OUT OF BAND AND ICI REDUCTION TECHNIQUE

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- There is a substantial need for more frequency bandwidth and the efficient and flexible use of existing bands.

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Cognitive Radio

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Multi-carrier modulation

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OFDM (orthogonal frequency division modulation)

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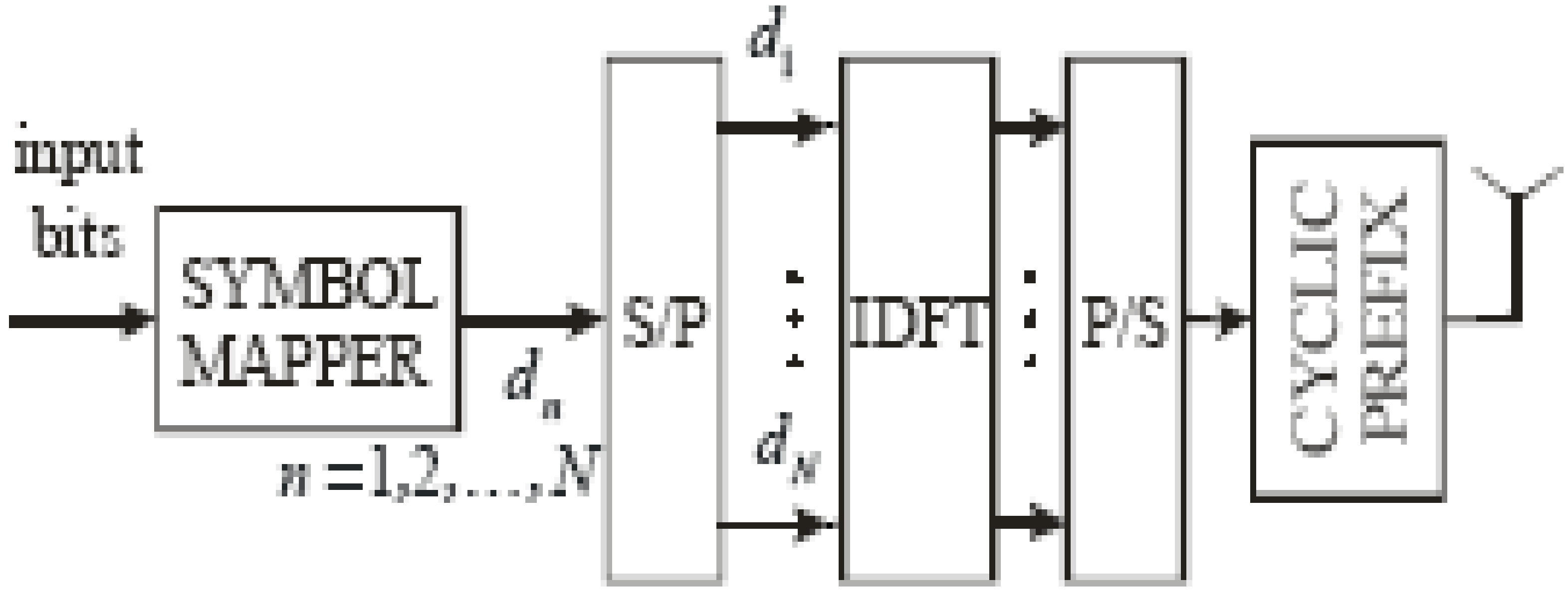
Out-of-band (OOB) radiation -- Inter-carrier-interference (ICI)

Peak-to-average power ratio (PAPR)

OFDM system

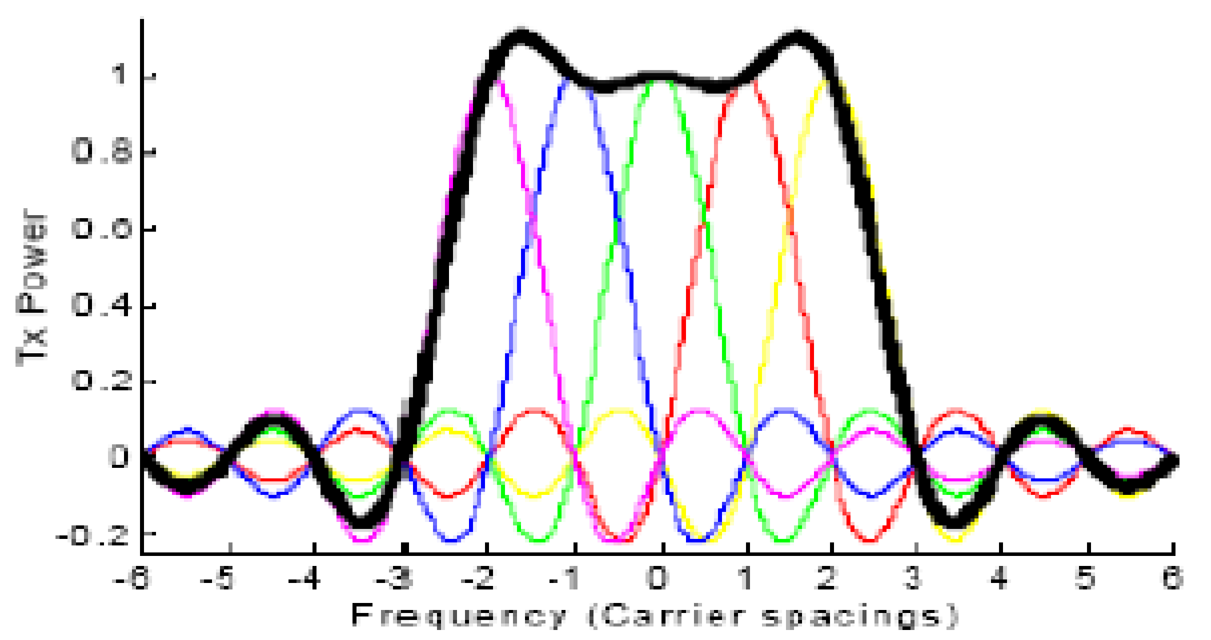
$$s(t) = \sum_{i=-\infty}^{+\infty} \sum_{k=1}^{N_{SC}} c_{ki} e^{j2\pi f_k (t - iT_s)} f(t - iT_s)$$



Out of band (OOB) component

- $S(x) = \sum_{n=-N/2}^{N/2-1} dn \cdot \mathrm{sinc}\,(x - xn)$, $x = (f - f_o)\,T_o$

- The sidelobe power of this sum signal only decays with $1/(x^2 N)$ resulting in a high out-of-band radiation.



OOB reduction technique

- Windowing
- Guard band
- Cancellation Carrier (CC)
- Subcarrier Weighting (SW)
- Multiple Choice Sequences (MCS)
- Constellation Expansion (CE)
- Additive Signal Method (AS)
- Combined methods

Windowing

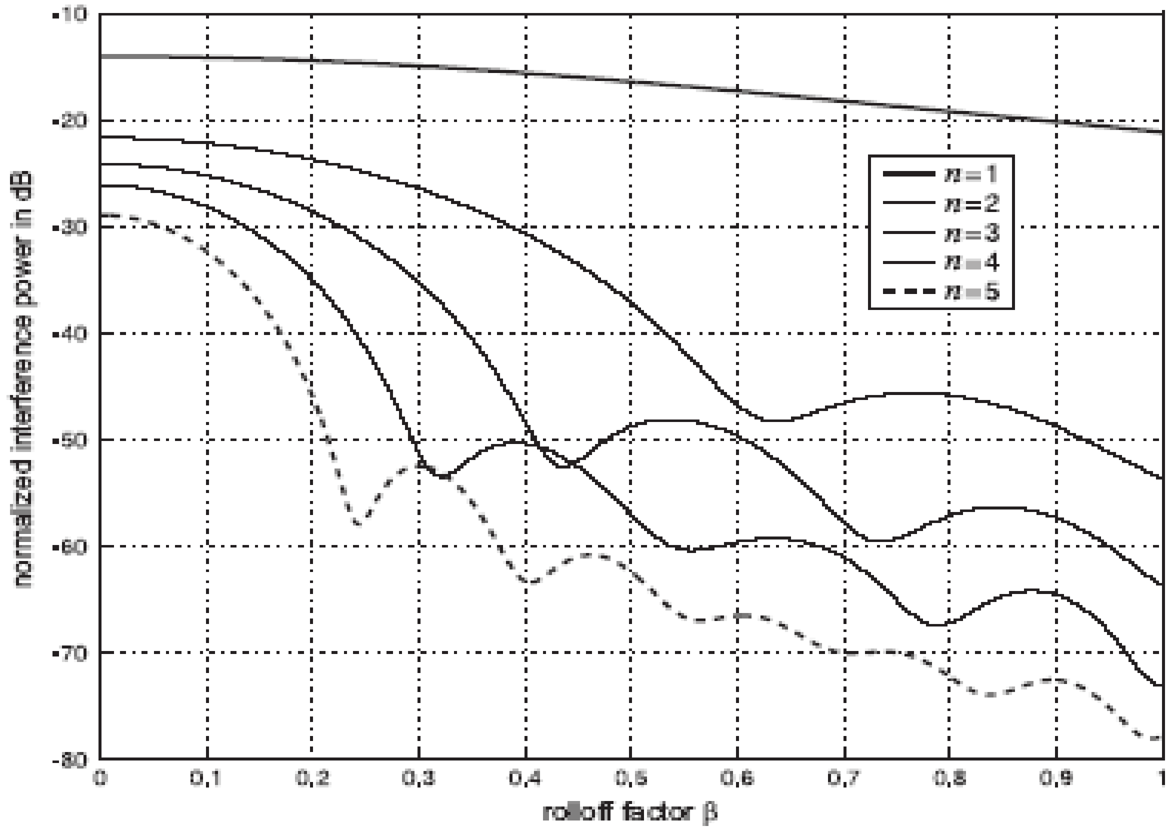
- The signal *r(k)* is windowed in the time domain by a window function *w(k)* :

$$\hat{r}(k) = r(k)\, w(k)$$

- making the PDS of an OFDM modulated carrier go down more rapidly by windowing the transmit signal of the OFDM symbols.
- A commonly used window type is the raised cosine window.
- drawback of this method is that windowing expands the signal in time domain and intersymbol interference (ISI) is introduced.

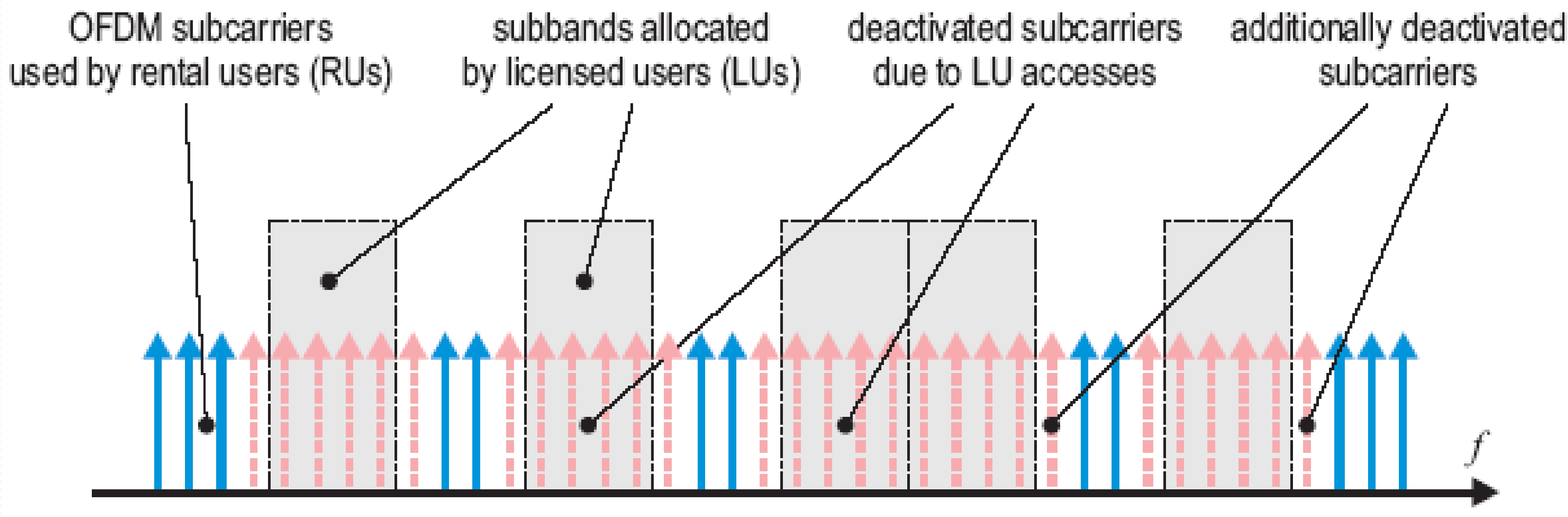
Windowing

- Even at very high rolloff factors, the achievable interference reduction is only about 6dB.



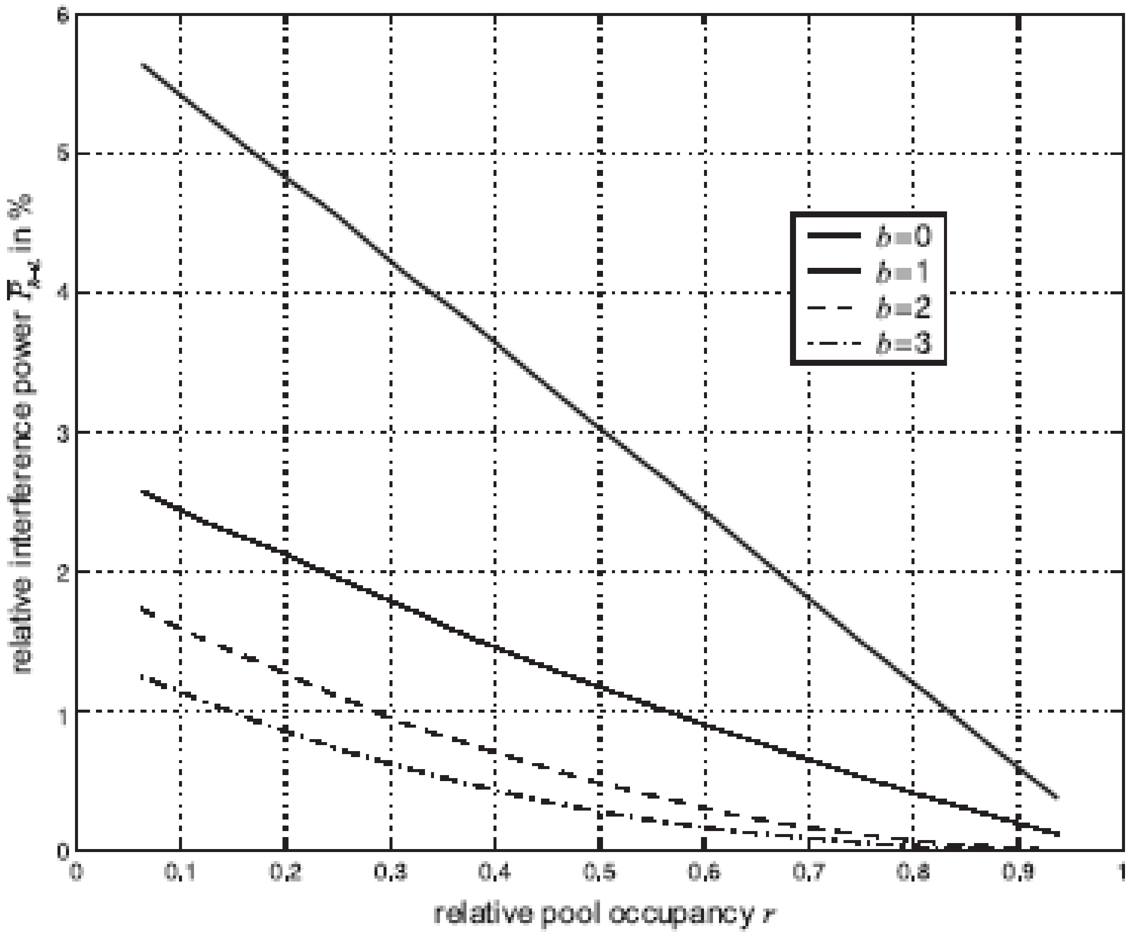
n = number of adjacent sub-band

Guard band



The drawback of this method is the less effective use of the available bandwidth.

Guard band

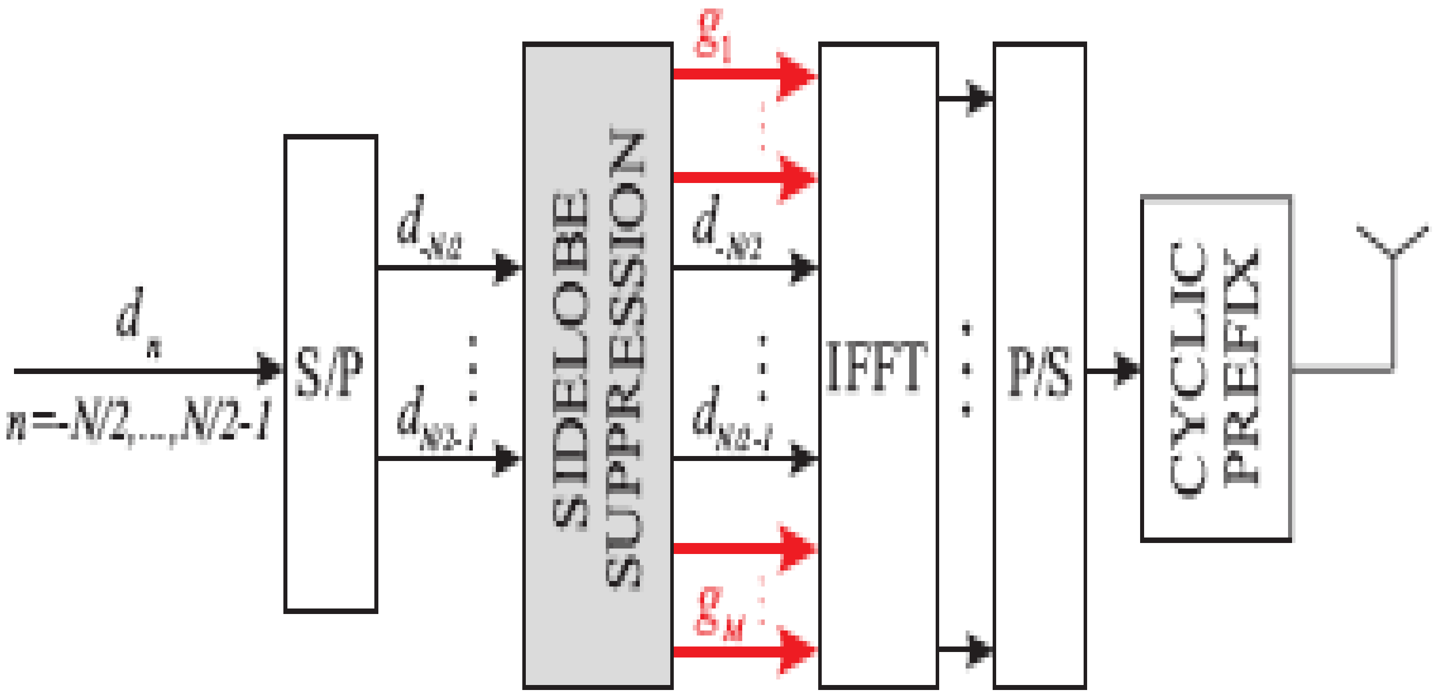


b = number of deactivated adjacent subcarriers

deactivation of the first adjacent subcarrier ($b = 1$) *delivers the largest* benefit. The additional deactivation of more subcarriers ($b \geq 2$) only provides a minor further improvement.

Cancellation Carrier (CC)

- Each CC is multiplied by a *complex weighting factor gm*
- the transmit symbol is modulated on N + M subcarriers



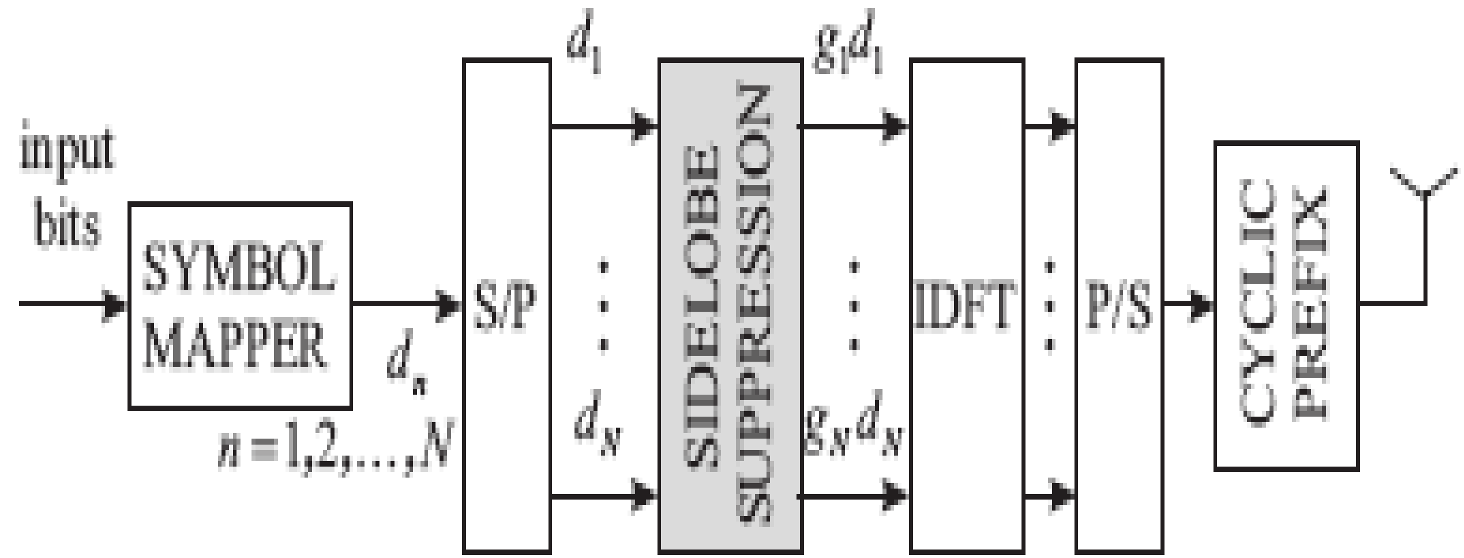
Cancellation Carrier (CC)

$$\min_{\mathbf{g}} \left\| \mathbf{s} + \sum_{m=1}^{M} g_m \cdot \mathbf{c}_m \right\|^2 \quad \text{subject to} \quad \|\mathbf{g}\|^2 \leq \alpha$$

- The constraint limits the power of the CCs to α in order not to spend too much Tx power on the CCs.
- with only two CCs at each side of the used spectrum the out-of-band radiation can be reduced by more than 20 dB.
- The price is → Loss in BER performance
  → Increased computational complexity.

Subcarrier Weighting (SW)

- multiplication of each symbol *dn* with a real valued weighting factor *gn*.
- Pulse shaping



Subcarrier Weighting (SW)

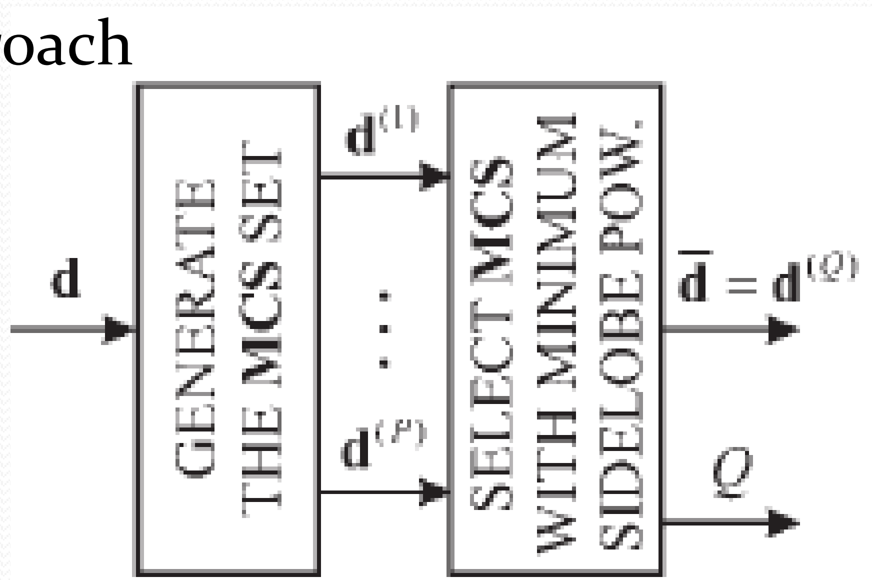
- solving the optimization problem with two constraints:
  - Keeps the transmission power the same as in the case without weighting i.e. $||\bar{\mathbf{d}}||^2 = ||\mathbf{d}||^2$.
  - elements of $\mathbf{g}$ are between pre-defined limits, i.e., $g_{min} \le g_n \le g_{max}$

- $\rho = g_{max}/g_{min} \uparrow$ $\rightarrow$ bit-error rate (BER) $\uparrow$

  $\rightarrow$ OOB $\downarrow$

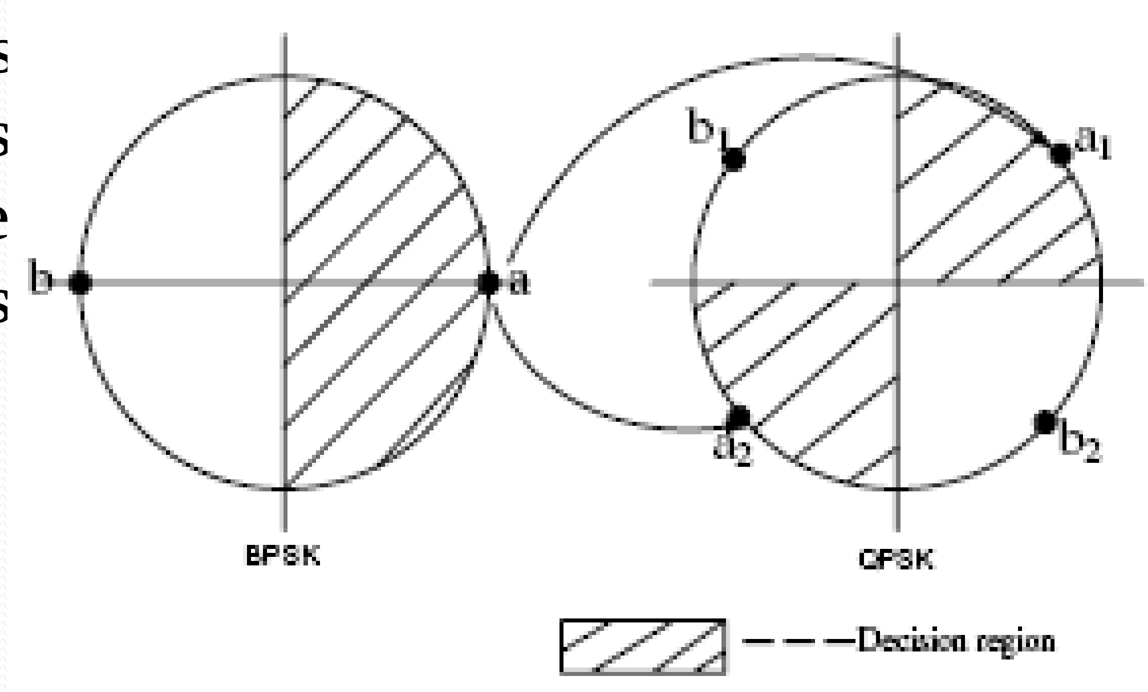
Multiple Choice Sequences (MCS)

- The principle is to map original transmission sequence into another transmission sequence, which has lower sidelobes.
- algorithms to generate an MCS set :
  - Symbol constellation approach
  - Interleaving approach
  - Phase approach



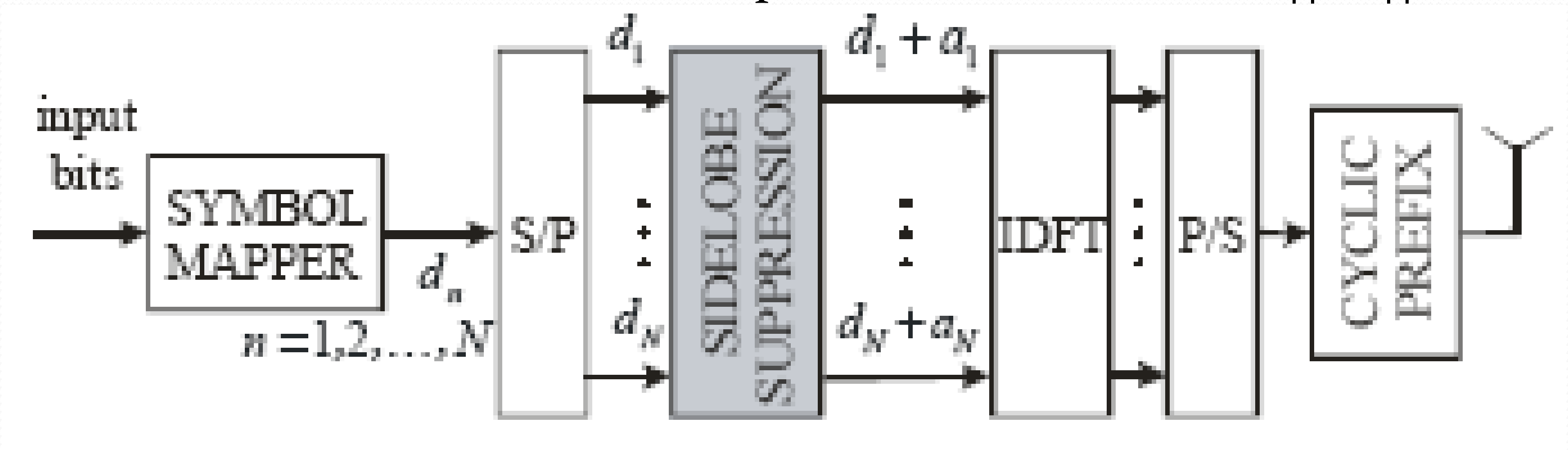
Constellation Expansion (CE)

- Exploiting the fact that different sequences have different sidelobe power levels
- the s ... 2^k
  cons ... lation
  sche ... nd
  cons



Additive Signal Method (AS)

- optimization problem with two constraints:
  - Transmission power the same as in the original sequence
  - elements of **a** are between pre-defined limits , i.e.,$||a_n|| \leq R$



There is a trade-off between the additional sidelobe suppression obtained by enlarging the radius *R* and the increased loss in SNR performance.

Combined methods

- CC + CE
- CC + windowing
- MCS + CC
- MCS + SW
- SW + guard band

Inter carrier interference (ICI)

- OFDM is very sensitive to frequency errors, caused by :
  - Carrier frequency mismatch between the transmitter and receiver
  - The Doppler shift.
- Leads to an orthogonality-loss between carriers and intercarrier interference (ICI) will occur.

Inter carrier interference (ICI)

- Received signal

$$y(t) = \exp j(2\pi\Delta f t + \theta_0) \sum_{k=0}^{N-1} b_{k,i} q\left(t - \frac{kT}{N}\right)$$

- After FFT

$$Y(k) = X(k)S(0) + \sum_{l=0,\, l\neq k}^{N-1} X(l)S(l-k) + n_k,$$

- carrier-to-interference power ratio (CIR)

$$\mathrm{CIR} = \frac{|S(k)|^2}{\sum_{l=0,\, l\neq k}^{N-1} |S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=1}^{N-1} |S(l)|^2}.$$

ICI reduction methods

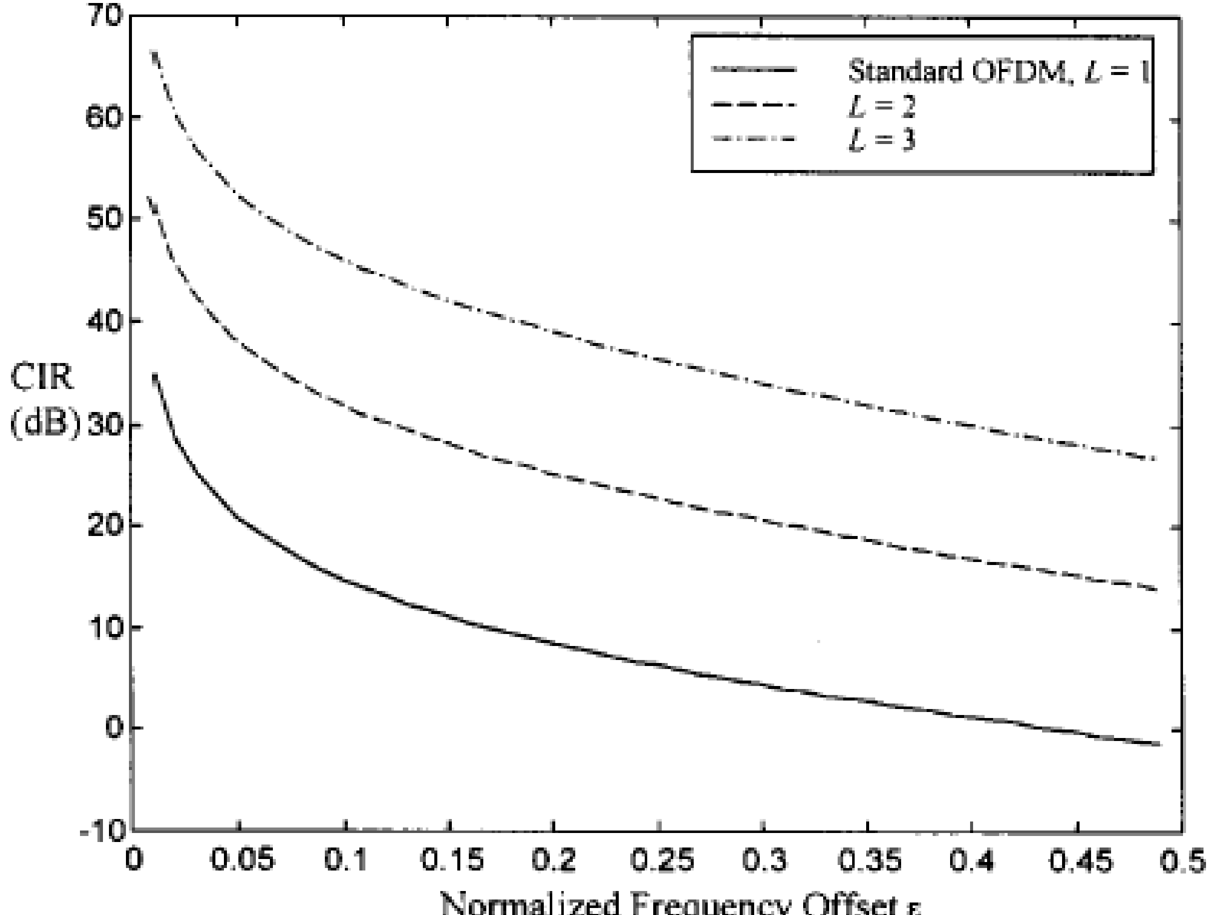
- ICI self-cancellation
- pulse shaping
- select mapping
- frequency-domain equalization
- time-domain windowing

ICI self-cancellation

- the difference between S(l-k) and S(l-k+1) is very small.
- If a data pair is modulated onto two adjacent subcarriers (a,-a), then the ICI signals generated by the subcarriers will cancel themselves.

ICI self-cancellation

ICI self-cancellation scheme can also be extended to group of L subcarriers.



pulse shaping

$$x(t) = \exp\{j2\pi f_c t\}\sum_{k=0}^{N-1} s_k p(t)\exp\{j2\pi f_k t\}$$

- Rectangular pulse (REC)

$$P_{REC}(f) = \sin c(fT)$$

- Raised cosine pulse (RC)

$$P_{RC}(f) = \sin c(fT)\frac{\cos(\pi\alpha fT)}{1-(2\alpha fT)^2},$$

- Better than raised cosine pulse (BTRC)

$$P_{BTRC}(f) = \sin c(fT)\frac{2\beta fT\sin(\pi\alpha fT) + 2\cos(\pi\alpha fT) - 1}{1+(\beta fT)^2}$$

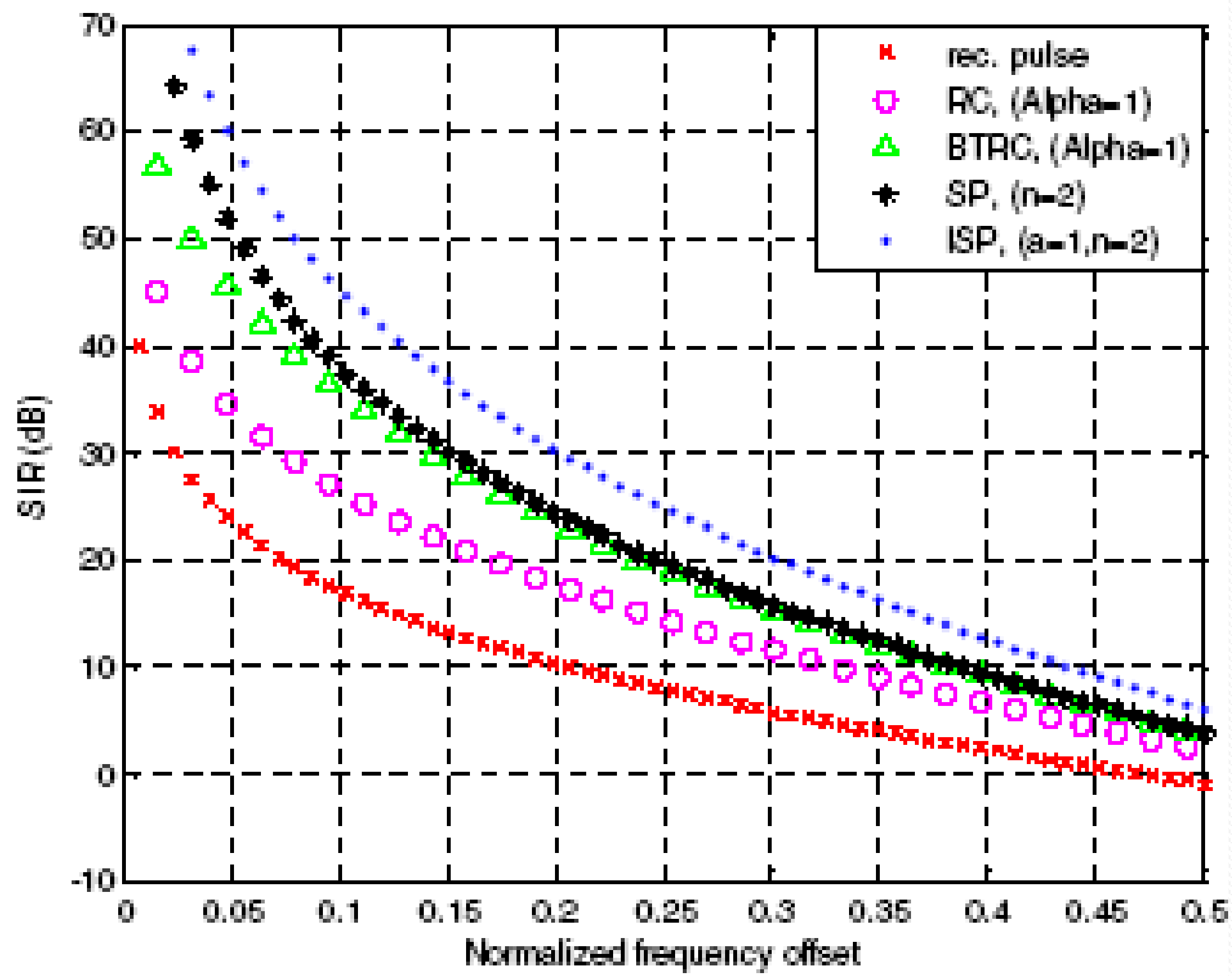
- Sinc power pulse (SP)

$$P_{SP}(f) = \sin c^n(fT)$$

- Improved sinc power pulse (ISP)

$$P_{ISP}(f) = \exp\{-a(fT)^2\}\mathrm{sinc}^n(fT).$$

pulse shaping



Thanks

Question ?