ITERATIVE INTERFERENCE SUPPRESSION FOR PSEUDO RANDOM POSTFIX OFDM BASED CHANNEL ESTIMATION

Markus Muck[1], Marc de Courville[1], Xavier Miet[1] and P. Duhamel[2]

[1]Motorola Labs – Paris, Espace Technologique Saint-Aubin 91193 Gif-sur-Yvette, France
[2]CNRS/LSS Supelec, Plateau de moulon, 91192 Gif-sur-Yvette, France

MOTOROLA LABS

Position of the work

✔ **Classic Cyclic Prefix-OFDM (CP-OFDM):**

- **Idea:** FFT + Cyclic Prefix appending ⇝ block redundant transmissions
- **Advantage:** very simple (FFT-based) equalization scheme for FIR channels
- **Drawback:** symbols sent on subcarriers subject to strong attenuations are irremediably lost
- **Classical remedy:** channel coding but does not eliminate performance losses incurred by channel nulls

✔ **Zero Padded-OFDM (ZP-OFDM)**:

- **Idea**: replace the CP appending by Trailing Zeros (TZ) insertion at the tail of the block to be transmitted
- **Advantage**: guarantees symbol recovery regardless of channel zero locations & allows performance vs complexity trade-offs in the receiver
- **Drawback**: a priori increased receiver complexity, ranging from simple techniques (Overlap-Add) to high performance / high complexity approaches (MMSE)

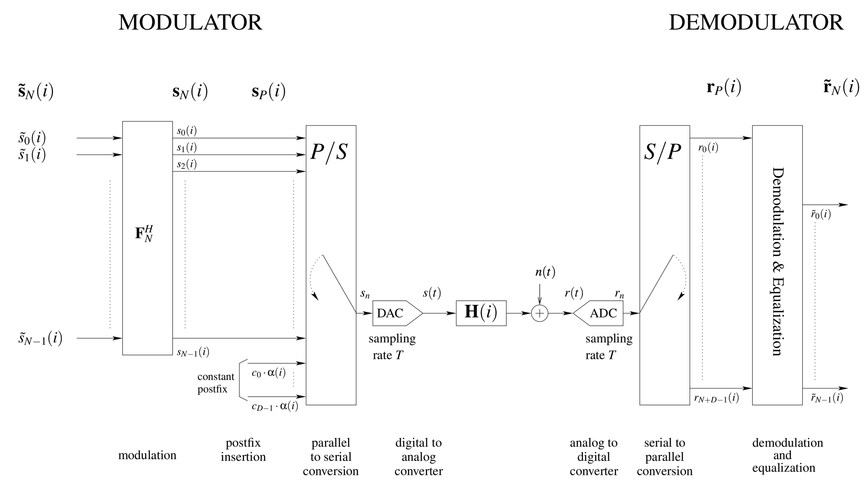
✔ **Pseudo Random Postfix OFDM (PRP-OFDM)**:

- **Idea**: instead of TZ, use pseudo-randomly weighted deterministic sequence ⇝ exploitation for simple channel estimation and tracking.
- **Advantage**: keep advantages of ZP-OFDM, while introducing possibility to estimate/track channel with minimum pilot/preamble overhead.
- **Drawback**: depending on decoding approach, slight to medium increase of complexity

✔ **Contribution:** proposition of an efficient channel estimation/tracking scheme for PRP-OFDM.
✔ **Context:** any wireless system requiring i) a minimum pilot overhead, ii) the possibility of simple channel tracking (e.g. high mobility context) and iii) adjustable receiver complexity/performance trade-offs without requiring any feed-back loop to the transmitter.

Discrete Model of the PRP-OFDM transceiver

✔ **Parameters**: consider a N carrier OFDM system with a length D prefix leading to a block size of $P = N + D$ samples



General design assumption: the channel order is upper bounded by the length D in samples of the prefix (i.e. respectively the cyclic extension/zeros padded to the head/tail of the block)

$$\boxed{\mathbf{r}_P(i) = \mathbf{H}_{\beta_i}\begin{pmatrix}\mathbf{F}_N^H\tilde{\mathbf{s}}_N(i)\\ \alpha(i)\mathbf{c}_D\end{pmatrix} + \mathbf{n}_P(i)}$$

with $\mathbf{F}_{ZP}^H = \begin{bmatrix}\mathbf{I}_N\\ \mathbf{0}_{D,N}\end{bmatrix}_{P\times N}\mathbf{F}_N^H$, $\mathbf{H}_{\beta_i} = (\mathbf{H}_{ISI} + \beta_i\mathbf{H}_{IBI})$, $\beta_i = \frac{\alpha(i-1)}{\alpha(i)}$, $\alpha(i) \in \mathbb{C}, |\alpha(i)| = 1$ and $E[\alpha(i)] = 0$.

PRP-OFDM Postfix based Channel Estimation

✔ **General Idea:** Separate OFDM data symbols from PRP-OFDM postfixes convolved by channel. Extract channel impulse response by de-convolution.

Low Complexity Approach: Separation by Mean Value Calculation

✔ **Low Complexity Approach:** Exploit zero-mean nature of OFDM data symbols - A simple mean-value calculation is sufficient in order to extract PRP-OFDM postfixes convolved by channel.

Based on the received vector

$$\mathbf{r}_P(i) = \begin{pmatrix}\mathbf{H}_{ISI}(D)\mathbf{s}_{N,0}(i) + \alpha(i-1)\mathbf{H}_{IBI}(D)\mathbf{c}_D + \mathbf{n}_{D,0}\\ \vdots\\ \mathbf{H}_{IBI}(D)\mathbf{s}_{N,1}(i) + \alpha(i)\mathbf{H}_{ISI}(D)\mathbf{c}_D + \mathbf{n}_{D,1}\end{pmatrix}, \text{ where}$$

- $\mathbf{H}_{CIR}(D) := \mathbf{H}_{ISI}(D) + \mathbf{H}_{IBI}(D)$ is the $D \times D$ circulant channel matrix of first row $row_0(\mathbf{H}_{CIR}(D)) = [h_0, 0, \rightarrow, 0, h_{L-1}, \cdots, h_1]$. Note that $\mathbf{H}_{ISI}(D)$ and $\mathbf{H}_{IBI}(D)$ contain respectively the lower and upper triangular parts of $\mathbf{H}_{CIR}(D)$.
- the transmitted data symbol is $\mathbf{s}_N(i) := [s_0(i), \cdots, s_{N-1}(i)]^T$, from which 2 parts are extracted: $\mathbf{s}_{N,0}(i) := [s_0(i), \cdots, s_{D-1}(i)]^T$, $\mathbf{s}_{N,1}(i) := [s_{N-D}(i), \cdots, s_{N-1}(i)]^T$, and performing the same operations for the noise vector: $\mathbf{n}_P(i) := [n_0(i), \cdots, n_{P-1}(i)]^T$, $\mathbf{n}_{D,0}(i) := [n_0(i), \cdots, n_{D-1}(i)]^T$, $\mathbf{n}_{D,1}(i) := [n_{P-D}(i), \cdots, n_{P-1}(i)]^T$.

The postfix convolved by the channel is extracted as follows:

$$\begin{aligned}\hat{\mathbf{r}}_{c,0} &:= E\left[\frac{\mathbf{r}_{P0}(i)}{\alpha(i-1)}\right] = \mathbf{H}_{IBI}(D)\mathbf{c}_D,\\ \hat{\mathbf{r}}_{c,1} &:= E\left[\frac{\mathbf{r}_{P,1}(i)}{\alpha(i)}\right] = \mathbf{H}_{ISI}(D)\mathbf{c}_D.\\ \hat{\mathbf{r}}_c &:= \hat{\mathbf{r}}_{c,0} + \hat{\mathbf{r}}_{c,1} = \mathbf{H}_{CIRC}(D)\mathbf{c}_D\end{aligned}$$

$$\boxed{\hat{\mathbf{r}}_c = \mathbf{C}_D\mathbf{h}_D = \mathbf{F}_D^H\tilde{\mathbf{C}}_D\mathbf{F}_D\mathbf{h}_D}$$ ⇝ **The channel is extracted by de-convolution**.

$\mathbf{C}_D$ is a $D \times D$ circulant matrix with first row $row_0(\mathbf{C}_D) := [c_0, c_{D-1}, c_{D-2}, \cdots, c_1]$ and $\tilde{\mathbf{C}}_D := \text{diag}\{\mathbf{F}_D\mathbf{c}_D\}$.

Issue: for high MSE requirements on CIR, mean value window must be very large ⇝ not realistic in general for latency issues and in particular for mobility context.

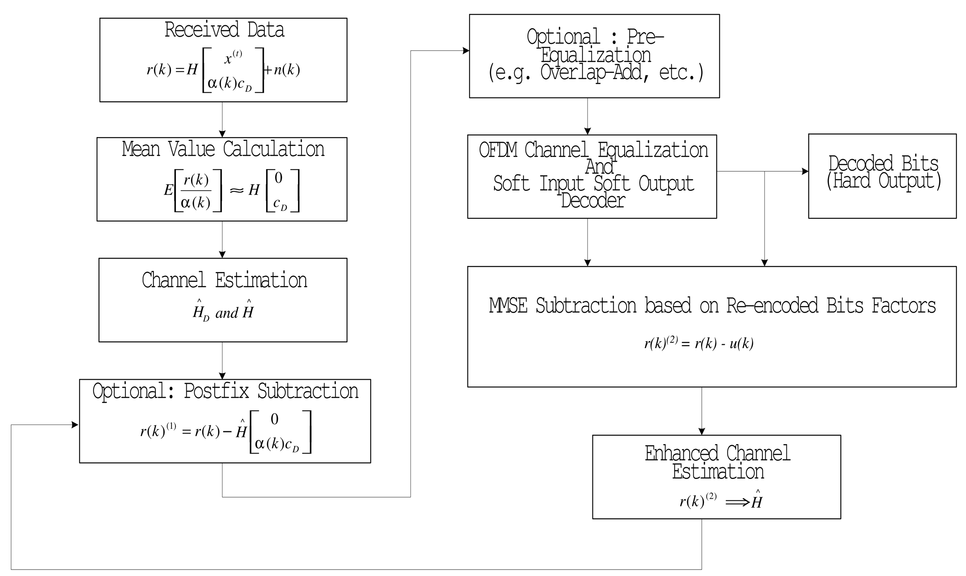
Improved Novel Proposal: Iterative Interference Suppression

✔ **Novel Proposal:** Re-encode decoded data, perform channel convolution and subtract these estimates from received data stream ⇝ Mean-value calculation over few symbols is sufficient in order to extract postfixes convolved by channel.

Proposition 1: optimum interference estimates in MSE sense exploiting soft decoder outputs:

$$\mathbf{u}_P^k(i) = \sum_{\mathbf{a}_N \in [a_0, \cdots, a_{Q-1}]^N} p(\tilde{\mathbf{s}}_N(i) = \mathbf{a}_N | \hat{\mathbf{y}}_N^{k-1}(i)) \mathbf{H}_{\beta_i}^{k-1}\mathbf{F}_{ZP}^H\mathbf{a}_N, \text{ where}$$

$\{a_n \in \mathbb{C}, n \in [0, \cdots, Q-1]\}$ is the set of constellation symbols (alphabet) and Q the constellation order.

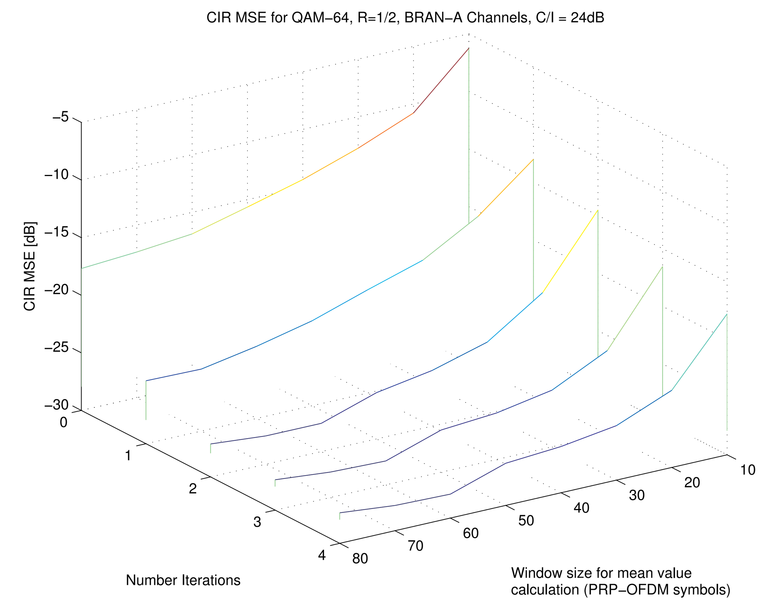


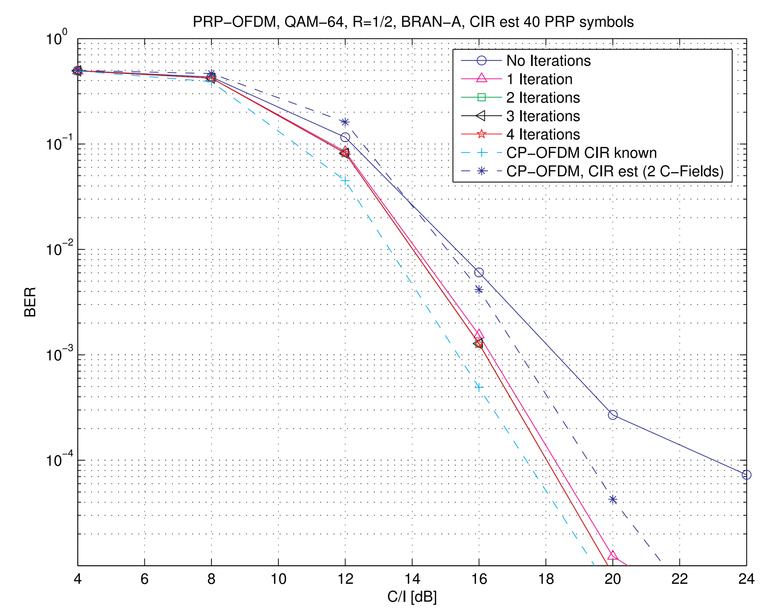
Result: accurate CIR estimation with 2-3 iterations. Typically applicable if iterative decoding is applied anyhow (Turbo Codes, LDPC, etc.).

Performance Evaluation

✔ **Simulation Parameters:**

- IEEE802.11a WLAN context: $N = 64$ carriers, $D = 16$ postfix samples, 20MHz bandwidth, 5.2GHz
- Standard CC code $R = 1/2$, $K = 7$ (o171/o133), SOVA decoder, QAM-64 constellations
- BRAN-A frequency-selective channel (NLOS, 50ns rms delay spread)
- At first iteration, CIR is estimated based on standard mean-value approach





Results and Conclusion

- One iteration is sufficient in order to decrease the CIR estimation MSE by approx. 10dB.
- Very few iterations are required in order to approach quasi-asymptotic performances (2-3 iterations).
- Iterative interference suppression makes PRP-OFDM applicable to higher-order constellation applications.
- Constraints: soft-output decoding should be inherent to the system implementation in order to justify PRP-OFDM.
- The usefulness of PRP-OFDM is proven if the target application requires: i) a minimum pilot overhead, ii) low-complexity channel tracking (e.g. high mobility context) and iii) adjustable receiver complexity/performance trade-offs without requiring any feed-back loop to the transmitter.