Improving DS-CDMA Performance in Practical Channel Conditions

We now discuss 2 practical problems facing CDMA system and their mitigation techniques:

1. Near-far problem and power control
2. Multipath fading problem and RAKE combining

1.Power Control for Near Far Problem

- Users closer to the base station generally have their signals received with less attenuation than those who may be further away. In an asynchronous DS-CDMA system in which all users interfere with each other due to non-orthogonality between their received signals, strong received signals will enjoy good BER but they are also strong interferers to others, thereby pulling down the others' BERs. This non-uniform performance scenario is commonly called the **near-far condition/problem.** It causes the CDMA uplink capacity to degrade.

- An effective technique to combat the near-far problem is to implement **power control** in the system such that all user signals from within a cell are received with approximately the same power level (this assumption was used earlier in capacity calculation). This can be achieved by adaptively controlling the transmitter power output of the mobile units based on some measured knowledge of the channel attenuation sustained at the receiver.

2. RAKE Receiver for DS-CDMA Multipath Channel

Multipath Fading Channels

- **Multipath signals**: multiple received copies of the same transmitted signal with random amplitudes, delays and phases
- When multipath signals combine at the receiver, they produce undesirable **multipath fading** effects such as weak signal strength, unknown phase, pulse broadening etc.

Frequency Fading:

- Frequency-*Flat* fading (narrowband, low-rate systems like AMPS):
    - Transmit 1 pulse, receive 1 faded pulse
    - Solution: diversity combining

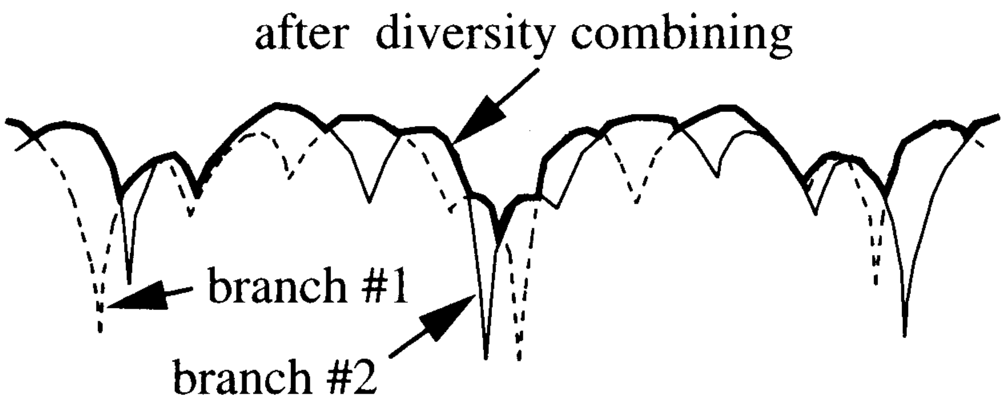
- Frequency-*Selective* Fading (broadband, high-rate systems like GSM, Qualcomm CDMA):
  - Transmit 1 pulse, receive multiple faded pulses with delays greater than a pulse interval
  - Solution: RAKE receiver, equalizer, OFDM (orthogonal frequency division multiplexing)

Time Fading:

- Slow Fading: fading remains constant (stationary) during observation period.
- Fast Fading: fading changes during observation period.

Diversity Combining to Mitigate/Alleviate Fading

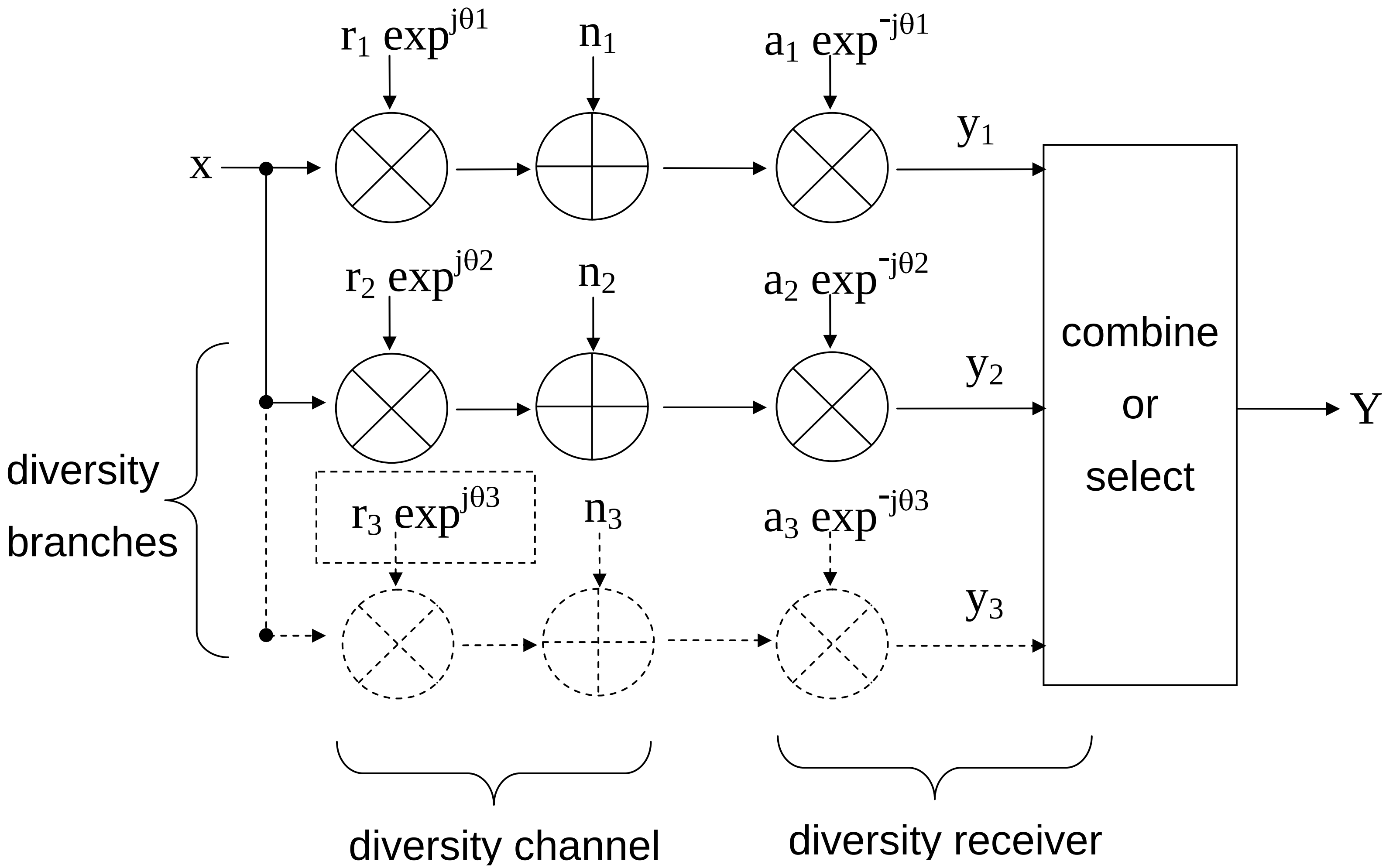
- Generate multiple received signals with independent/uncorrelated fades (diversity signals)
- Phase-align the diversity signals and combine them, e.g.



Combining Schemes

- Selection combining (SC), maximal ratio combining (MRC), equal gain combining (EGC)

Diversity Channel and Receiver Models

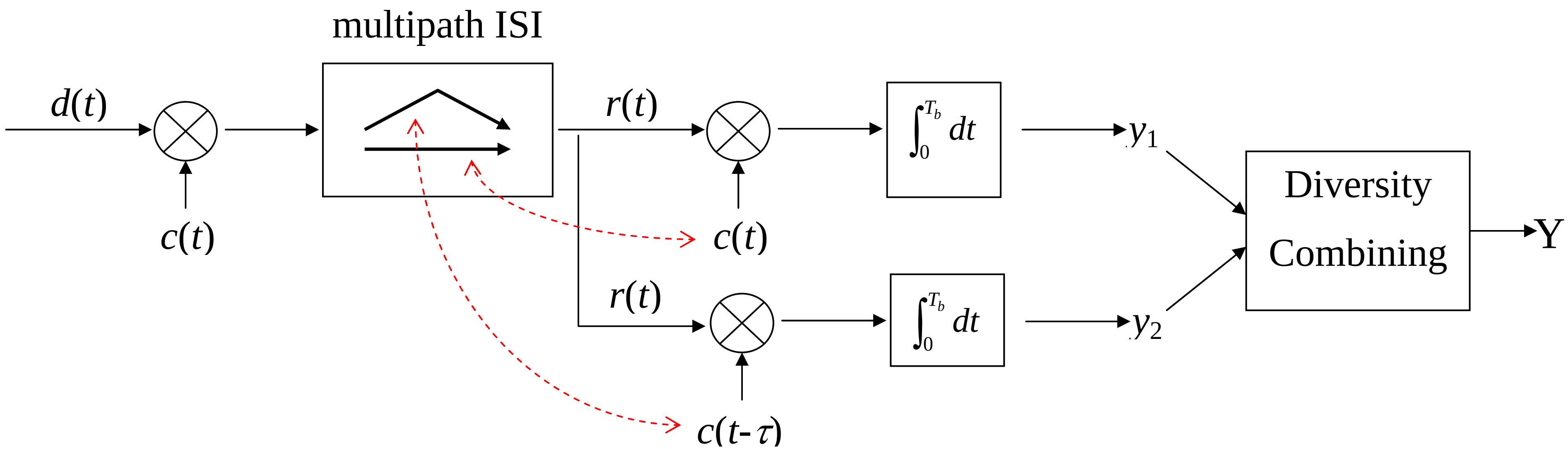


Diversity Channel and Receiver Models

- Selection combining (SC)
  - o $a_1 = a_2 = a_3 = \ldots = 1$
  - o $Y = y_i$ with $\max(r_i)$
- Equal gain combining (EGC)
  - o $a_1 = a_2 = a_3 = \ldots = 1$
  - o $Y = \text{Sum}[\ y_i\ ] = \sum r_i$
- Maximal ratio combining (MRC)
  - o $a_1 = r_1$; $a_2 = r_2$; $a_3 = r_3$ …
  - o $Y = \text{Sum}[\ y_i\ ] = \sum r_i^2$

RAKE Receiver as a Path Diversity Combiner

Since DS-CDMA signals are spreaded using sequences with good autocorrelation characteristics for ease of synchronisation, the de-spreader is capable of locking onto any of the multipath components with inter-path delays exceeding 1 chip duration. Separate receiver branches can hence be built to separately track and de-spread different multipath components for subsequent diversity combining, as shown below. Such a DS-CDMA diversity-combiner is called A **RAKE receiver**.



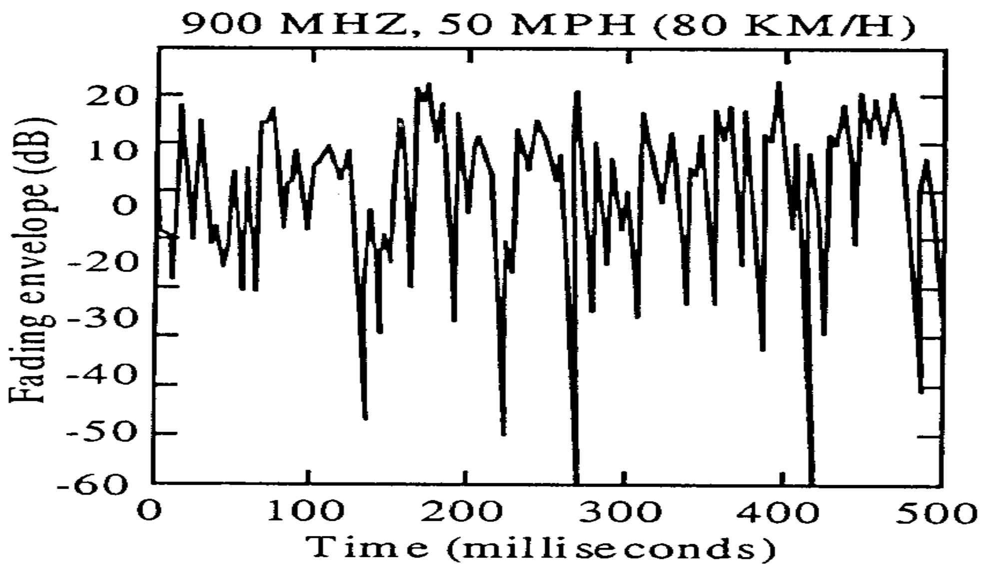
BER in Fading Channel

In AWGN channel, for single user:

$$\text{BER} = Q\left(\sqrt{2 \times \frac{E_b}{N_0}}\right) \qquad \text{where} \quad E_b = A^2\, T_b \text{ is fixed in time}$$

In fading channel,

- channel gain A fluctuates randomly due to fading
- hence BER fluctuates accordingly.



Power control is not effective against fast fading because the fading rate $f_d = (v/c)\, f_c$ may be quite high if the product of the receiver speed v and the carrier frequency f_c are large compared to the speed of light c. This makes it difficult for power control to track the channel and compensate for fading attenuation.

In dense urban environment with no line of sight between the tx^r and rx^r, the random fading channel gain A can be modeled using a probability distribution (or probability density function, pdf) called *Rayleigh* distribution:

$$p(A) = \frac{2A}{P} \exp\left(-\frac{A^2}{P}\right), \quad \text{where} \quad A \geq 0, \;\; P = E\left[A^2\right].$$

Equivalently, $\gamma = A^2$ follows the *Exponential* distribution:

$$p(\gamma) = \frac{1}{P} \exp\left(-\frac{\gamma}{P}\right)$$

Correspondingly, $\mathrm{BER} = Q\left(\sqrt{2 \times \frac{A^2 T_b}{N_0}}\right)$ is now a random quantity too.

So, average BER of a <u>*slow*</u>, *flat*-fading CDMA channel with conventional receiver (no RAKE) is:

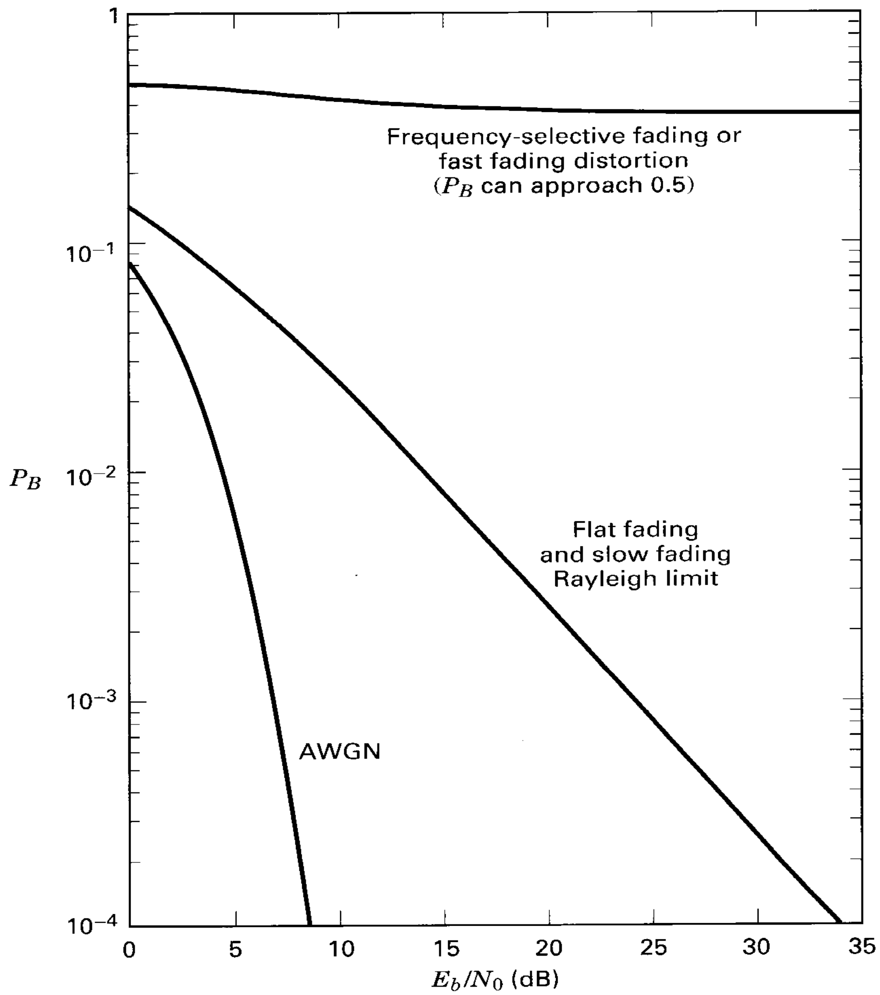
$$\overline{\text{BER}} = \int_{A=0}^{\infty} Q\left(\sqrt{2\times\frac{A^2T_b}{N_0}}\right)\times p(A)\ dA$$

$$= \frac{1}{2}\left(1-\sqrt{\frac{E_b/N_0}{1+E_b/N_0}}\right) \approx \frac{1}{4\,E_b/N_0}$$

where $E_b = \mathrm{E}[A^2]\,T_b$ = average bit energy of a path (instead of $E_b = A^2\,T_b$ for AWGN channel)

For frequency-*selective* fading, ISI should be included:

$$\text{BER} \approx \frac{1}{4E_b/(ISI_0 + N_0)}$$



BER with MRC-RAKE Combining

With RAKE receiver, different RAKE branch/finger outputs fade differently. After combining, they give an overall output with much less fading.

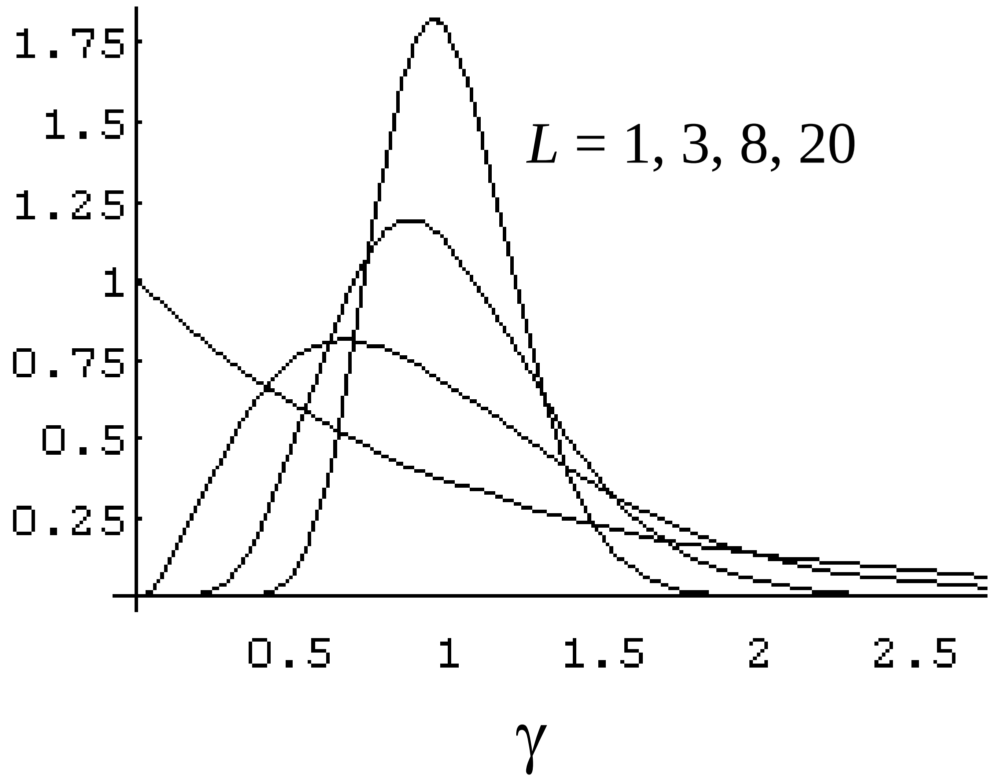
Mathematically, the combined output $\gamma = \sum_{l=1}^{L} A_l^2$ (A_l denotes the l^{th} path gain) of a RAKE receiver with maximal ratio combining (MRC) with L RAKE-fingers has a "*Chi-Square*" distribution with "2L degrees of freedom".

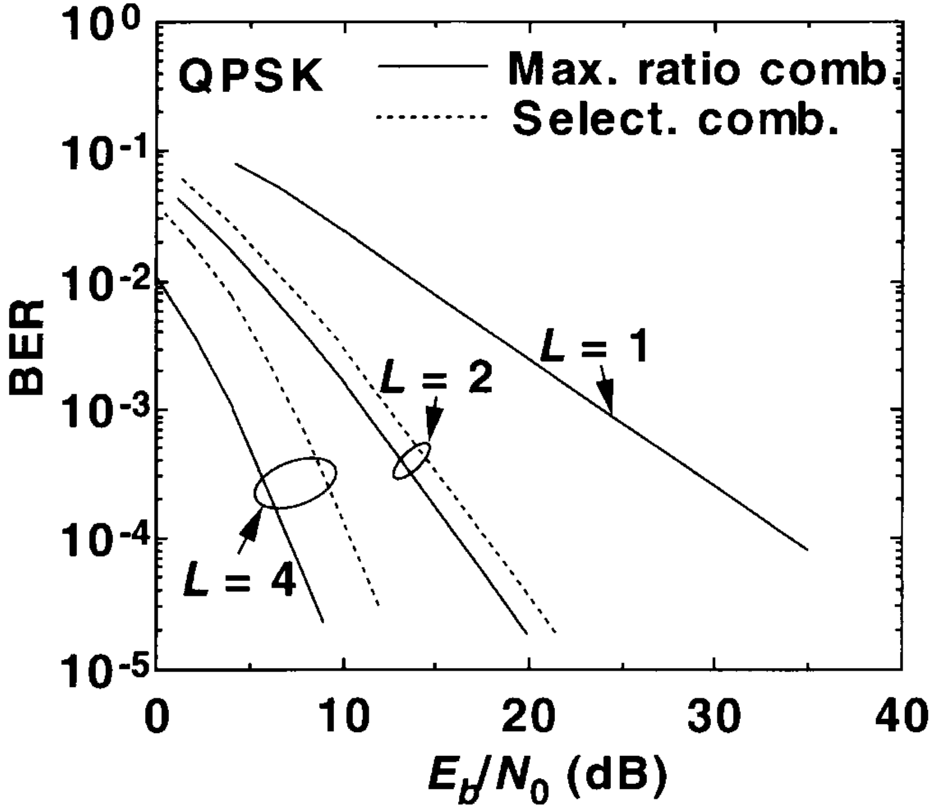
The resultant average BER with MRC-RAKE combining is

$$\overline{\text{BER}} = \binom{2L-1}{L} \prod_{l=1}^{L} \left[\left(\frac{4E_b}{\text{ISI}_0 + N_0} \right)_l \right]^{-1} \qquad \text{where } E_b = \text{E}[A_l^2] \cdot T_b$$

$$= \underbrace{\frac{(2L-1)!}{L!(L-1)!} \left(\frac{4E_b}{\text{ISI}_0 + N_0} \right)_{path1}^{-1} \left(\frac{4E_b}{\text{ISI}_0 + N_0} \right)_{path2}^{-1} \cdots \left(\frac{4E_b}{\text{ISI}_0 + N_0} \right)_{path\,L}^{-1}}_{\text{L-order diversity combining}} < \underbrace{\left(\frac{4E_b}{\text{ISI}_0 + N_0} \right)^{-1}}_{\text{no diversity}}$$

pdf of γ


1.75
1.5
1.25
1
0.75
0.5
0.25
L = 1, 3, 8, 20
0.5
1
1.5
2
2.5
γ


QPSK
Max. ratio comb.
Select. comb.
BER
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
L = 1
L = 2
L = 4
0
10
20
30
40
Eb/N0 (dB)

TUTORIAL

We will discuss Tutorial 4 together today.