Multi-FFT Detection of OFDM Signals in Time-Varying Channels

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OFDM systems are typically based on the assumption that the channel does not change over one block of duration $T = 1/\Delta f$ (inverse of the carrier separation). The baseband received signal is then given by

$$v(t) = \sum_{k=0}^{K-1} H_k d_k e^{j2\pi k \Delta f t} + w(t) \tag{1}$$

where H_k is the channel transfer function $H(f)$ evaluated at the k-th carrier frequency $f_k = f_0 + k\Delta f$, d_k is the data symbol transmitted on the k-th carrier, and $w(t)$ is the noise. A single FFT is employed to demodulate the signal, yielding a set of detection variables

$$y_k = \int_T v(t) e^{-j2\pi k \Delta f t} dt = T H_k d_k + z_k, \;\; k = 0, \dots K-1 \tag{2}$$

When the time-invariance assumption does not hold, FFT demodulation alone is no longer optimal. Time-variation of the channel functions $H_k(t)$ must now be taken into account through additional channel-matched filtering, which yields the variables

$$v_k = \int_T H_k^*(t) v(t) e^{-j2\pi k \Delta f t} dt, \;\; k = 0, \dots K-1 \tag{3}$$

These variables have to be processed further to equalize the inter-carrier interference (ICI).

In practice, it would be difficult (if not impossible) to accurately estimate all the K functions $H_k(t)$ in order to build the bank of channel-matched filters. As a result, the problem is often sidestepped by performing FFT demodulation as before, and proceeding to equalize the resulting ICI.

Multi-FFT demodulation takes a different approach to address the problem of channel-matched filtering. It is based on the assumption that the channel functions $H_k(t)$ can be projected onto a small set of *pre-defined* functions $\phi_i(t)$, such that

$$H_k(t) \approx \sum_{i=0}^{I-1} H_{k,i} \phi_i(t), \;\; k = 0, \dots K-1 \tag{4}$$

Some of the choices for the projection functions are illustrated in Fig.1.

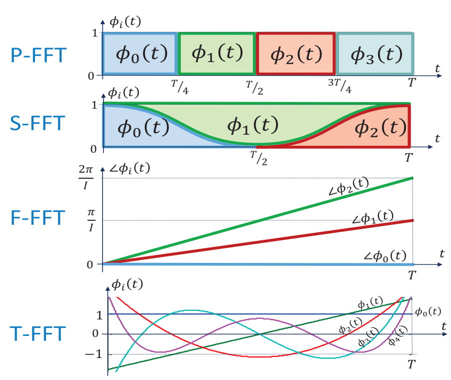

Fig. 1. The functions $\phi_i(t)$ can be chosen as rectangular windows in time, each covering a different portion of the block interval T (top). This choice is motivated by approximating $H_k(t)$ as piece-wise constant over T. Other choices include shaped windows (which help with edge effects), complex exponentials (which cater to time-variation in the form of Doppler shifts) and Taylor-series functions (bottom).

Assuming that the representation (4) is valid, channel-matched filtering (3) reduces to

$$v_k \approx \sum_{i=0}^{I-1} H_{k,i}^* y_{k,i} \tag{5}$$

where

$$y_{k,i} = \int_T \phi_i^*(t) v(t) e^{-j2\pi k \Delta f t} dt, \;\; k = 0, \ldots K-1 \tag{6}$$

A closer inspection of the last expression reveals an implementation that requires nothing but an FFT operation applied to the samples of signal $\phi_i^*(t)v(t)$. Hence, it suffices to employ only I FFT demodulators whose outputs can be combined for further processing. This is the basic idea of multi-FFT detection, whose block diagram is shown in Fig.2. More details, including those of multichannel multi-FFT combining, can be found in Ref. [1].

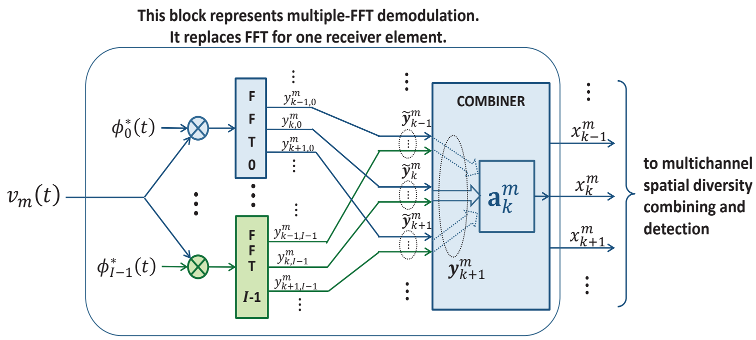

Fig. 2. Block diagram of the multi-FFT receiver.

Multi-FFT demodulation can be applied with either coherent or differentially coherent detection. Differentially coherent detection may have advantages on time-varying channels where coherent detection suffers from channel estimation errors. Differential encoding is best performed in the frequency domain, i.e. across the OFDM carriers. Fig.3 illustrates the order of differential detection across multiple blocks (one frame) and the allocation of pilots needed to train the receiver before it is switched into decision-directed mode.

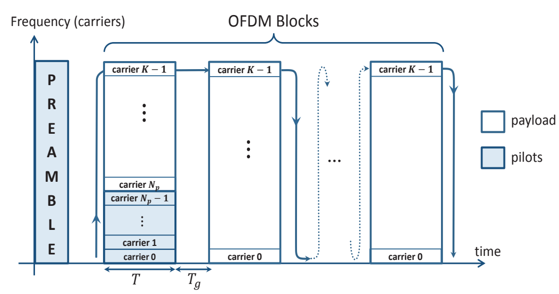

Fig. 3. Pilot placement and order of differential detection in a frame of blocks.

In the **source code** package available for download at http://millitsa.coe.neu.edu/?q=projects, multi-FFT demodulation is implemented with differentially coherent detection and multiple receiving elements (spatial diversity). The package includes four choices of projection functions shown in Fig.1, for implementation of partial (P), shaped (S), fractional (F) and Taylor series (T) FFT demodulation with selectable size I. Included also as a benchmark is conventional ICI equalization. The code is not optimized to achieve low complexity, but is meant to provide a flexible platform for the readers to try the algorithms on their own and re-write the details of their choice. The package provides most of the features described in Ref. [1], but several have been omitted to simplify the exercise. Features that have been omitted are marked as such, and their implementation is left to the readers. Any of the functions in the package may be used for non-commercial purposes. For questions about the implementation, please contact Yashar, aval.y@husky.neu.edu.

References

[1] Y.Aval and M.Stojanovic, "Differentially coherent multichannel detection of acoustic OFDM signals," *IEEE J. Oceanic Eng.* 2014.