Multicarrier Modulation for HF Communications

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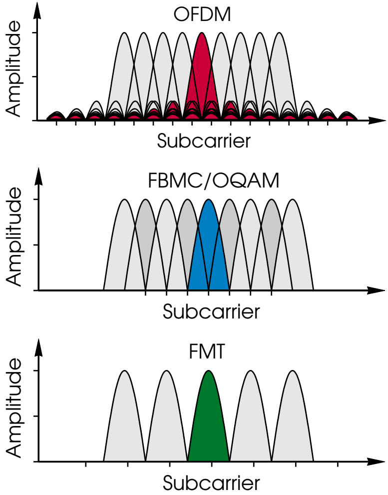
Multicarrier Modulation for HF

Use large number of parallel narrow-band subcarriers instead of a single wide-band carrier



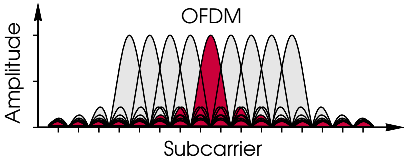
Benefits

- High flexibility in fragmented spectrum use
- Simple subcarrier-wise channel equalization

Challenges

- Peak-to-average power ratio (PAPR) issue
- Pilot structures and channel equlization with high Doppler

Orthogonal Frequency Division Multiplexing (OFDM)



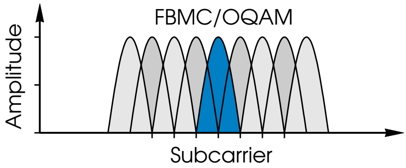
Pros

- Simple and straightforward equalization
- High flexibility in allocating spectral resources to different users
- Simplicity of combining multi-antenna schemes

Cons

- Poor spectral containment resulting to
  1) interferences from asynchronous spectral components
  2) adjacent channel leakage
- High peak-to-average power ratio (as for all MC techniques)

Filterbank Multicarrier (FBMC)



Pros

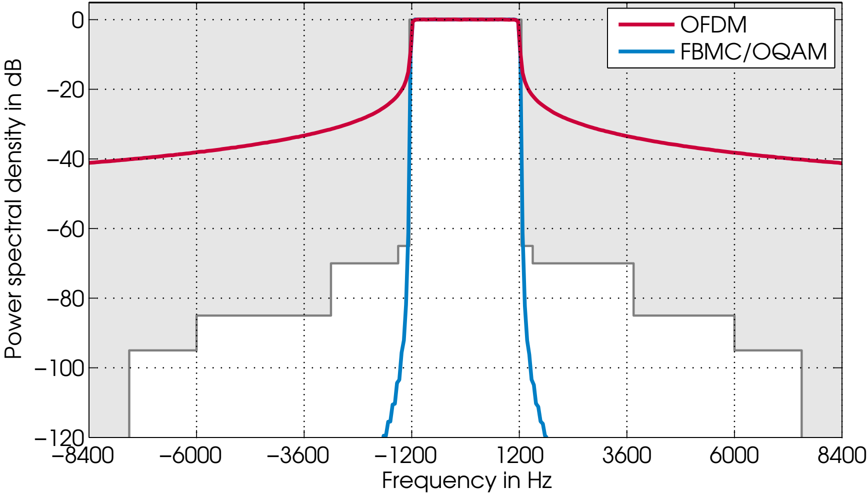
- Good time-frequency localization
- Maximal spectral efficiency by using overlapping subcarriers

Cons

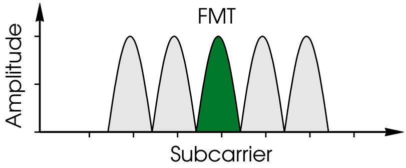
- Offset-QAM (OQAM) modulation is needed for orthognonality
- Challenges in developing effective pilot schemes and in applying certain multi-antenna configurations
- Increased complexity compared to OFDM (2 - 3 times)

Power Spectral Density vs Spectrum Mask

Spectrum mask for tactical HF transmitter (MIL-STD-118-141C)



Filtered Multitone (FMT)



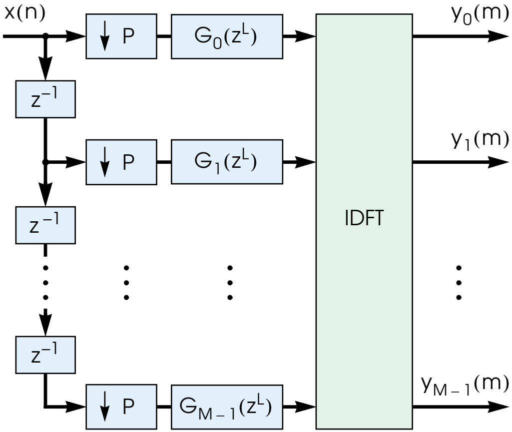
Pros

- QAM modulation with Nyquist filtering can be used ► More direct application of pilot based synchronization and channel estimation schemes.
- Multi-antenna configurations developed for OFDM can be straightforwardly utilized.

Cons

- Reduced spectral efficiency due to non-overlapping subcarriers
- Small roll-off is need to improve spectral efficiency

Realization Structures: Polyphase-DFT filterbank.



$G_k(z)$'s are FIR filters of length K.

$K = 3$ and $K = 4$ are typical selections.

Table: Parameters for the HF channel models from DRM Specification

Channel	Delay (τ_k) (ms)	Gain, rms (ρ_k)
C: US Consortium	$[0.0 \quad 0.7 \quad 1.5 \quad 2.2]$	$[1.0 \quad 0.7 \quad 0.5 \quad 0.25]$
D: CCIR poor	$[0.0 \quad 2.0]$	$[1.0 \quad 1.0]$
E: Channel no. 5	$[0.0 \quad 4.0]$	$[1.0 \quad 1.0]$
F: Channel no. 6	$[0.0 \quad 2.0 \quad 4.0 \quad 6.0]$	$[0.5 \quad 1.0 \quad 0.25 \quad 0.0625]$
Channel	Doppler shift (f_D) (Hz)	Doppler spread (B_D) (Hz)
C: US Consortium	$[0.1 \quad 0.2 \quad 0.5 \quad 1.0]$	$[0.1 \quad 0.5 \quad 1.0 \quad 2.0]$
D: CCIR poor	$[0.0 \quad 0.0]$	$[1.0 \quad 1.0]$
E: Channel no. 5	$[0.0 \quad 0.0]$	$[2.0 \quad 2.0]$
F: Channel no. 6	$[0.0 \quad 1.2 \quad 2.4 \quad 3.6]$	$[0.1 \quad 2.4 \quad 4.8 \quad 7.2]$

(DRM) Digital Radio Mondiale (DRM); System Specification, ETSI ES 201 980 V4.1.1, Jan. 2014.

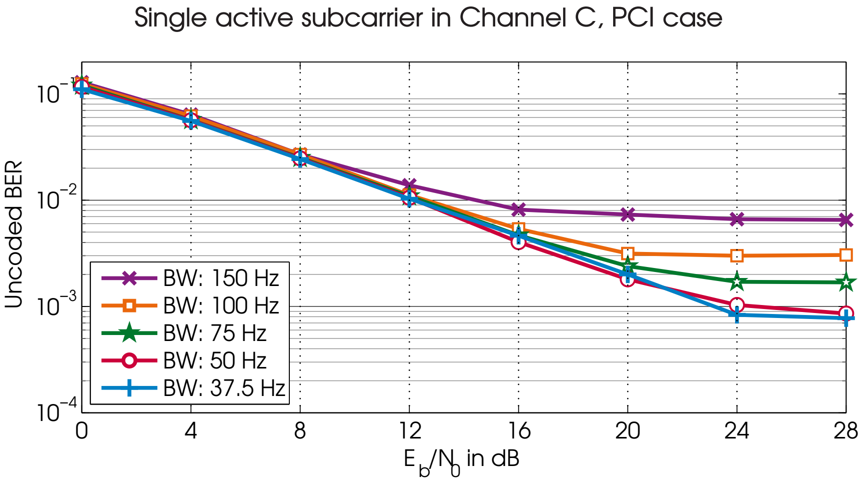
Parameterization: Subcarrier Spacing

- Sub-carrier spacing << coherence bandwidth B_c
- Symbol duration << coherence time T_c

$$B_c = \frac{1}{5T_{RMS}} \qquad T_c = \sqrt{\frac{9}{16\pi f_D^2}} \approx \frac{0.423}{f_D}$$

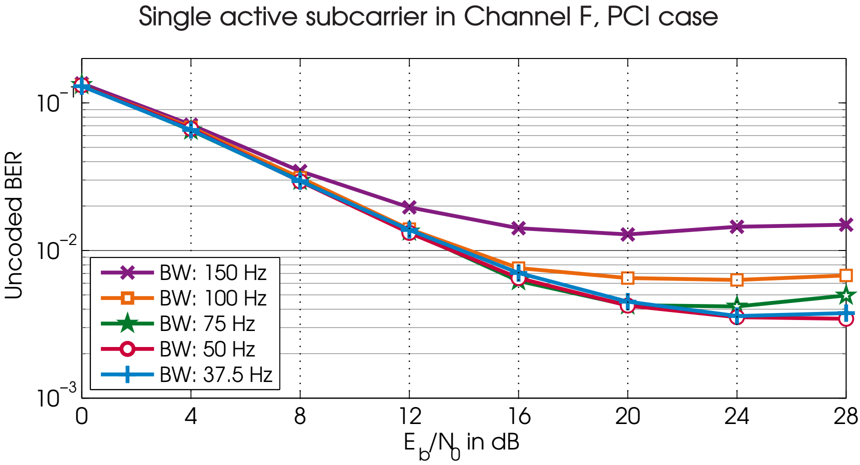
Channel	RMS delay spread	Coherence bandwidth	Max Doppler shift	Coherence time
C	$T_{RMS} = 0.75\,\text{ms}$	$B_c = 266.67\,\text{Hz}$	$f_D = 1.00\,\text{Hz}$	$T_c = 0.423\,\text{s}$
F	$T_{RMS} = 1.48\,\text{ms}$	$B_c = 133.33\,\text{Hz}$	$f_D = 3.60\,\text{Hz}$	$T_c = 0.118\,\text{s}$

Parameterization: Subcarrier Spacing vs BER



$f_s = 25.6\,\text{kHz}$, 512 subacarriers (SCs) => SC spacing is 50 Hz

Parameterization: Subcarrier Spacing vs BER



Parameterization: Cyclic Prefix Length for OFDM

Rule of thump

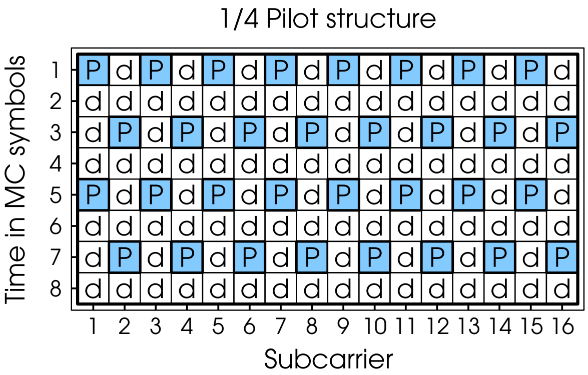
CP length should be RMS delay spread T_{RMS} multipled by a constant in the range between two to four (Arslan07).

Two CP lengths were studied.

- Short CP is about 8 percent of useful symbol duration $T_{\mathsf{CP}} = 1.563\,\mathsf{ms} \approx 2\,T_{\mathsf{RMS}}$ in Channel C with 50 Hz SC spacing
- Long CP is about 16 percent of useful symbol duration $T_{\mathsf{CP}} = 3.125\,\mathsf{ms} \approx 4\,T_{\mathsf{RMS}}$ in Channel C with 50 Hz SC spacing

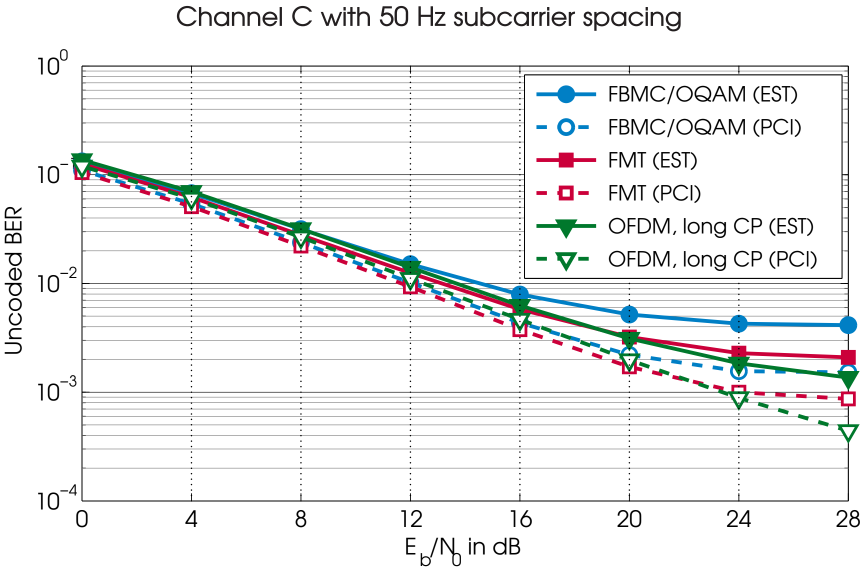
(Arslan07) Huseyin Arslan, *Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems*, pp. 238, 2007, Dordrecht, Netherlands, Springer.

Parameterization: Pilot Density

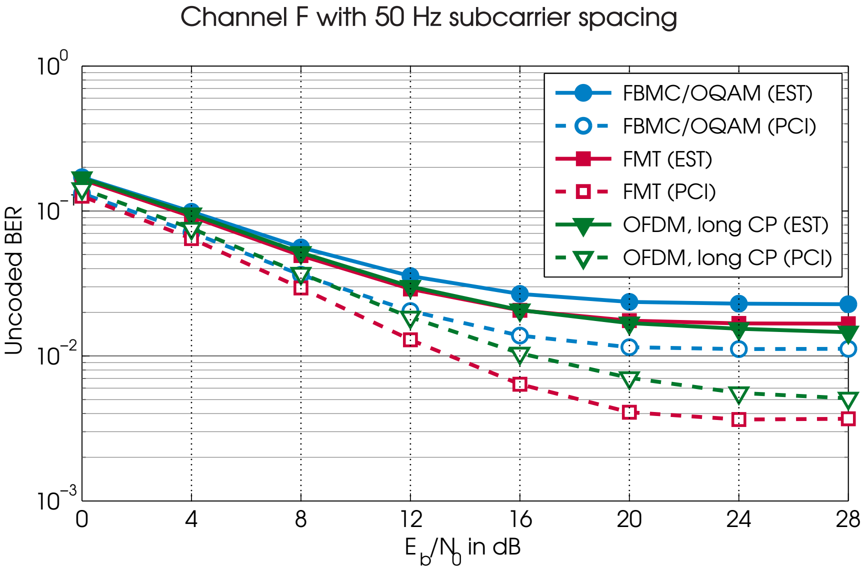


- 1/4 is needed to handle well the time & frequency selective channel
- Higher density challenging due to the used OQAM scheme

Perfect Channel Information (PCI) vs Estimation



Perfect Channel Information (PCI) vs Estimation



Performance Comparison: Frame Error Rate

Long term goal: Compare the MC techniques with single-carrier techniques

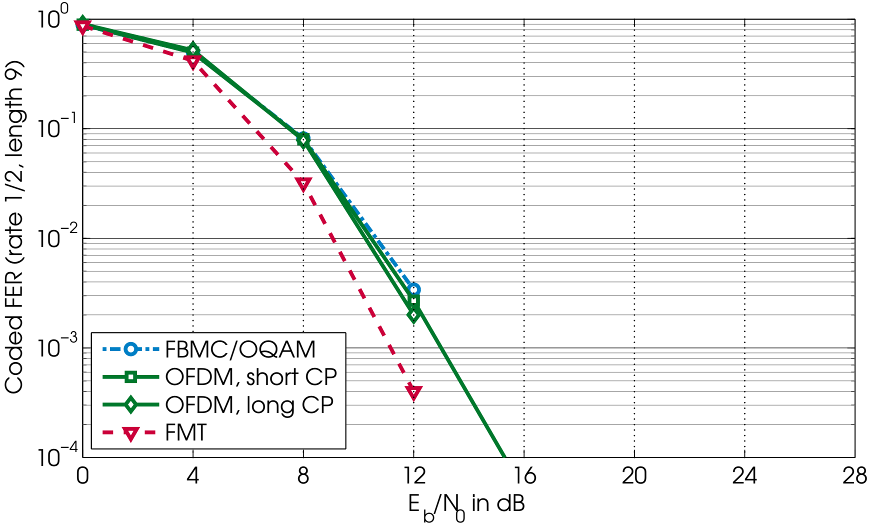
Parameters from MIL-STD-188-110C (Wideband SC waveforms)

- 1536 data symbols (with 50 Hz subcarrier spacing)
- Channel bandwidth 2.4 kHz (48 active subcarrier with 50 Hz subcarrier spacing)
- The convolutional code with code rate of $R_c = 1/2$ and code length of $L = 9$.
- Bit interleaver similar to that in MIL-STD-188-110C
- Every fourth symbol is a pilot

For FMT either the bandwidth or frame length has to be increased since the number of subcarrier carrying the information is only the half. We have doubled the frame length.

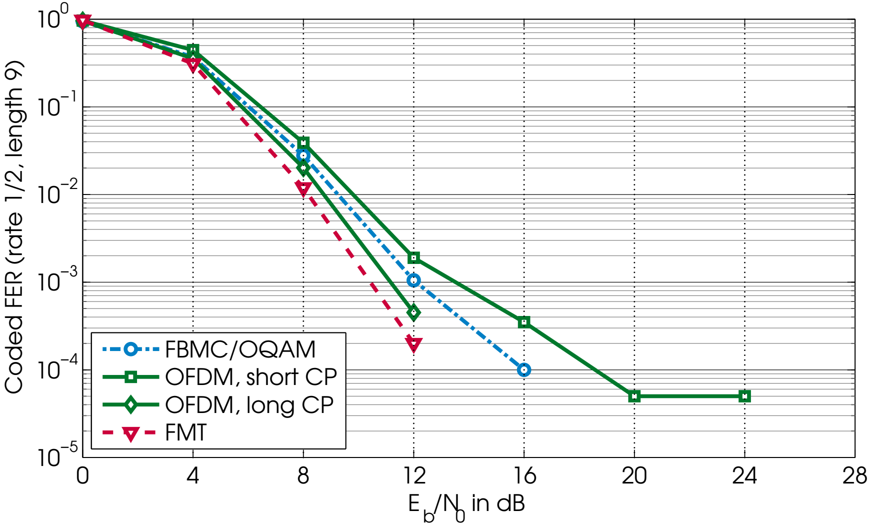
Performance Comparison: Frame Error Rate

Channel C with 50 Hz subcarrier spacing, QPSK, estimated channel



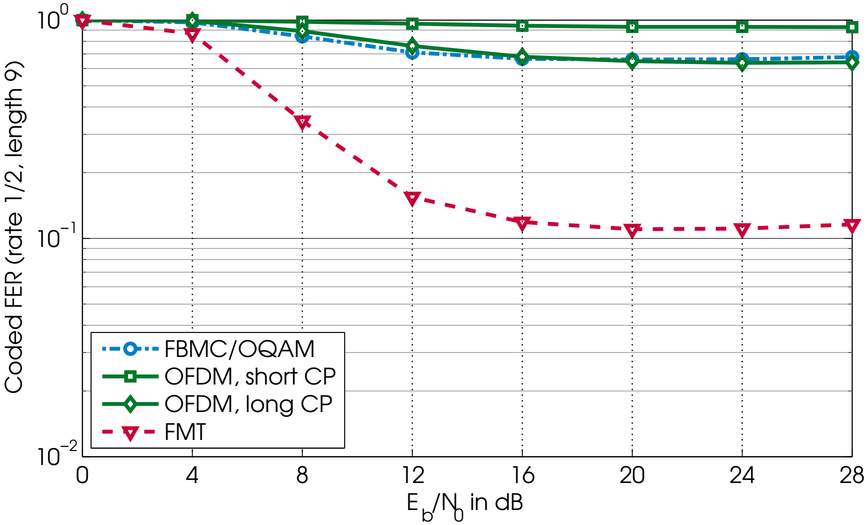
Performance Comparison: Frame Error Rate

Channel D with 50 Hz subcarrier spacing, QPSK, estimated channel



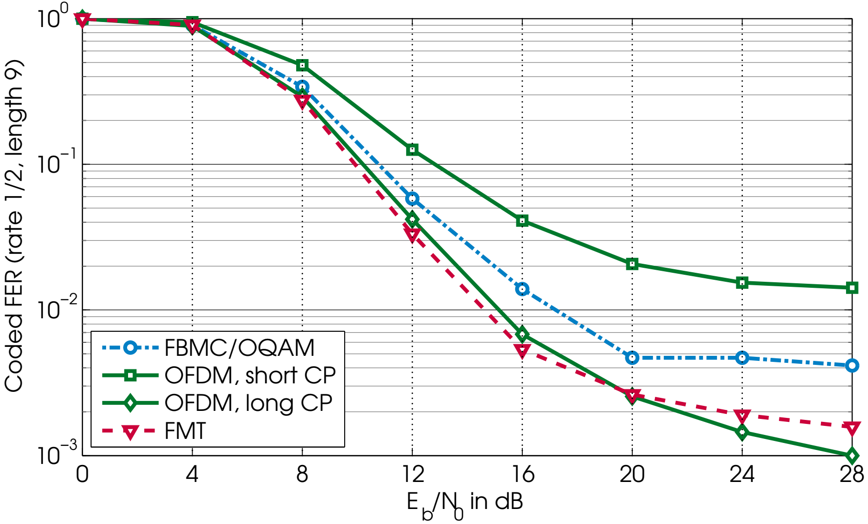
Performance Comparison: Frame Error Rate

Channel E with 50 Hz subcarrier spacing, QPSK, estimated channel



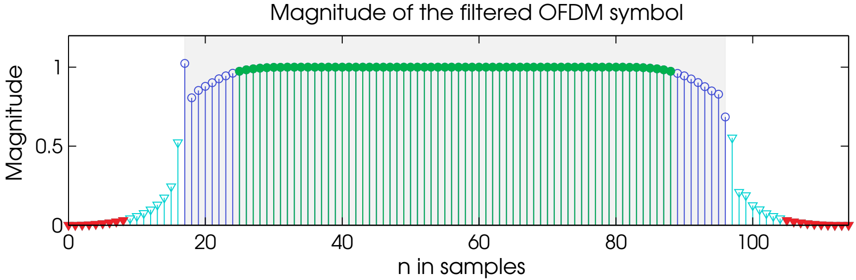
Performance Comparison: Frame Error Rate

Channel F with 50 Hz subcarrier spacing, QPSK, estimated channel



Conclusions and Further Research

- FMT has the best performance and FMBC the worst.
- The performance of the OFDM can be improved by increasing CP.
- However, the main problem with OFDM is the spectral leakage.
- Spectral leakage can be reduced by filtering
  → Filtering reduces the effective CP.



Further research is devoted in optimizing the roll-off parameter of the FMT with respect to latency and implementation complexity.