Multi-Axes Modulation for MC-CDMA Systems

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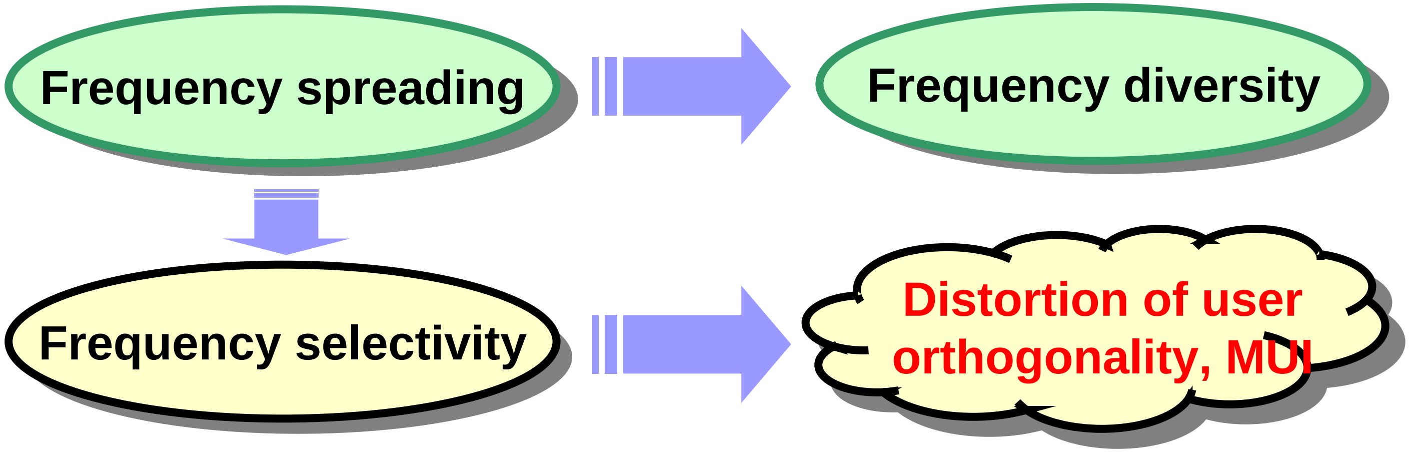
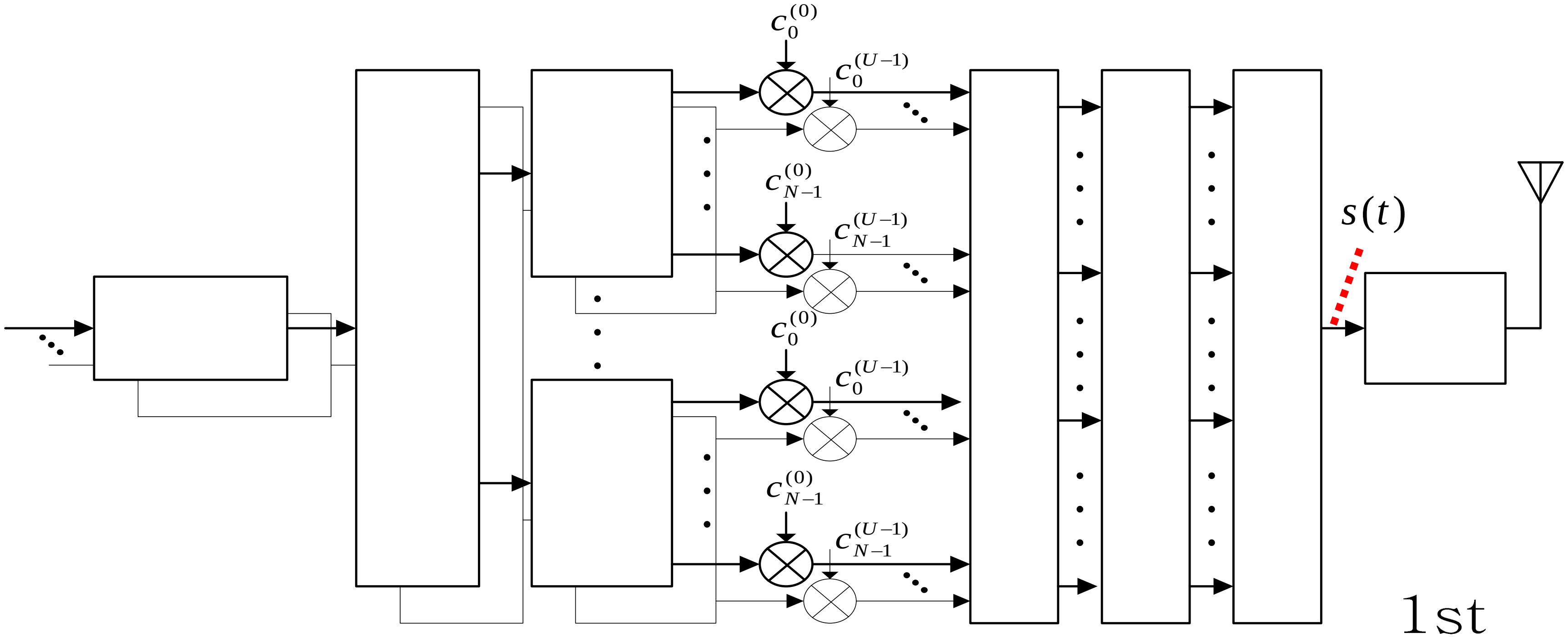
Introduction

- Features of MC-CDMA system



How can we reduce the MUI ?

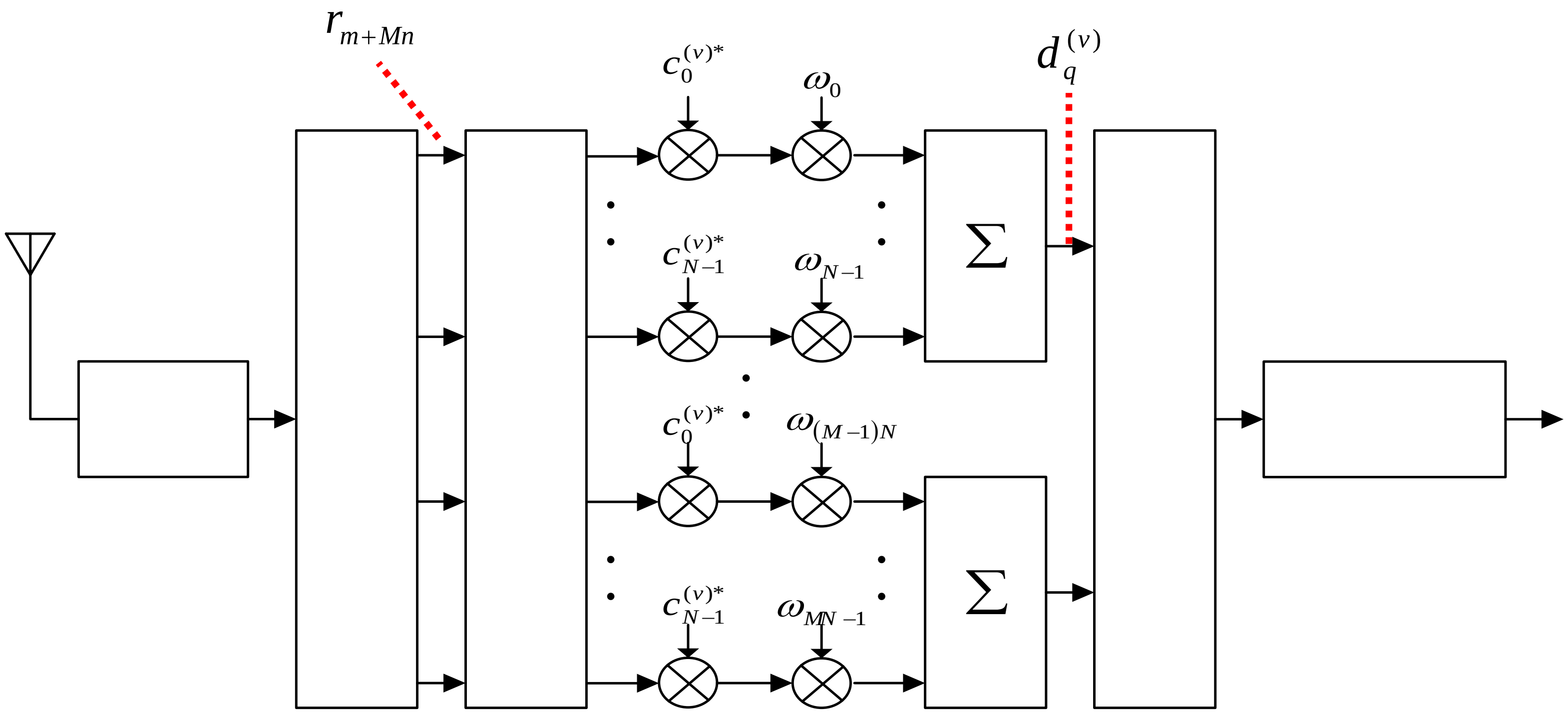
MC-CDMA Transmitter



- $s(t)=\sqrt{\frac{E_s}{N}}\sum_{u=0}^{U-1}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} b_m^{(u)} c_n^{(u)} e^{j2\pi(m+Mn)t/T}$
- $b_m^{(u)}$: (u)-th user's m-th data symbol
- E_s : Data symbol energy
- $\left\{c_n^{(u)}\right\}_{n=0}^{N-1}$: Frequency spreading sequence

1st Copier
Modulator
S/P

MC-CDMA Receiver



- $d_m^{(v)}$: Decision variable of (v)-th user's *m*-th data
- $\{\omega_n\}_{n=0}^{MN-1}$: Frequency domain equalization gain factor

Multi-User Interference

- Detection analysis
  - FFT demodulated symbol of ($m+Mn$)-th subcarrier

$$r_{m+Mn} = \sqrt{\frac{E_s}{N}} \sum_{u=0}^{U-1} b_m^{(u)} c_n^{(u)} H_{m+Mn} + N_{m+Mn}$$

  - Decision variable of (v)-th user's m-th data

$$d_m^{(v)} = \sum_{n=0}^{N-1} r_{m+Mn} c_n^{(v)*} \omega_{m+Mn} = \beta + \zeta + \eta$$

$$\beta = \sqrt{\frac{E_s}{N}} b_m^{(v)} \sum_{n=0}^{N-1} H_{m+Mn} \omega_{m+Mn}$$: Desired signal component

$$\zeta = \sqrt{\frac{E_s}{N}} \sum_{u=0,u\neq v}^{U-1} b_m^{(u)} \underline{\sum_{n=0}^{N-1} c_n^{(u)} c_n^{(v)*} H_{m+Mn} \omega_{m+Mn}}$$: MUI

$$\eta = \sum_{n=0}^{N-1} N_{m+Mn} c_n^{(v)*} \omega_{m+Mn}$$: AWGN

Linear Combining Methods

- Interference analysis according to combining methods

	Gain factor (ω)	Desired Component	MUI
MRC	H^*_{m+Mn}	$\sqrt{\frac{E_s}{N}} b_m^{(v)} \sum_{n=0}^{N-1} H^*_{m+Mn} H_{m+Mn}$	$\sqrt{\frac{E_s}{N}} \sum_{u=0,u\neq v}^{U-1} b_m^{(u)} \sum_{m=0}^{N-1} \lvert H_{m+Mn} \rvert^2 c_n^{(u)} c_n^{(v)*}$
EGC	$\frac{H^*_{m+Mn}}{\lvert H_{m+Mn} \rvert}$	$\frac{1}{2}\sqrt{\frac{E_s}{N}} b_m^{(v)} \sum_{n=0}^{N-1} \left(1 + H^*_{m+Mn} H_{m+Mn}\right)$	$\frac{1}{2}\sqrt{\frac{E_s}{N}} \sum_{u=0,u\neq v}^{U-1} b_m^{(u)} \sum_{n=0}^{N-1} \lvert H_{m+Mn} \rvert^2 c_n^{(u)} c_n^{(v)*}$
ORC	$\frac{H^*_{m+Mn}}{\lvert H_{m+Mn} \rvert^2}$	$\sqrt{NE_s} b_m^{(v)}$	$\sqrt{\frac{E_s}{N}} \sum_{u=0,u\neq v}^{U-1} b_m^{(u)} \sum_{n=0}^{N-1} c_n^{(u)} c_n^{(v)*} = 0$
MMSEC	$\frac{H^*_{m+Mn}}{\lvert H_{m+Mn} \rvert^2 + \frac{2\sigma^2}{U} \frac{N}{E_s}}$	$\sqrt{\frac{E_s}{N}} b_m^{(v)} \sum_{n=0}^{N-1} \frac{H^*_{m+Mn} H_{m+Mn}}{\lvert H_{m+Mn} \rvert^2 + \frac{2\sigma^2}{U} \frac{N}{E_s}}$	$\frac{2\sigma^2 \sqrt{N / E_s} / U}{1 + 2\sigma^2 N / UE_s} \sum_{u=0,u\neq v}^{U-1} b_m^{(u)} \sum_{n=0}^{N-1} \lvert H_{m+Mn} \rvert c_n^{(u)} c_n^{(v)*}$

Multi-Axes Modulation(MAM)

Multi-axes modulation

$$b_m^{(u)} = x_m^{(u)} e^{\left(j\frac{u-1}{Q}\pi\right)}$$

- x : one dimensional signaling
- Q : the number of axes

Decision analysis of MAM

- Desired signal component

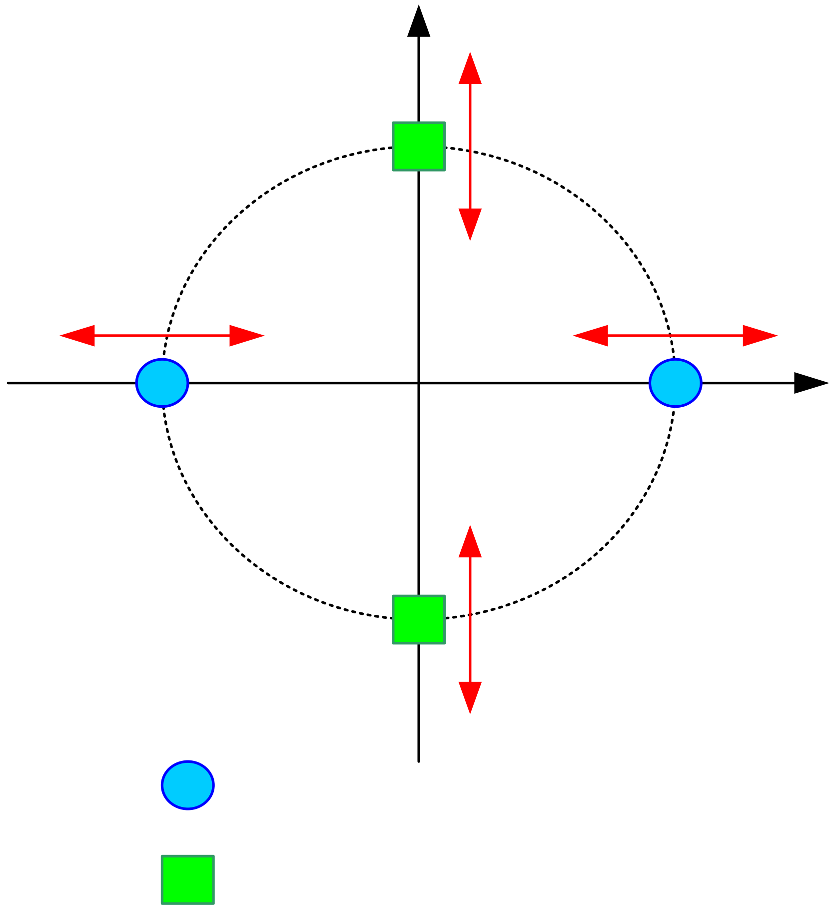
$$\beta = \sqrt{\frac{E_s}{N}} x_m^{(v)} \sum_{n=0}^{N-1} H_{m+Mn} \omega_{m+Mn}$$

- MUI component

$$\zeta = \sqrt{\frac{E_s}{N}} \sum_{u=0,u\neq v}^{U-1} x_m^{(u)} \underline{e^{\left(j\frac{u-v}{Q}\pi\right)}} \sum_{n=0}^{N-1} c_n^{(u)} c_n^{(v)*} H_{m+Mn} \omega_{m+Mn}$$

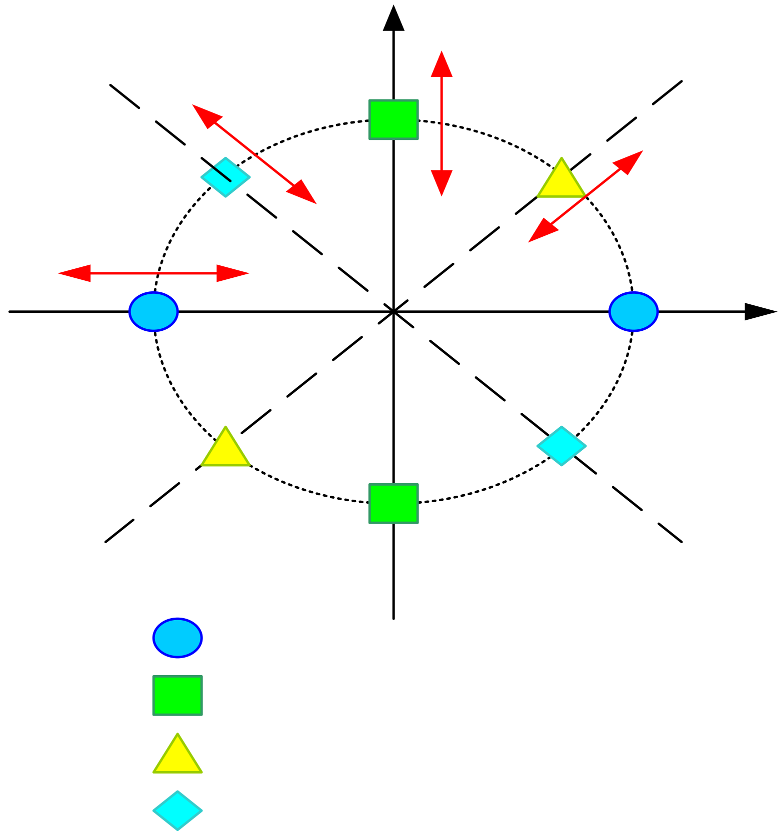
Example 1

- 2-axes BPSK (Q=2)
  - half of users
    - ➔ $(+1,-1)$
  - The other of users
    - ➔ $(+j,-j)$
  - Spreading factor N=8
    - 2 users case
      - ➔ 0 user MUI
    - 4 users case
      - ➔ 1 user MUI
    - 8 users case
      - ➔ 3 user MUI



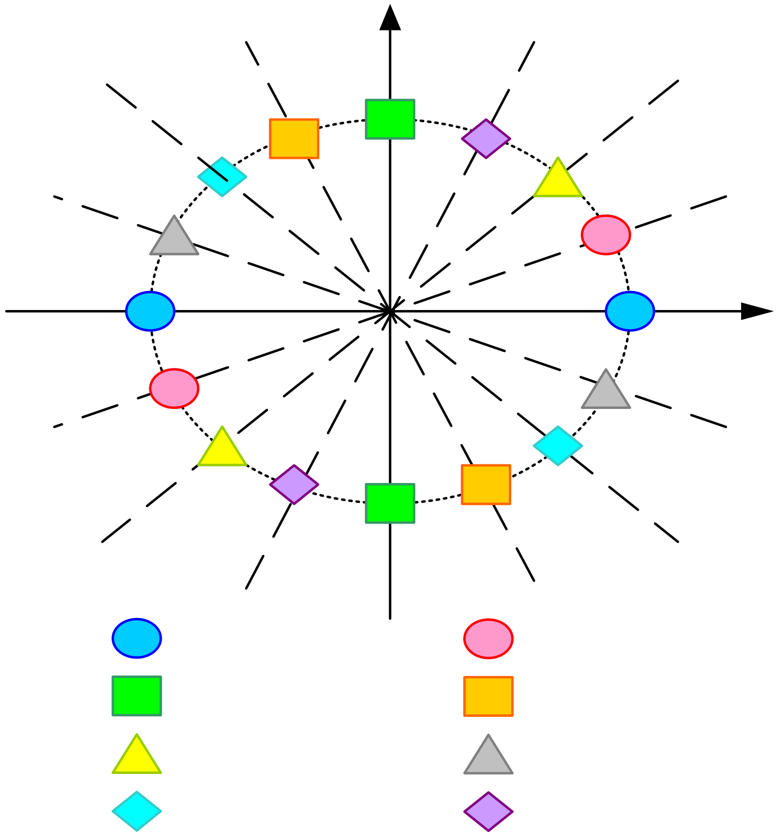
Example 2

- 4-axes BPSK (Q=4)
  - quarter of users
    ➔ $(+1,-1)$
  - another quarter of users
    ➔ $(+j,-j)$
  - another quarter of users
    ➔ $(+1+j,-1-j)/\sqrt{2}$
  - The other quarter of user
    ➔ $(+1-j,-1+j)/\sqrt{2}$
  - Spreading factor N=8
    - 4 users case
      ➔ reduced 2 user's MUI
    - 8 users case
      ➔ 1 user's MUI and reduced 4 user's MUI



Example 3

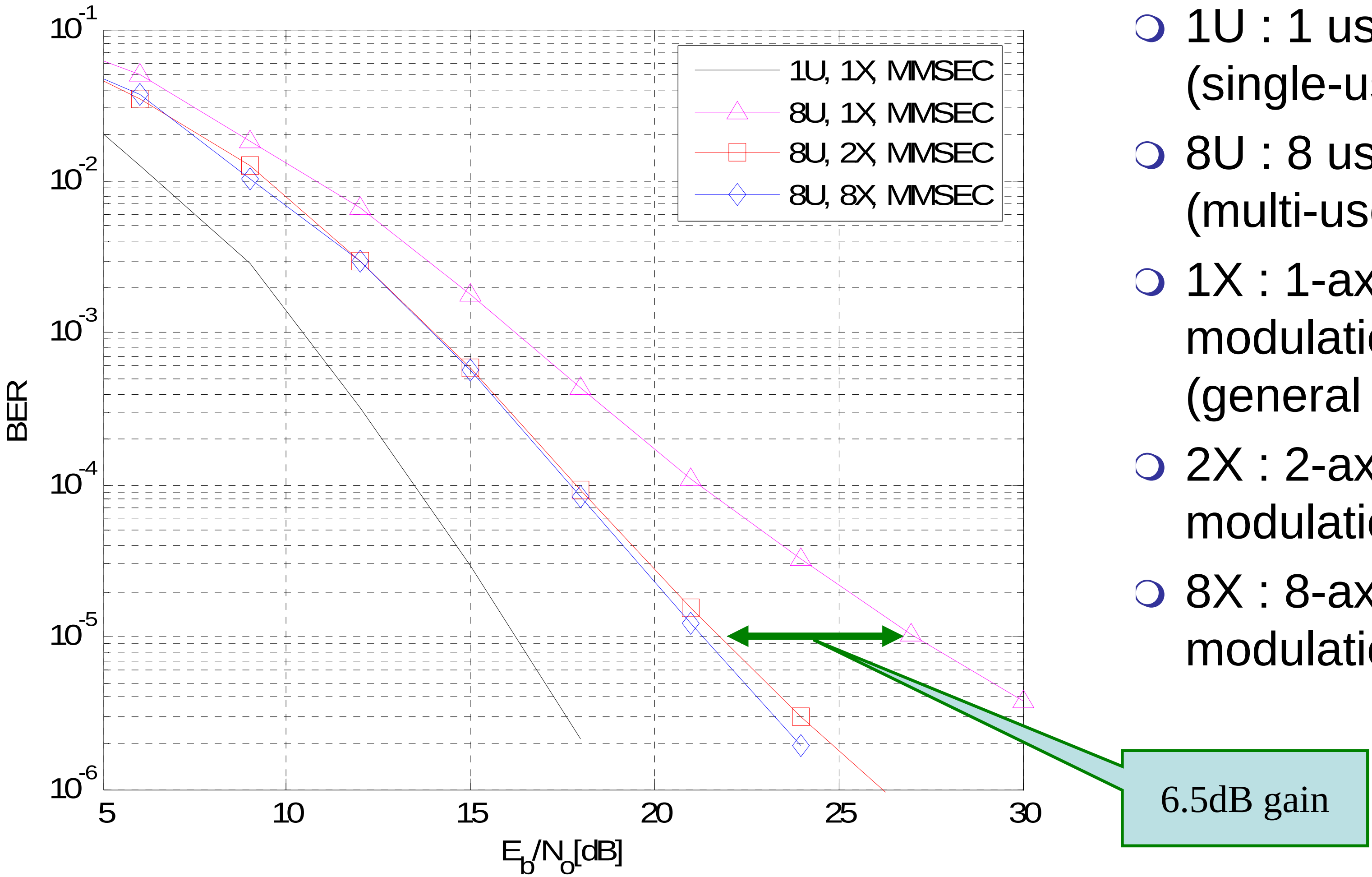
- 8-axes BPSK (Q=8)



Simulation Model

- System parameters
  - Length of sequence : N=8
  - S/P size : M=64
  - # of subcarriers : M·N=512
  - Guard interval : GI = 64
  - Total symbol sample :
    M·N+GI=512+64=576
  - # of multipaths : 8
  - Multipaths : uniformly distrubuted and exponentially decayed
  - # of users : 8
  - Modulation : Multi-axes BPSK
  - Spreading sequence : binary Walsh-Hadamard

Simulation Result



- 1U : 1 user (single-user case)
- 8U : 8 users (multi-user case)
- 1X : 1-axe modulation (general case)
- 2X : 2-axes modulation
- 8X : 8-axes modulation

Conclusion

- Multiuser interference in MC-CDMA
  - MUI : distortion orthogonality between users
  - Closely related with modulation methods
- Multi-axes modulation
  - Rotate one-dimensional modulation signal
  - MUI free for some users and reduced MUI for the other user
  - Flexible application according to various environments
  - When $Q=N$, MAM is similar to *rotated Hadamard spreading code

* A. Bury, J. Egle, and J. Lindner, "Diversity Comparison of Spreading Transforms for Multicarrier Spreading Spectrum Transmission, " *IEEE Trans. on Commun.*, Vol. 51, No. 5, pp. 774-781, May 2003