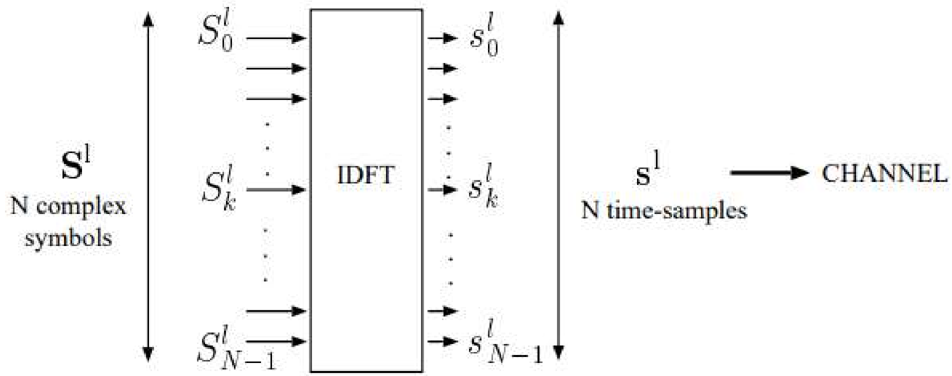
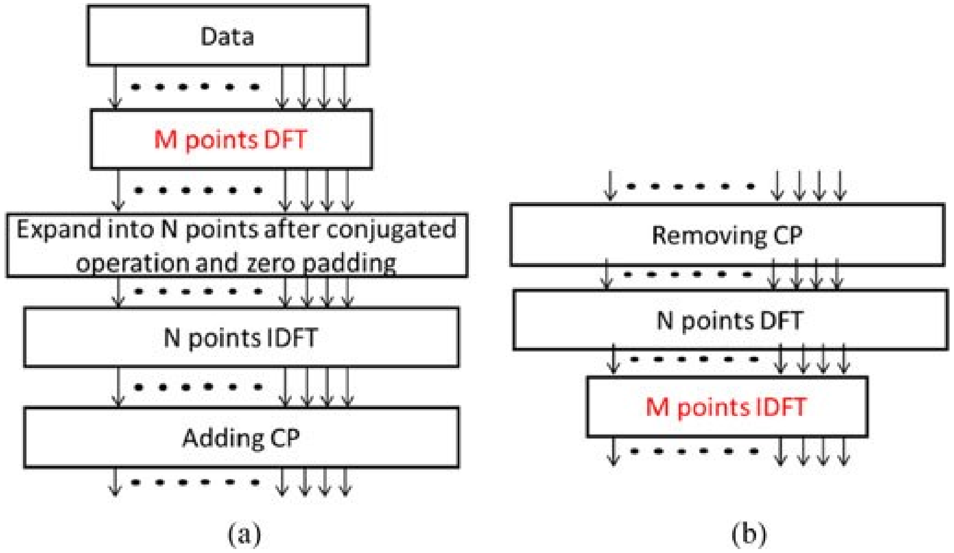
DFT spreading OFDM: DFTS-OFDM

Iván Corral Viñas

Index

OFDM vs DFTS-OFDM





Orthogonal Frequency Division Multiplexing (OFDM) modulation is a cost-effective solution for coping with large delay spread channels. The attractiveness of OFDM is mainly due to its capability of converting the frequency selective channel to multiple flat channels, enabling simple one-tap equalization at the receiver

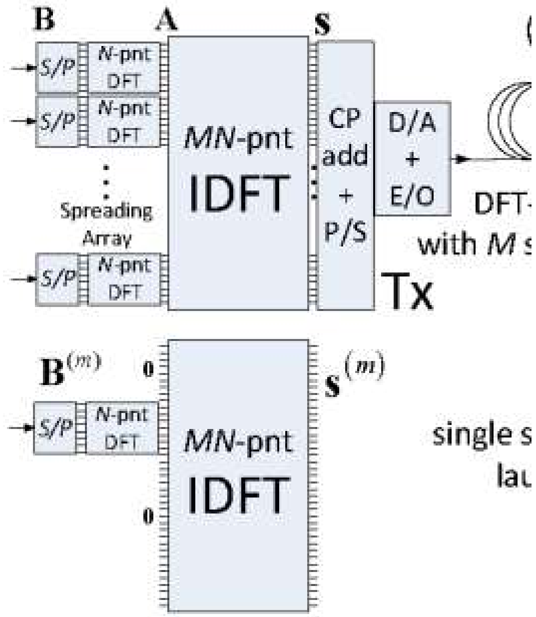
Discrete Fourier Transform -spread- OFDM (DFTs-OFDM) is a straightforward add on over OFDM allowing to emulate a single carrier modulation with significant advantages in terms of power efficiency [1]

Theoretical Description

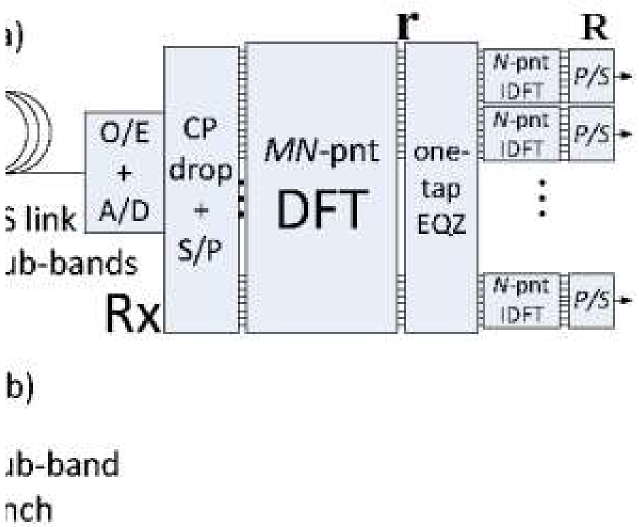
The DFT spreading idea consists of applying additional DFT based array pre-processing ahead of the main IDFT in the OFDM transmitter. This typically results in a reduction of the Peak to Average Power Ratio (PAPR) of the OFDM signal.

In the DFT-S Tx, the main OFDM DFT of size MN is preceded by an array of DFT modules each of size N. Here M is also the number of sub-bands, which is also the number of DFTs forming the pre/post-processing arrays while N is the number of OFDM tones per sub-band.

Each sub-band is pre-processed at the transmitter by an N-pnt DFT. The M outputs of the spreading DFT array are concatenated to form an MN-pnt vector, A, which is applied to the main OFDM IDFT in the Tx and is CP-extended and applied to the Tx DAC.



Theoretical Description



In the DFT-S OFDM receiver the inverse processes occur. The output of the main OFDM DFT is partitioned into M equal sub-blocks, each of which is passed through an N-pnt IDFT.

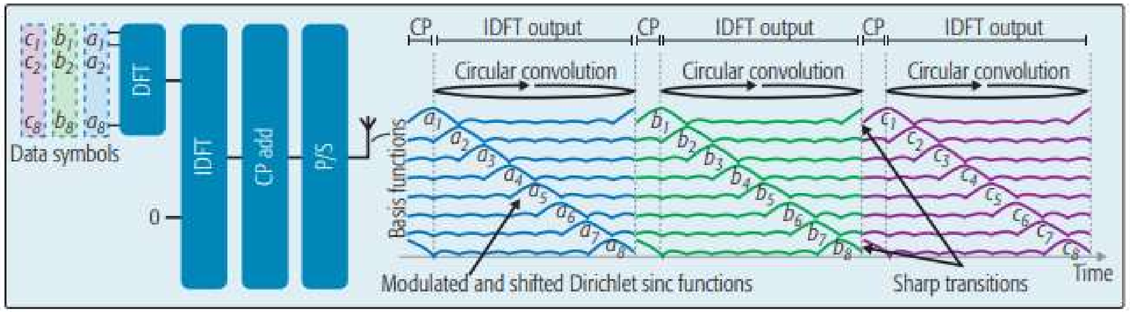
The sub-band IDFTs in the Rx form the de-spreading IDFT array. The cascade of the main MN-pnt DFT and the de-spreading array acts to demultiplex and decimate each of the subbands, undoing the action of the DFT-S Tx [2]

Advantages & Disadvantages [3]

Peak-to-Average-Power Ratio: DFTS-OFDM is a precoded OFDM scheme, where the precoding with DFT aims to reduce the PAPR. This interpretation has its own merit as it may yield different precoding strategies.

Inter symbol transitions: DFT-S-OFDM can be considered as a scheme that upsamples the data symbols by a factor equal to the ratio of the IDFT and DFT block sizes and applies a circular pulse shaping with a Dirichlet sinc function before the CP extension. DFT-S-OFDM does not provide smooth transition between the consecutive symbols.

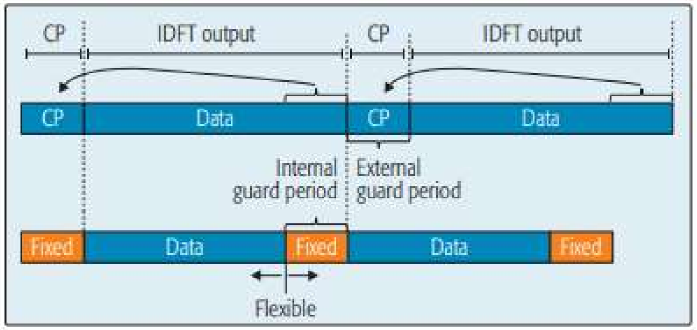
DFT-S-OFDM is tightly related to SC waveforms that allow using single-tap **Frequency Domain Equalization (FDE).** In SC-FDE, the CP is first attached to the beginning and/or end of each data symbol block. Afterward, the symbols are linearly convolved with a predetermined pulse shaping function. Hence, SC-FDE differs from DFT-SOFDM in that it uses a linear convolution and generates the CP (or UW) before the pulse shaping.

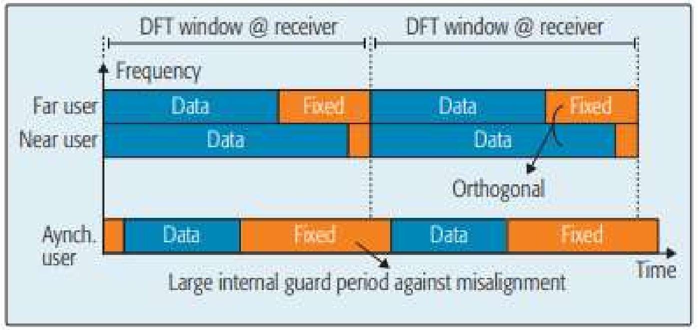


Advantages & Disadvantages [3]

Flexible Internal Guard Period: Cyclic prefix is a method to add an external guard period to deal with multipath channels that introduce ISI and mitigate timing synchronization errors. In general, its duration is fixed and designed based on the worst-case scenario so it penalizes the users that experience shorter delay spreads.

The functionality of the CP can also be provided by an internal guard period, whose ratio with the data period is flexible, so even if the duration of the guard period changes, the total symbol duration remains constant. The benefits of using the CP approach are retained by using a fixed signal (UW signal), so the fixed part of the current symbol functions as a CP for the next symbol.





Flexible DFTS-OFDM [3]

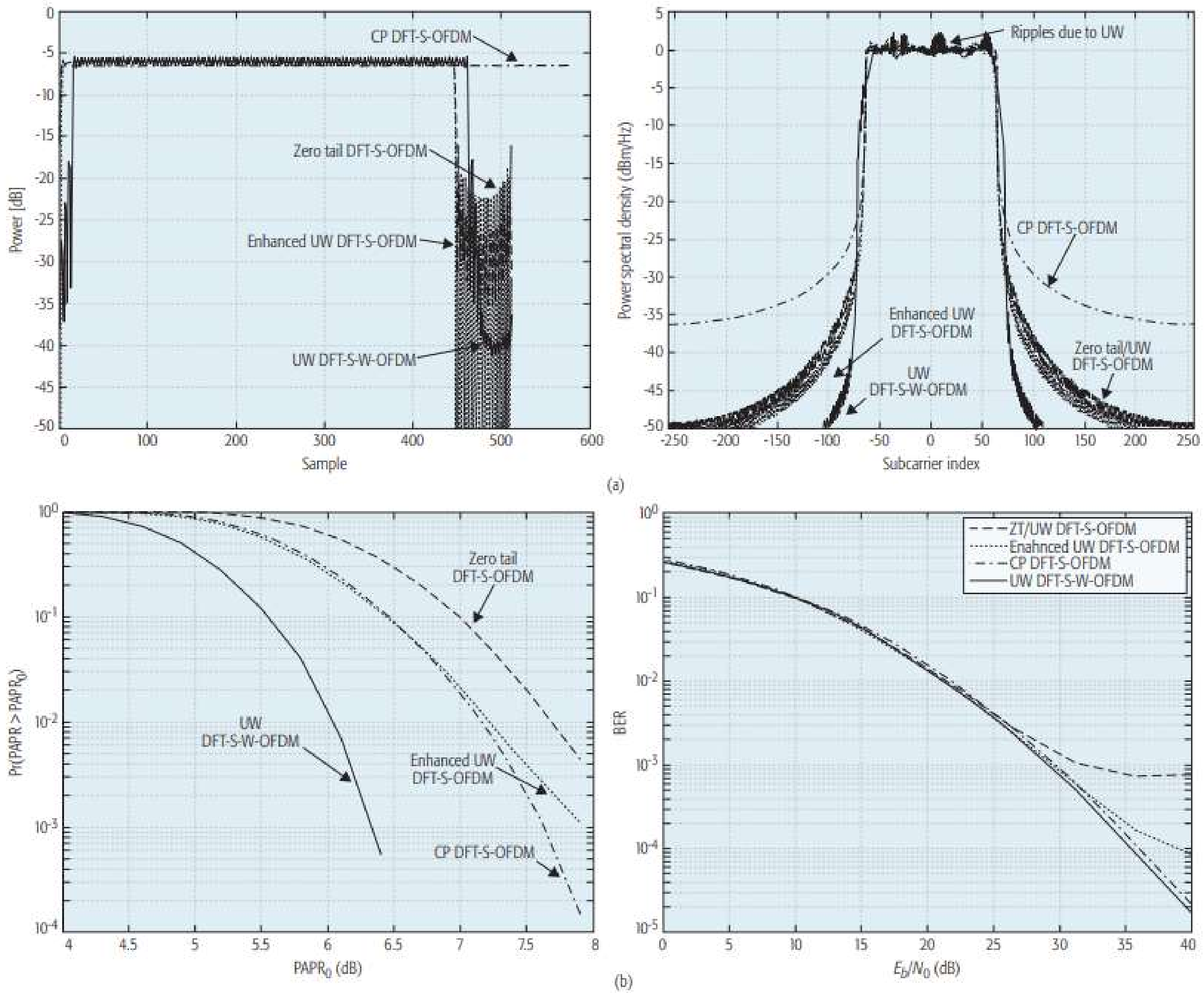
Zero-Tail DFTS-OFDM: zero guard interval is generated by zeroing the data symbols that modulate the Dirichlet sinc functions, contributing to the tail of the symbol. To achieve this, this scheme needs to have a zero sample at least for the first input of DFTS-OFDM, which also leads to a short zero-head. As the samples that cause significant discontinuity between the adjacent symbols are removed, this scheme generates signals that are very similar to basic single-carrier waveform with guard intervals. Therefore, it achieves substantial OOB (Out-of-Band) leakage reduction

Unique Word DFTS-OFDM: this scheme aims to generate a non-zero fixed tail and head by adding a fixed signal to the ZT DFTS-OFDM symbols. The signal can be inserted in the time domain, or in the frequency domain**.** The orthogonality between the UW signal and the data signal is maintained and the receiver does not need to know the UW for the demodulation of the data symbols, the contiguity between the UW signals is still maintained (does not change the leakage characteristics of ZT DFTS-OFDM) and it can be further utilized in PHY and MAC processing jointly.

Enhanced Unique Word DFTS-OFDM: mitigates ISI in large spread channels by introducing a perturbation signal such that when added to the original ZT DFTS-OFDM symbol, the energy that leaks from the data symbols to the tail is suppressed.

Unique Word DFTS-W-OFDM: suppresses the leakage to the tail by using a frequency domain windowing approach and introducing a fixed sequence to generate a UW signal at the tail of the DFT-SOFDM symbol, omitting CP.

Flexible DFTS-OFDM [3]



Conclusion

DFT-S-OFDM is a promising waveform due to its **low PAPR** and **flexibility** in accommodating an internal guard period that has several advantages including robustness against timing misalignment and adaptability of the guard period. [3]

In optical applications the DFT-spread OFDM system with polarization division multiplexing and coherent detection, compared with the conventional single-carrier systems, has the advantages of **flexible bandwidth allocation**, **high spectral efficiency**, **low sampling rate**, and **low-complexity equalization**. [4]

DFTS-OFDM **can replace the CP** with an internal guard interval whose length can be set dynamically according to the delay spread of the channel rather than being hardcoded in the system numerology easing scalability as well as coexistence among cells operating over channels with diverse dispersion characteristics. [5]

References

[1] Gal Shulkind and Moshe Nazarathy, “An analytical study of the improved nonlinear tolerance of DFT-spread OFDM and its unitaryspread OFDM generalization”, 2012, (060.1660) Coherent communications; (060.2330) Fiber optics; (060.0060).

[2] A. Sahin, E. Bala, R. Yang and R. L. Olesen, "DFT-Spread OFDM with Frequency Domain Reference Symbols," GLOBECOM 2017 - 2017 IEEE Global Communications Conference, 2017, pp. 1-6, doi: 10.1109/GLOCOM.2017.8254241.

[3] A. Sahin, R. Yang, E. Bala, M. C. Beluri and R. L. Olesen, "Flexible DFT-S-OFDM: Solutions and Challenges," in IEEE Communications Magazine, vol. 54, no. 11, pp. 106-112, November 2016, doi: 10.1109/MCOM.2016.1600330CM.

[4] Fanggang Wang and Xiaodong Wang, “Coherent Optical DFT-Spread OFDM”, 2010, Hindawi Publishing Corporation Advances in Optical Technologies Volume 2011, Article ID 689289, doi:10.1155/2011/689289

[5] G. Berardinelli, "Generalized DFT-s-OFDM Waveforms Without Cyclic Prefix," in IEEE Access, vol. 6, pp. 4677-4689, 2018, doi: 10.1109/ACCESS.2017.2781122.