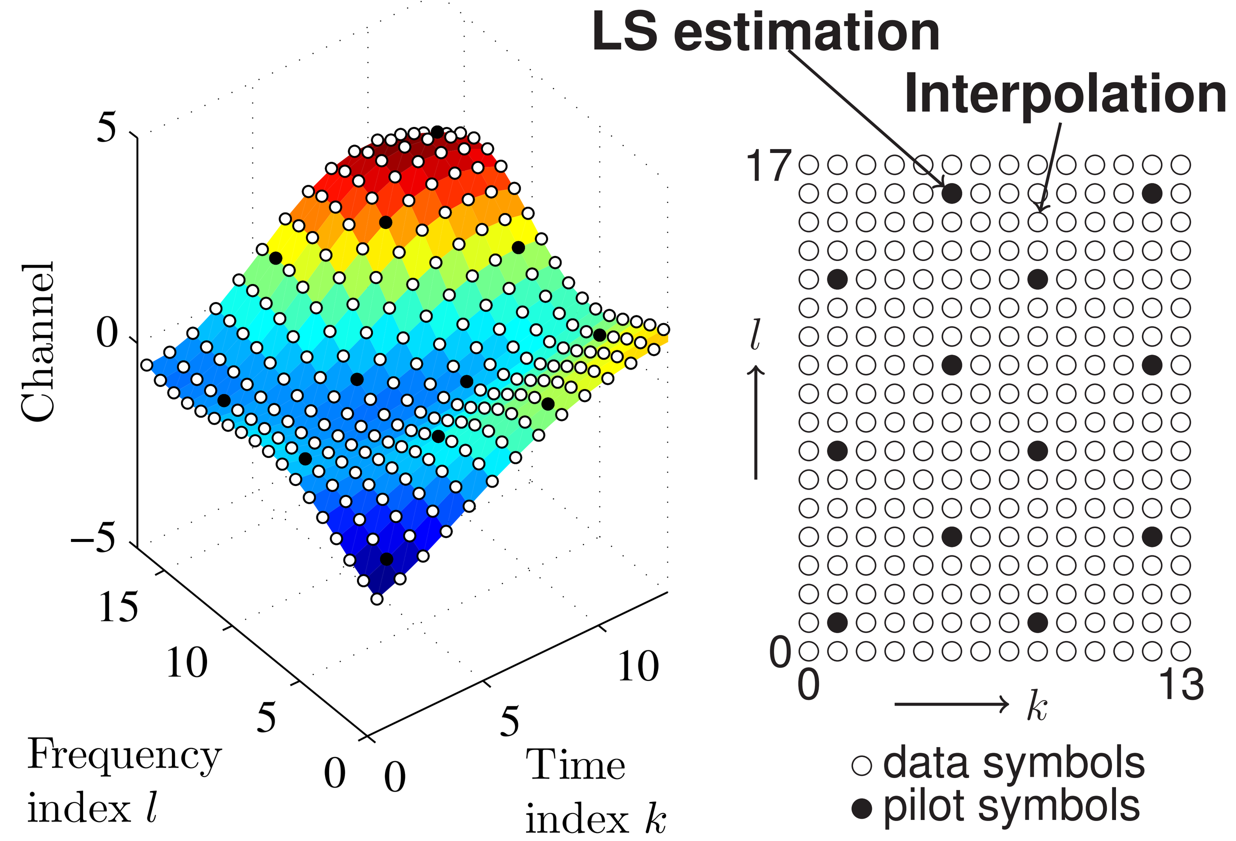
$$\mathbf{y} = \mathrm{diag}\{\mathbf{h}\}\mathbf{D}\mathbf{x} + \mathbf{n}, \qquad (5)$$

with $\mathbf{h}$ denoting the channel, $\mathbf{n}$ the noise and

$$\mathbf{D} = \mathbf{G}^H\mathbf{G}. \qquad (6)$$

In OFDM, the orthogonality condition is fulfilled, i.e., $\mathbf{D} = \mathbf{I}_{LK}$, whereas in FBMC, we observe only real orthogonality, i.e., $\Re\{\mathbf{D}\} = \mathbf{I}_{LK}$.

Pilot-Symbol Aided Ch. Est.



The LS channel estimates at pilot positions experience **imaginary interference**, given by:

j0.0001	j0.0003	−j0.0054	j0.0098	−j0.0054	j0.0003	j0.0001
j0.0003	0	j0.0369	0	−j0.0369	0	−j0.0003
−j0.0054	j0.0369	−j0.2393	j0.4357	−j0.2393	j0.0369	−j0.0054
j0.0098	0	j0.4357	1	−j0.4357	0	−j0.0098
−j0.0054	−j0.0369	−j0.2393	−j0.4357	−j0.2393	−j0.0369	−j0.0054
j0.0003	0	j0.0369	0	−j0.0369	0	−j0.0003
j0.0001	−j0.0003	−j0.0054	−j0.0098	−j0.0054	−j0.0003	j0.0001

Frequency / Time — Pilot (Data), Auxiliary1, Auxiliary2; $N=4$, $N=8$, $N=16$, $N=28$

Cancel the imaginary interference:
- Auxiliary pilot symbols, or
- Coding

Auxiliary Pilot Symbols

The imaginary interference at the pilot positions can be completely eliminated if the auxiliary pilot symbols are chosen so that:

$$\mathbf{x}_\mathcal{P} = \begin{bmatrix}\mathbf{D}_{\mathcal{P},\mathcal{P}} & \mathbf{D}_{\mathcal{P},\mathcal{D}} & \mathbf{D}_{\mathcal{P},\mathcal{A}}\end{bmatrix}\begin{bmatrix}\mathbf{x}_\mathcal{P}\\ \mathbf{x}_\mathcal{D}\\ \mathbf{x}_\mathcal{A}\end{bmatrix}, \qquad (7)$$

We solve (7) using the Moore-Penrose pseudoinverse (spend as little energy as possible on auxiliary pilot symbols):

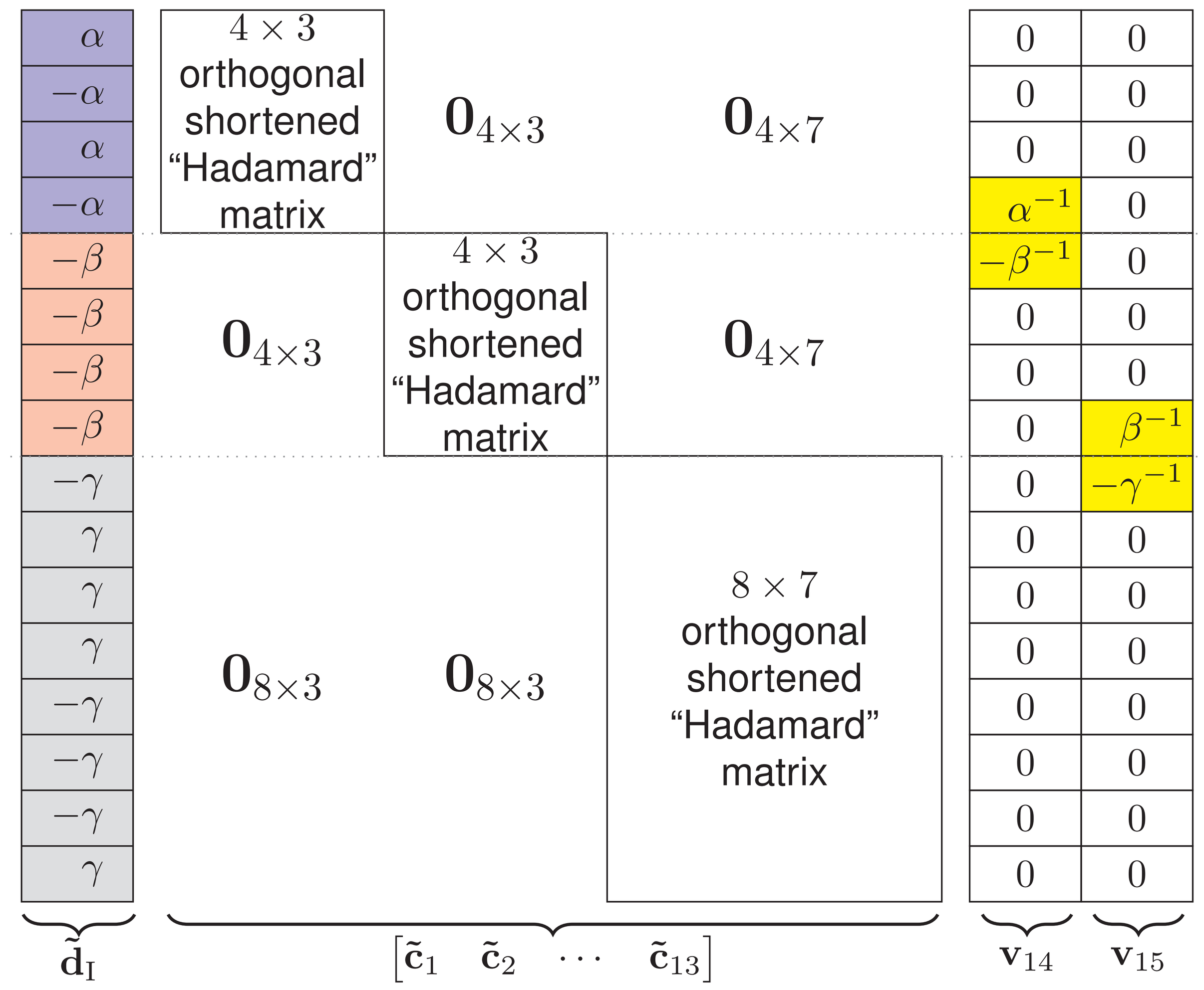
$$\mathbf{x}_\mathcal{A} = \mathbf{D}^{\#}_{\mathcal{P},\mathcal{A}}\left(\mathbf{I}_\mathcal{P} - \mathbf{D}_{\mathcal{P},\mathcal{P}}\right)\mathbf{x}_\mathcal{P} - \mathbf{D}^{\#}_{\mathcal{P},\mathcal{A}}\mathbf{D}_{\mathcal{P},\mathcal{D}}\mathbf{x}_\mathcal{D}, \qquad (8)$$

with

$$\mathbf{D}^{\#}_{\mathcal{P},\mathcal{A}} = \mathbf{D}^{H}_{\mathcal{P},\mathcal{A}}\left(\mathbf{D}_{\mathcal{P},\mathcal{A}}\mathbf{D}^{H}_{\mathcal{P},\mathcal{A}}\right)^{-1}. \qquad (9)$$

Coding

Orthogonality condition on the coding vectors $\tilde{\mathbf{c}}_i$:
- To each other, $\tilde{\mathbf{c}}_i^T\tilde{\mathbf{c}}_j = 0$ for $i \neq j$
- To the imaginary interference, $\tilde{\mathbf{d}}_\mathrm{I}^T\tilde{\mathbf{c}}_i = 0$



Use Gram-Schmidt orthogonalization on $\mathbf{v}_j$ to find the remaining coding vectors:

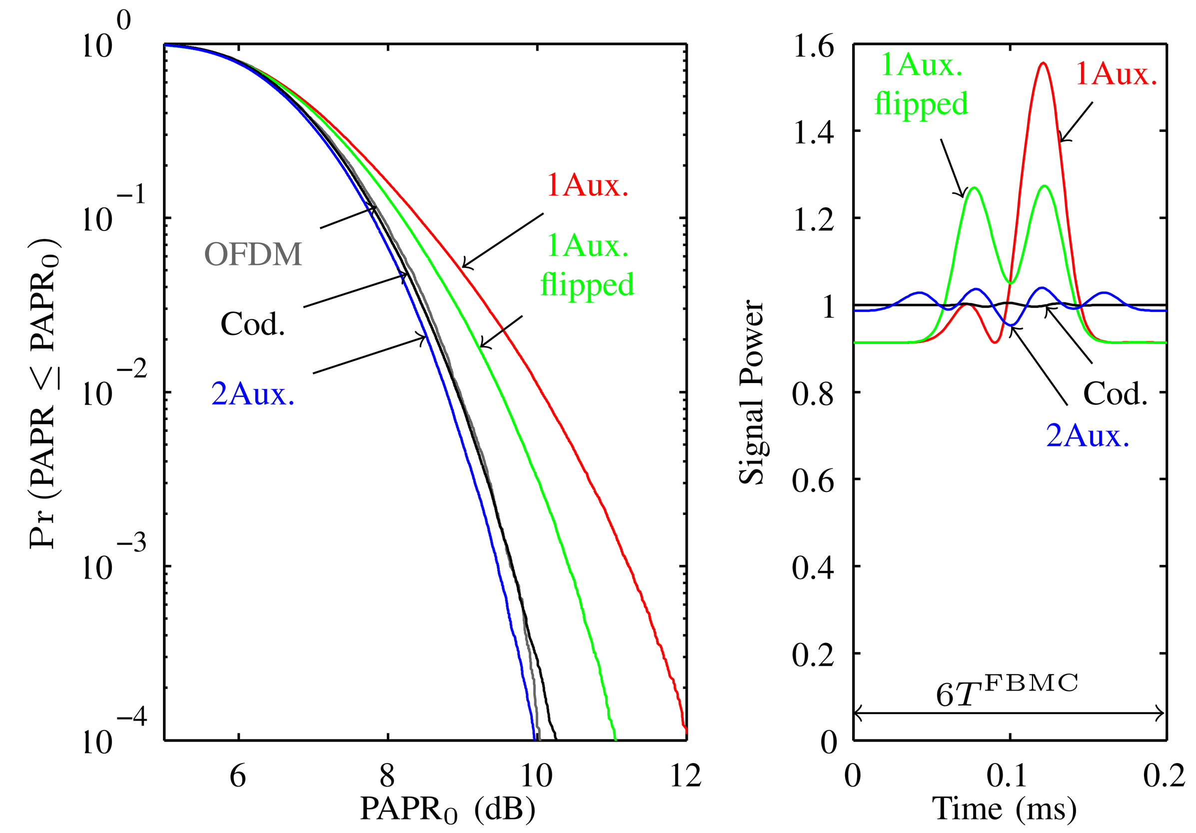
$$\tilde{\mathbf{c}}_j = \mathbf{v}_j - \sum_{i=1}^{j-1}\frac{\mathbf{v}_j^T\tilde{\mathbf{c}}_i}{\tilde{\mathbf{c}}_i^T\tilde{\mathbf{c}}_i}\tilde{\mathbf{c}}_i. \qquad (10)$$

Numerical Results

1.4 MHz LTE resembling OFDM signal:

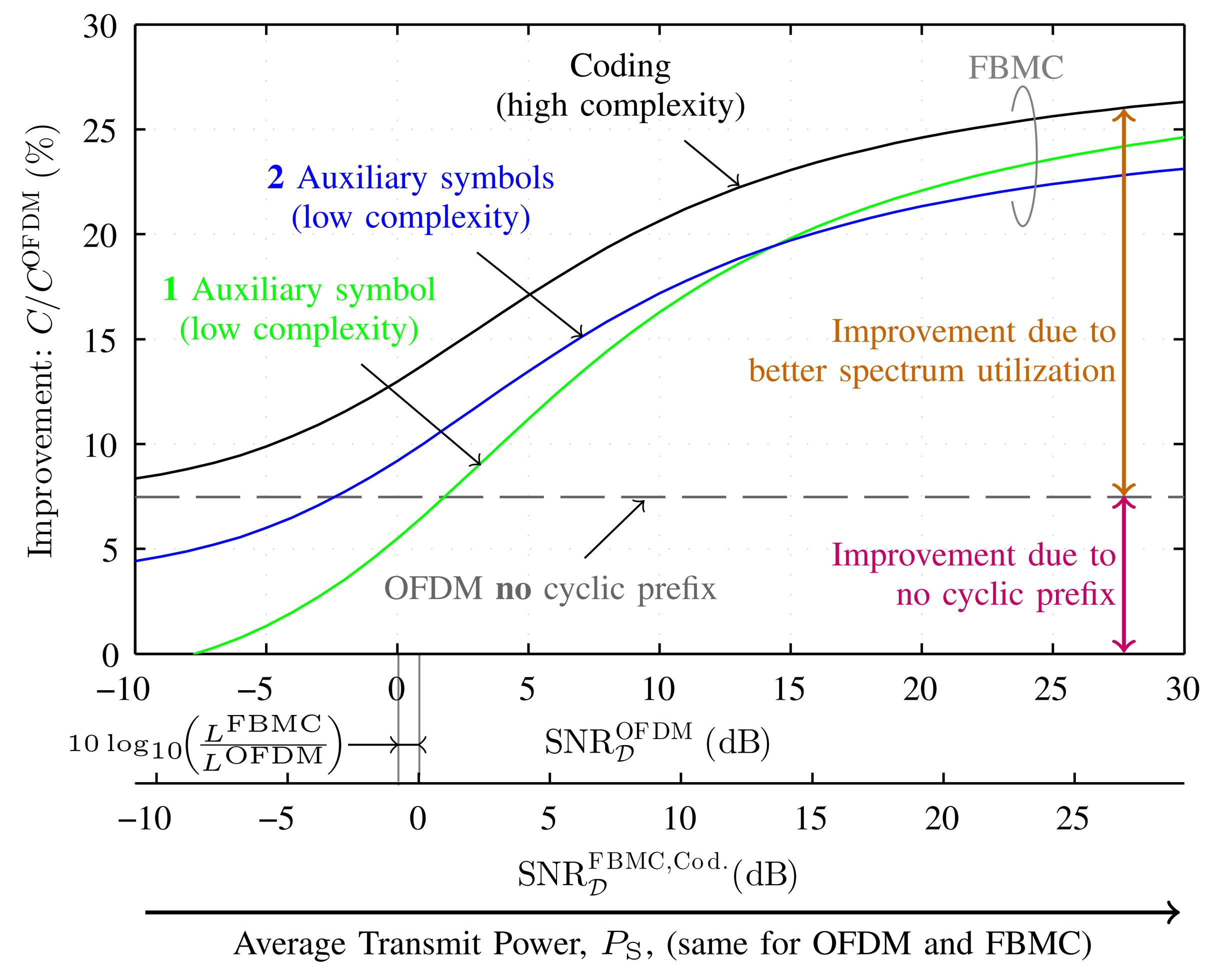
	OFDM	FBMC
Nr.Subcarriers	72 (1.1 MHz)	87 (1.3 MHz)
Nr.TimeSymbols	14 (1ms)	30 (1ms)

Peak-to-power average ratio and signal power:



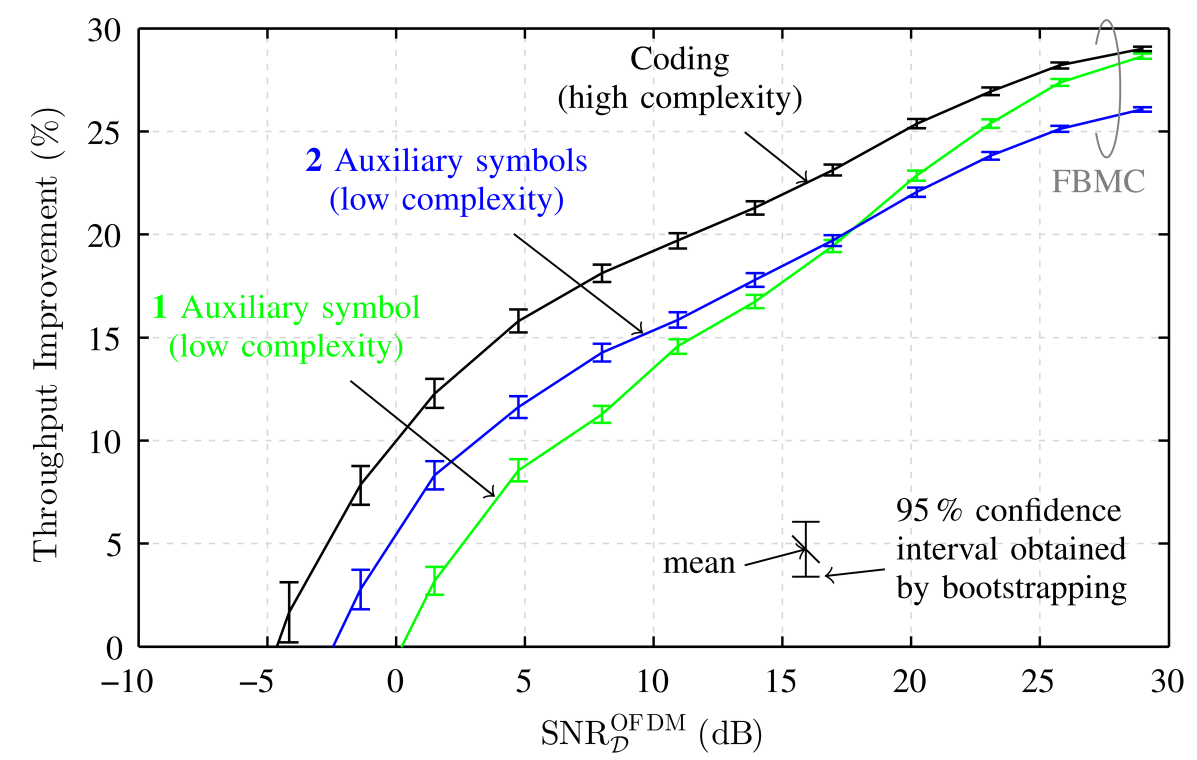
Numerical Results

Improvement in **achievable capacity** of FBMC compared to OFDM



Testbed Measurement

Throughput improvement of FBMC compared to OFDM (recent results, not included in the paper)



Conclusion

We suggest to use coding for pilot symbol aided channel estimation. However, if computational complexity becomes relevant, auxiliary pilot symbols might be a better choice. One auxiliary symbol per pilot, as suggested in literature, has some serious drawbacks. We thus suggest to use two auxiliary symbols per pilot.

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