“Blind” Space-Frequency Beamforming for FFH & OFDM

Kainam Thomas Wong

ktwong@ieee.org
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Aerospace Corporation,
El Segundo, California
Algorithmic Capabilities Offered

The proposed beamformer

- **substantially** improves the signal-to-interference-and-noise ratio (SINR):
  - could reject co-channel interference and noise,
  - could constructively summing the SOI.

- applies **multi-dimensionally** across receiving antennas & across hop-frequencies / subcarriers.

- operates "**blindly**, in the sense of requiring **no** prior information on
  - the SOI's angle-of-arrival,
  - the SOI's space-frequency propagation-channel impulse response,
    - any statistically decorrelated or independent fading across the antennas (i.e., the channel fading may be uncorrelated from antenna to antenna).
    - any spectral coherence of the channel's fading (i.e, the channel fading may be uncorrelated from frequency-hop bin to frequency-hop bin).
  - the other co-channel FFH-CDMA users' hop-sequences,
  - the other co-channel FFH-CDMA users' angles-of-arrival, nor
  - the receiving sensor-array's nominal or actual array manifold — the sensors may have unknown and arbitrary gain/phase/polarization responses and mutual coupling.
Algorithmic Philosophy

- To form two parallel sets of space-frequency data:
  1. The “S+I+N” data set contains the (signal-of-interest (SOI) plus any interference and noise.
  2. The “I+N” data set contains only the interference and noise.

- The “I+N” data set allows (implicit) estimation of the interference & noise in the “S+I+N” data set.
Key Question

How to obtain

- “S+I+N” data set vs. “I+N” data set?
- for FFH-SS? for OFDM?
Part I
“Blind” Beamformer for Fast Frequency-Hop (FFH) Spread Spectrum (SS) Signaling
FFH-SS Signal Model

For the $k$th user’s $s$th symbol:

$$\sqrt{P_k} \sum_{h=1}^{H} \exp\left\{ j \left[ 2\pi f_k^{(b_{k,s},h)} + \varphi_k^{(b_{k,s},h)} \right] \right\} u(t - (s - 1)T_S - (h - 1)T_H)$$

where

- $b_{k,s}$ = information-symbol at the $s$th symbol for the $k$th user
- $f_k^{(b_{k,s},h)}$ = hop-frequency at the $h$th hop-period for $b_{k,s}$
- $\varphi_k^{(b_{k,s},h)}$ = initial phase at the $h$th hop-period for $b_{k,s}$
- $T_S$ = symbol-period = $HT_H$
- $T_H$ = hop-period
- $u(\cdot)$ = symbol-pulse
- $P_k$ = power of the $k$th user
Figure 1:
Two sample hop-sequences for a hop-set of size $N_H=5$, and $H=4$ frequency-hops per symbol. For a binary constellation of $M=2$, the left diagram could correspond to a logical-1 symbol-value, with the right diagram for logical-0.
Figure 2:
s_k(t) for the symbol-sequence of \{b_{k,s=1} = 1, b_{k,s=2} = 0, b_{k,s=3} = 1, b_{k,s=4} = 0\}, using the hop-sequences of Figure 1.
**Assumptions**

- The transmitter’s MFSK-FFH hopping-pattern is a priori known to the intended receiver.

- If the channel’s coherence-time $\geq D$ symbols, the channel is statistically correlated over any $S < D$ symbols.

- The strongest co-channel interferers would persist for at least the next few information-symbols.
The Proposed “Blanking” Scheme

- **Recall**: The signal-of-interest (SOI) has $H$ hop-periods / symbol.

- **Proposed “Blanking”**:  
  - “Blank” a different hop-period at each different symbol. I.e., during each symbol (= $H$ hop-periods), transmits NO energy (i.e., to “blank”) at 1 hop-period.
  - Over $H$ symbol-periods, a different hop-period (out of the $H$ hop-periods per symbol) is to be “blanked”.
  - All $H$ hop-periods would thus be “blanked” once, over the course of $H$ consecutive information-symbols.
Figure 3:

The sample hop-sequences of Figure 1, after “blanking” the $h=s$ th hop-period at the $s$th symbol.
Figure 4: The counterpart to $s_k(t)$ of Figure 2, but after the “blanking” of Figure 1.

For a sequence of $S$ number of $M$-ary symbols, there are $MS$ different symbol-sequences $\{m_q, q = 1, 2, \cdots, M\}$ as estimation-candidates of $b_k$. 
The Proposed “Blanking” Scheme

To form the “I+N” data set, $X_q^{(I+N)}$:

Time-sample at each “blanked” hop-period, at only the hop-frequency of that particular candidate symbol-sequence, if there were no “blanking”.

To form the “S+I+N” data set, $X_q^{(S+I+N)}$:

Time-sample at each hop-period not “blanked”, at where the hop-frequency would be for that particular candidate symbol-sequence.
Figure 5: For candidate symbol-sequence of \( \{b_{k,s=1} = 1, b_{k,s=2} = 0, b_{k,s=3} = 1, b_{k,s=4} = 0\} \), top diagram = “I+N” data-set, bottom diagram = “S+I+N” data-set.
Figure 6: For candidate symbol-sequence of \( \{ b_{k,s=1} = 1, b_{k,s=2} = 0, b_{k,s=3} = 1, b_{k,s=4} = 1 \} \), top diagram = “I+N” data-set, bottom diagram = “S+I+N” data-set.
The Proposed “Blanking” Scheme

Next, for the $q$ th candidate symbol-sequence, do the following:

- Form the spatial covariance matrices

  \[
  R_q^{(S+I+N)} = X_q^{(S+I+N)} [X_q^{(S+I+N)}]^H
  \]

  \[
  R_q^{(I+N)} = X_q^{(I+N)} [X_q^{(I+N)}]^H
  \]

  (Each row / column = an antenna-frequency pairing.)

- Compute the principal generalized eigenvector $w_q$ for the matrix-pencil pair \{ $R_q^{(S+I+N)}$, $R_q^{(I+N)}$ \}. (Using this $w_q$ as the beamformer weight vector, the SINR$_q$ is maximized at the beam output.)

Lastly, the estimate of $b_k$ is $m_{q_{\text{max}}}$, where $q_{\text{max}}$ is the $q$ that gives the largest SINR$_q$
Figure 7:
The proposed “blind” space-frequency beamformer's SINR-gain (= output-SINR / input-SINR)
Figure 8:
The proposed “blind” space-frequency beamformer's SINR-gain (\(\text{output-SINR} / \text{input-SINR}\))
Figure 9:
The proposed “blind” space-frequency beamformer's SINR-gain (= output-SINR / input-SINR)
References


Part II
“Blind” Beamformer for Offset-Frequency Division Multiplexing (OFDM)
Review of OFDM System

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Thomas Wong, ktwong@ieee.org
Problem with Cyclic Prefix (CP)

- Function: IFFT & FFT need to avoid inter-symbol interference (ISI), i.e., need circular convolution (not linear convolution), made possible by a “cyclic prefix” (CP) that exceeds the channel’s delay spread.

- Problem:
  - The CP displaces data, hence reduces the data-rate.
  - Without a CP,
    - There would be ISI and ICI.
    - Orthogonality would be lost among the subcarriers.
    - The simple one-tap FEQ no longer applicable.
PROPOSED SCHEME’S ADVANTAGES

The proposed scheme can

- allow the “cyclic prefix” (CP) to be “insufficiently” long for the channel’s delay spread (to increase data-rate).

- blindly suppress many types of interference, e.g.,
  - Inter-carrier interference (ICI),
  - Inter-symbol interference (ISI),
  - co-channel interference,
  - Interference from overlaid systems.

But the proposed scheme needs perfect prior knowledge of channel’s per-tap gain, for $D$. 
"S+I+N" Dataset & "I+N" Dataset

\[ z(k) : \quad N \times 1 \quad \text{data-vector collected at the} \quad N \quad \text{subcarriers at} \quad k \quad \text{th time-sample.} \]
\[ D : \quad N \times N \quad \text{diagonal matrix, each element} = \quad \text{one-tab equalizer, assumed prior known} \]
\[ B, U : \quad \text{to-be-designed.} \]

Motivation:
- Upper leg: passes "SOI + I + N", while equalizing SOI.
- Lower Leg: ideally to pass "I + N" only, by a suitable design of \( B \) and \( U \).
- Hence, to subtract 2) from 1) to estimate SOI.
Lower Leg: Uses null subcarriers (a.k.a. virtual / unused / unmodulated subcarriers), already mandated in most wireless OFDM standards.

**B** is a selection matrix,

- with 1’s at the null subcarriers, to pass the “I + N”, but
- with 0’s to suppress the data-subcarriers, to block the SOI.

\[
\begin{align*}
U &= \arg \min_u E\|i(k) - U^H B^H x(k)\|^2_2 = \left(B^H R_{i(k)i(k)} B\right)^{-1} B^H R_{i(k)i(k)} D \\
R_{i(k)i(k)} &= H_{ICI} R_{s(k)s(k)} H_{ICI}^H + H_{ISI} R_{s(k-1)s(k-1)} H_{ISI}^H + W_N R_{n(k)n(k)} W_N^H
\end{align*}
\]
Fig. 1. BER versus SNR performance for competing equalizers: NSC-based FEQ [3], ZF-based 2-stage FEQ [10], MMSE-based 2-stage FEQ [9], and GSC-based FEQ [8].

SYMBOLS:
- $v = \text{CP length}$
- $N_r = \text{no. of receive-antennas}$
- $p = 12 \text{ null subcarriers}$
- $q = \text{channel delay-spread} = 10$
Fig. 2. BER vs. SNR for different number of NSC ($P$) for the proposed FEQ (no CP).

SYMBOLS:
- $v$ = CP length = 0
- $N_r$ = no. of receive-antennas = 1
- $p$ = no. of null subcarriers
- $q$ = channel delay-spread = 10
References


Thank you!