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Continuous Phase Modulation For The Indoor Wireless Channel

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Ph.D. Defense

February 3, 1998

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Motivation

- Indoor communication is increasingly important (computer networks, remote control & sensing).
- CPM yields increased spectral efficiency; increases system capacity.
- Understand CPM performance in the severe channel of multipath fading and cochannel interference.

Continuous Phase Modulation

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- Transmitted signal $s(t) = \sqrt{\frac{2E}{T}} \cos[\omega_c t + \phi(t,\alpha)]$

- Information phase $\phi(t,\alpha) = 2\pi h \sum_{i=-\infty}^{\infty} \alpha_i q(t - iT_b)$

- Phase function - 1REC

$$q(t) = \begin{cases} 0, & t < 0 \\ \frac{t}{2T_b}, & 0 \le t \le T_b \\ \frac{1}{2}, & t \ge T_b \end{cases}$$

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CPM (cont.)

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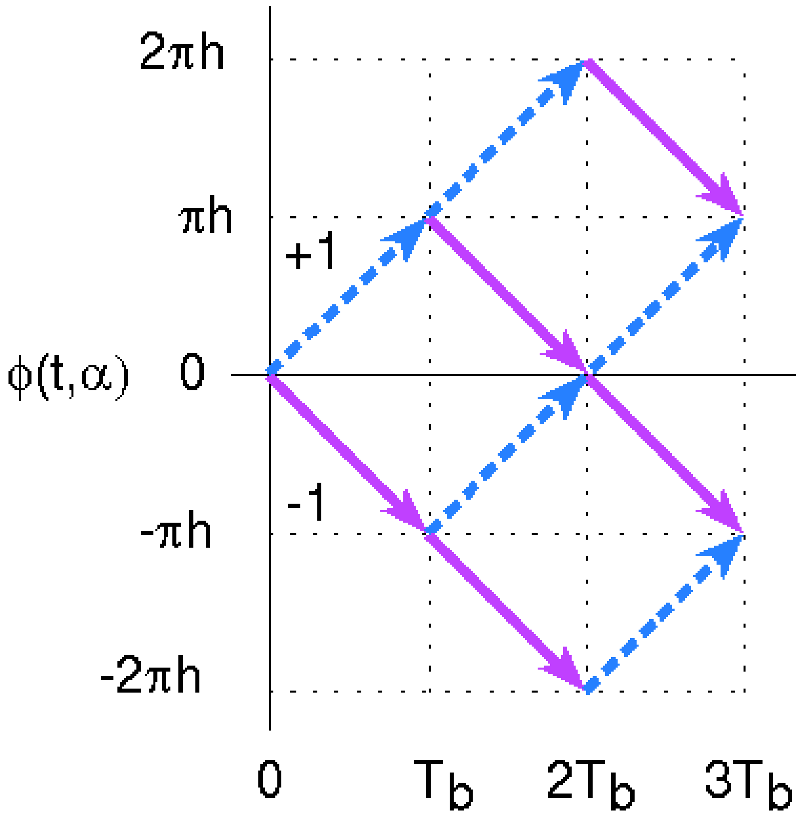
- Restrict modulation index

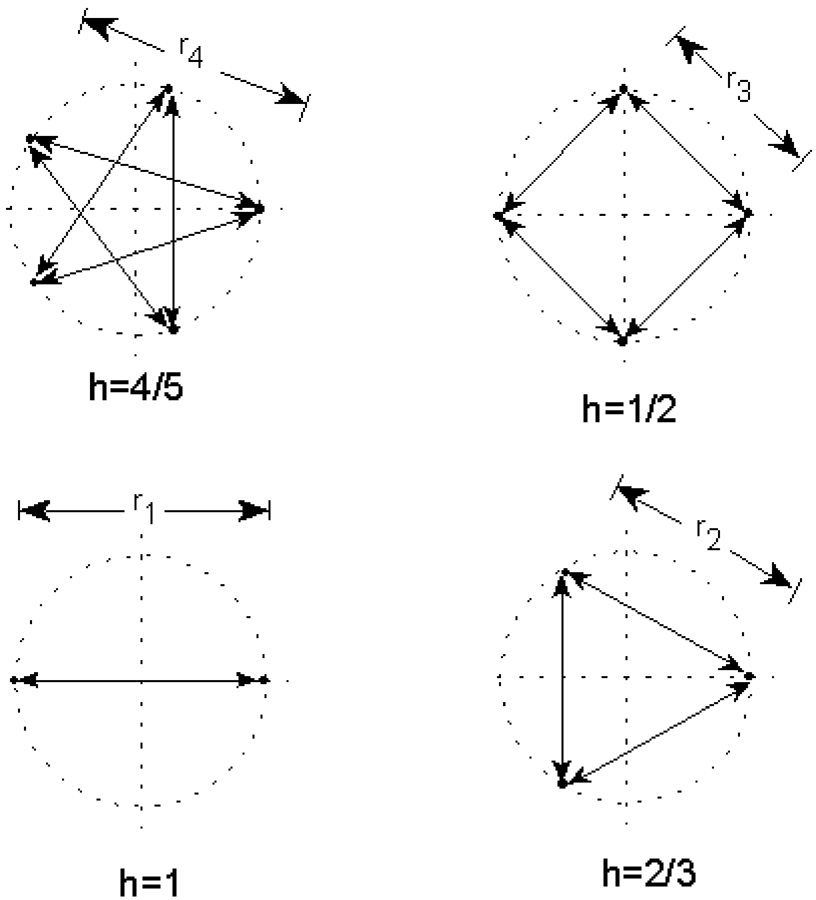


$$h = \frac{2n}{m}, \quad n, m = 1, 2, 3, \ldots$$

$$h = \frac{2}{3}, \frac{1}{2}, \frac{4}{5}, 1, \ldots$$

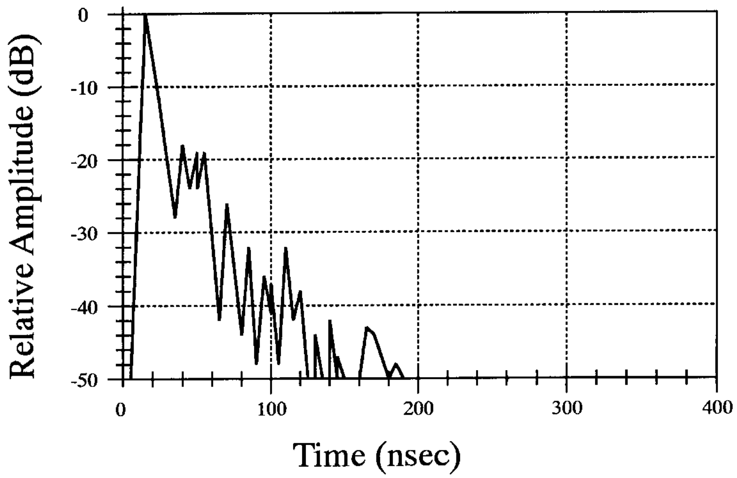
The number of trellis states is m.

CPM Constellations



Indoor Channel

- Channel impulse response



$$h(t) = Ae^{j\mu}\delta(t-\zeta) + \sum_{l=1}^{L} \bar{\beta}_l e^{j\bar{\gamma}_l}\delta(t-\bar{\tau}_l)$$

$$E[\overline{\beta_l^2}] = 2\rho_l$$

Homayoun Hashemi, "The Indoor Radio Propagation Channel", *IEEE Proceedings*, Vol. 51, No. 7, July 1993.

- Rician factor 6-12 dB

$$H_l = \frac{A^2}{2\rho_l}$$

MLSE Detection

- Maximum Likelihood Sequence Estimation maximizes the likelihood function up to the nth symbol

$$J_n(\vec{\alpha}) = \int_{-\infty}^{(n+1)T} r(t)s(t,\vec{\alpha})dt,$$

or equivalently written

$$J_n(\vec{\alpha}) = J_{n-1}(\vec{\alpha}) + Z_n(\vec{\alpha}),$$

where

$$Z_n(\vec{\alpha}) = \int_{nT}^{(n+1)T} r(t)s(t,\vec{\alpha})dt$$

CPM MLSE Receiver

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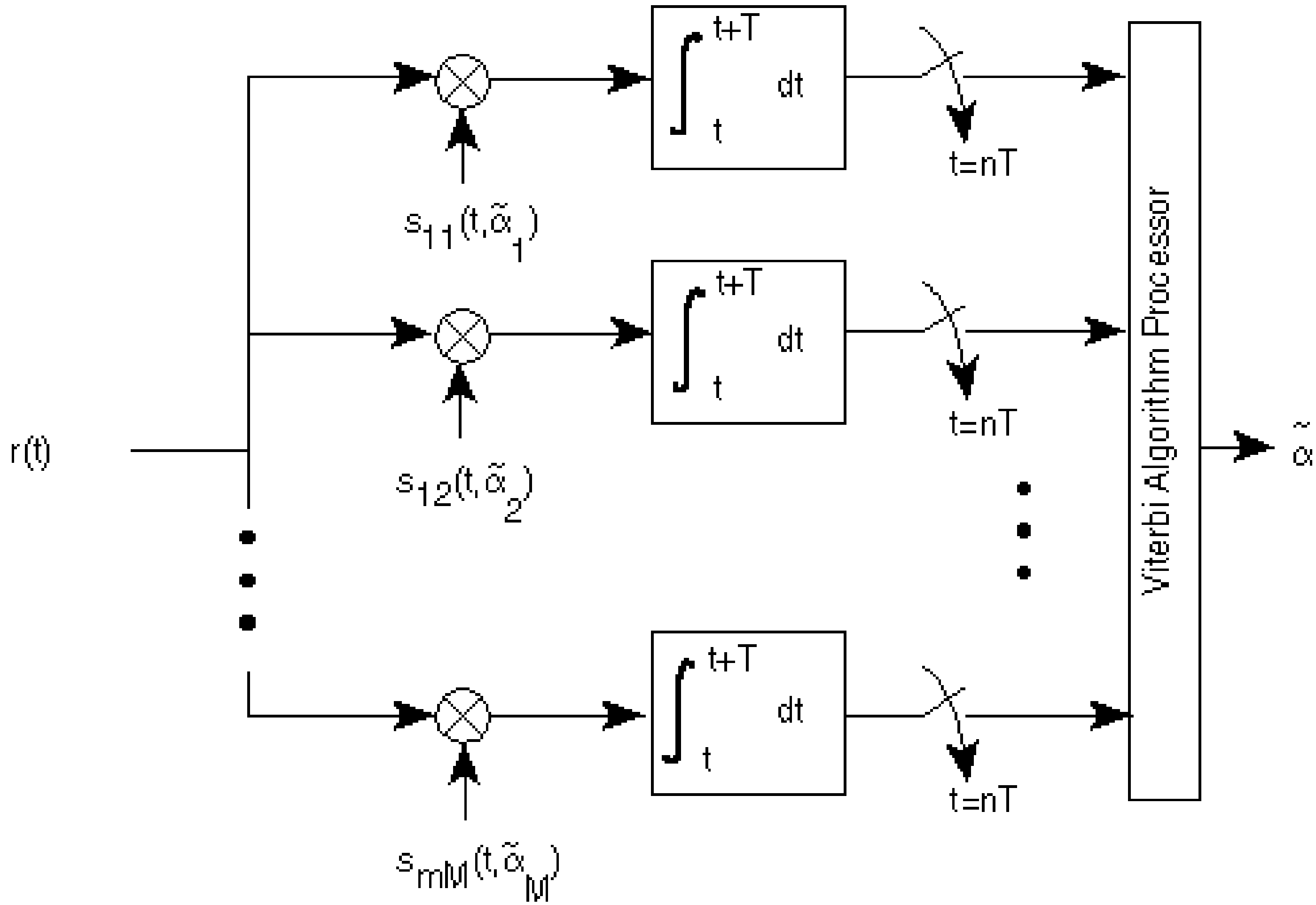

Received Signal

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$$r(t) = A\sqrt{2P}\cos[\omega_c t + \phi(t,\vec{\alpha})]$$

$$+\sum_{k=1}^{K} A\sqrt{2P_k}\cos[\omega_c(t-\bar{\tau}_k) + \phi(t-\bar{\tau}_k,\vec{\alpha}_k) + \bar{\theta}_k]$$

$$+n(t)$$

Where n(t) is conditional Gaussian, and is composed of AWGN, desired signal multipath and interference multipath random components.

System Performance

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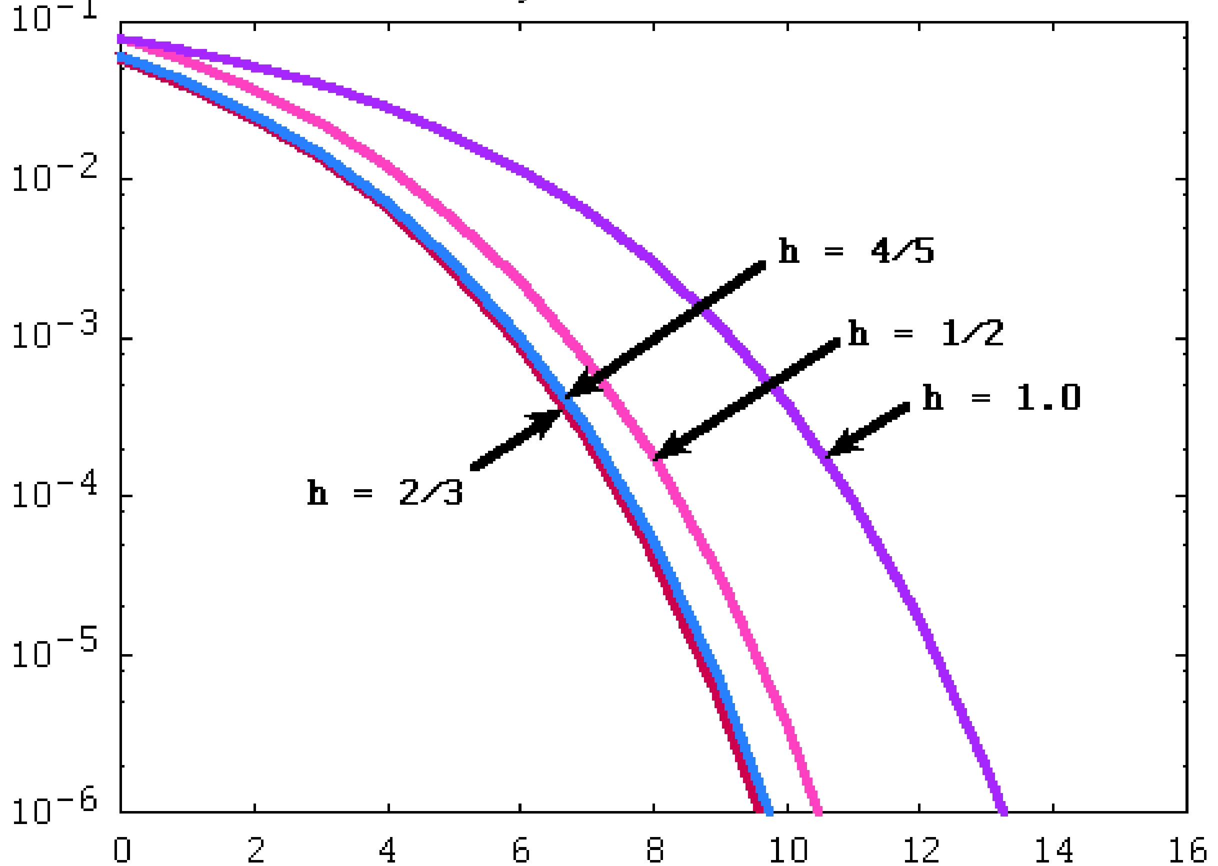
- Based on *Error Events* diverging from the correct trellis path and merging after some symbol periods

$$\Pr[E] = \sum_{\alpha_m} \sum_{\tilde{\alpha}_m \neq \alpha_m} w(\alpha_m, \tilde{\alpha}_m) \prod_{i=0}^{m-1} \frac{M - |\varepsilon_i|}{M} \frac{1}{2^{K(m+1)}} \sum_{k=1}^{2^{(m+1)}} \frac{1}{T^K} \frac{1}{T^L} \frac{1}{T^{KL}} \frac{1}{(2\pi)^K}$$

$$\int_0^T \int_0^T \int_0^T \int_0^{2\pi} Q\left(\frac{d_s^2(\alpha_m - \tilde{\alpha}_m) + x_I(\alpha_m, \tilde{\alpha}_m, \alpha_k, \bar{\theta}_K, \bar{\tau}_K)}{\sqrt{\sigma_{N\,m}^2(\alpha_m, \tilde{\alpha}_m, \alpha_k, \bar{\theta}_K, \bar{\tau}_K, \bar{\tau}_L, \bar{\tau}_{KL})}} \right) d\bar{\theta}_K \, d\bar{\tau}_K \, d\bar{\tau}_{KL} \, d\bar{\tau}_L$$

No Interference or Fading TRW



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Single Multipath

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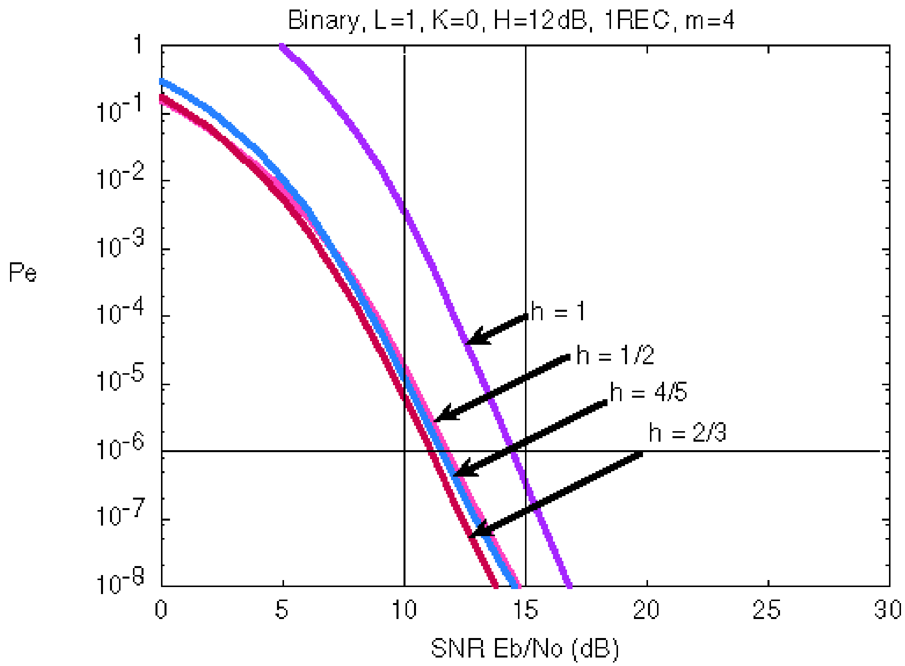

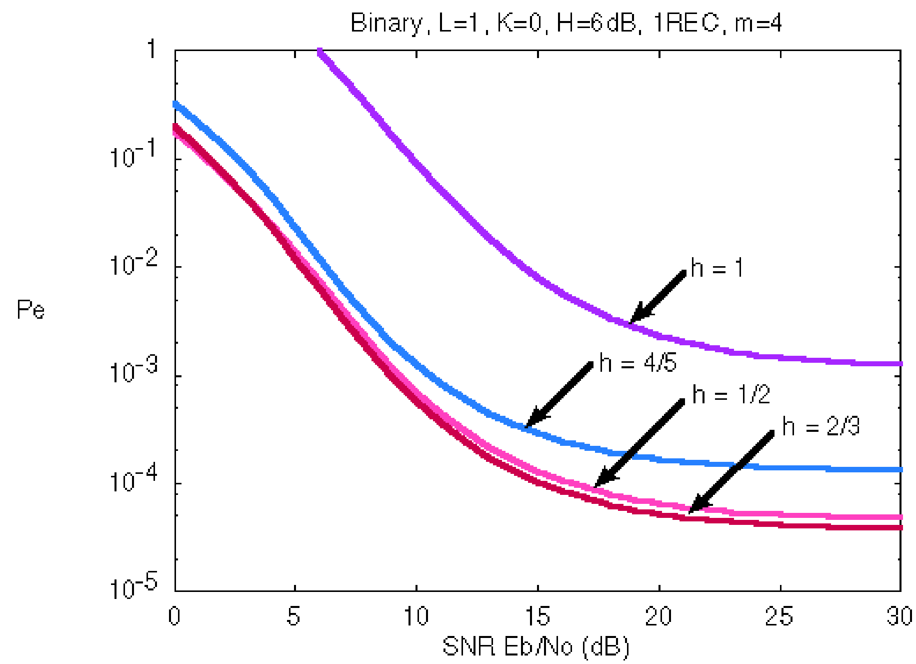

$$H = \frac{A^2}{2\rho_1}$$

Three Constant Power Multipaths

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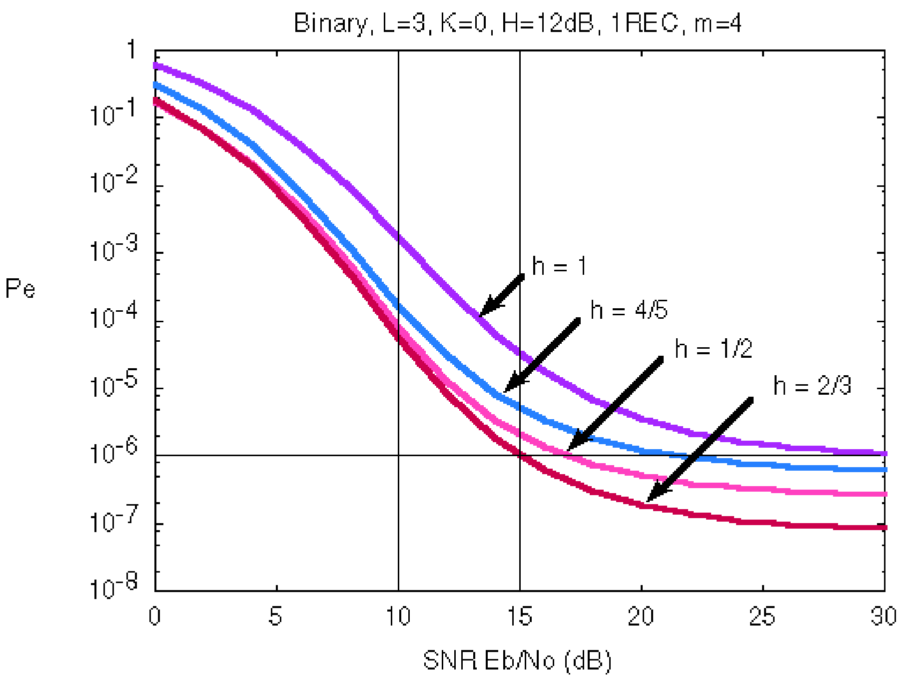

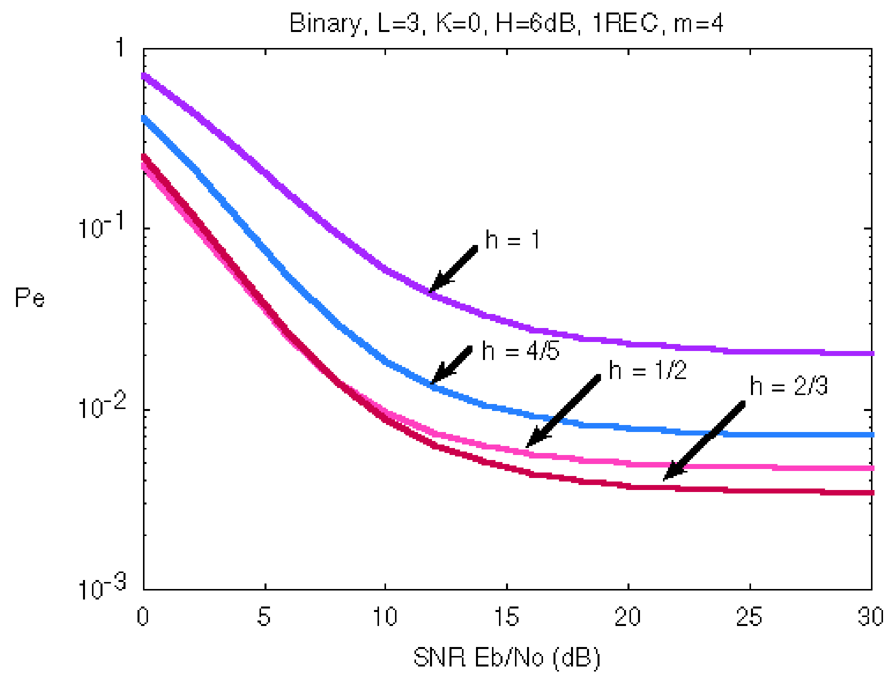

$$H = \frac{A^2}{2\rho_l}, \ \ l = 1,2,3 \qquad \rho_1 = \rho_2 = \rho_3$$

Three Decaying Multipaths

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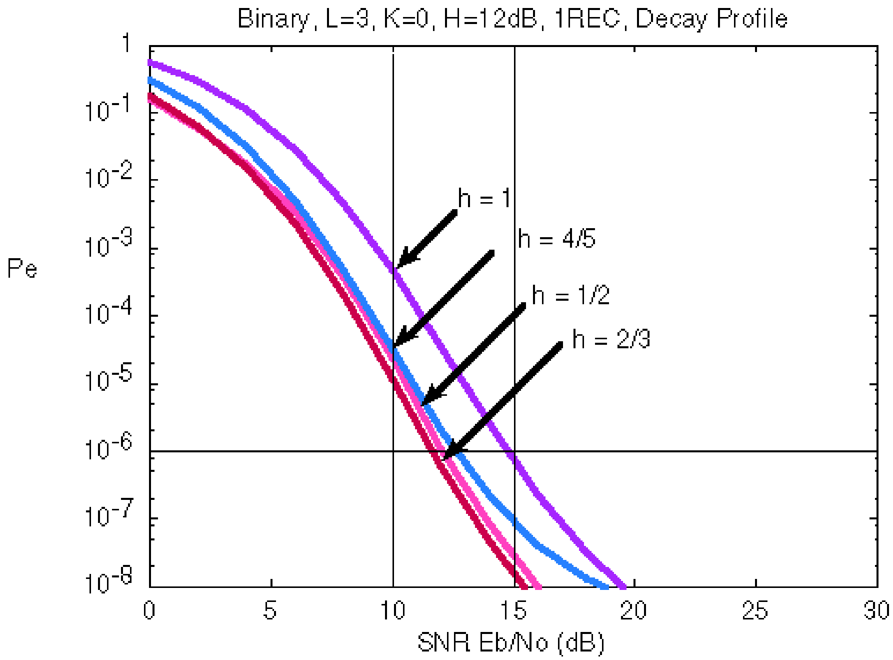

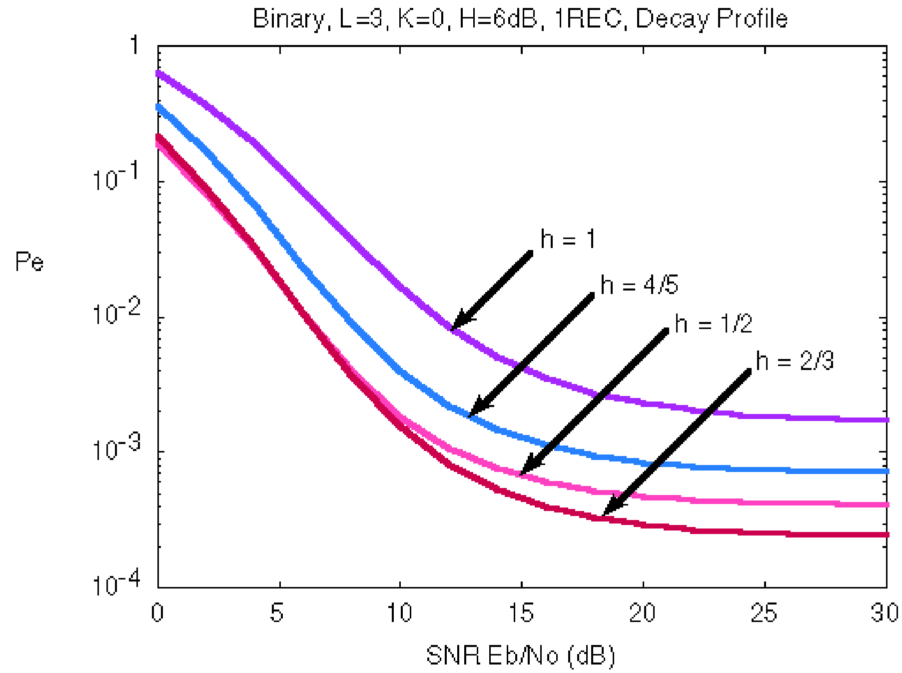

$$H = \frac{A^2}{2\rho_1}, \qquad \rho_1 = 2\rho_2 = 4\rho_3$$

Single Interferer

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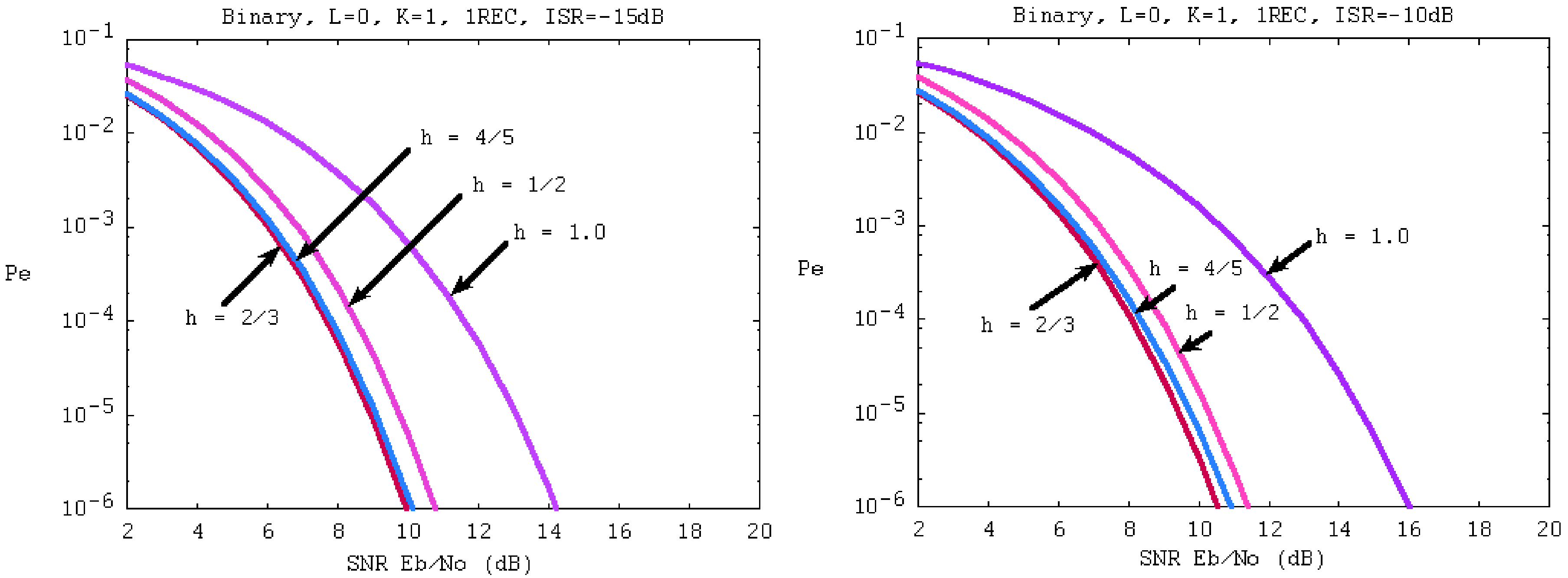

$$ISR = \frac{P_1}{P}$$

Gaussian Filtered MSK

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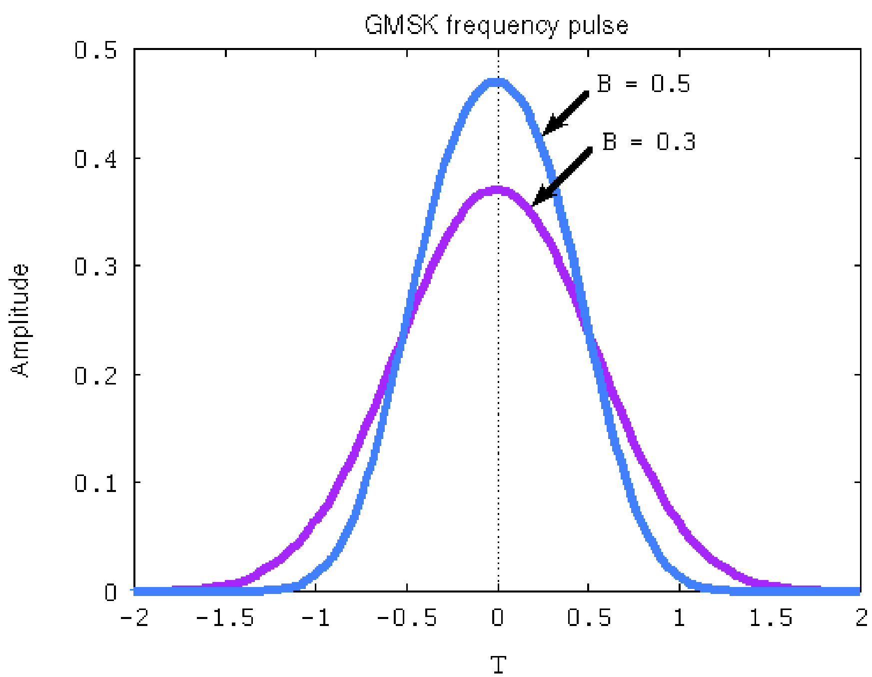
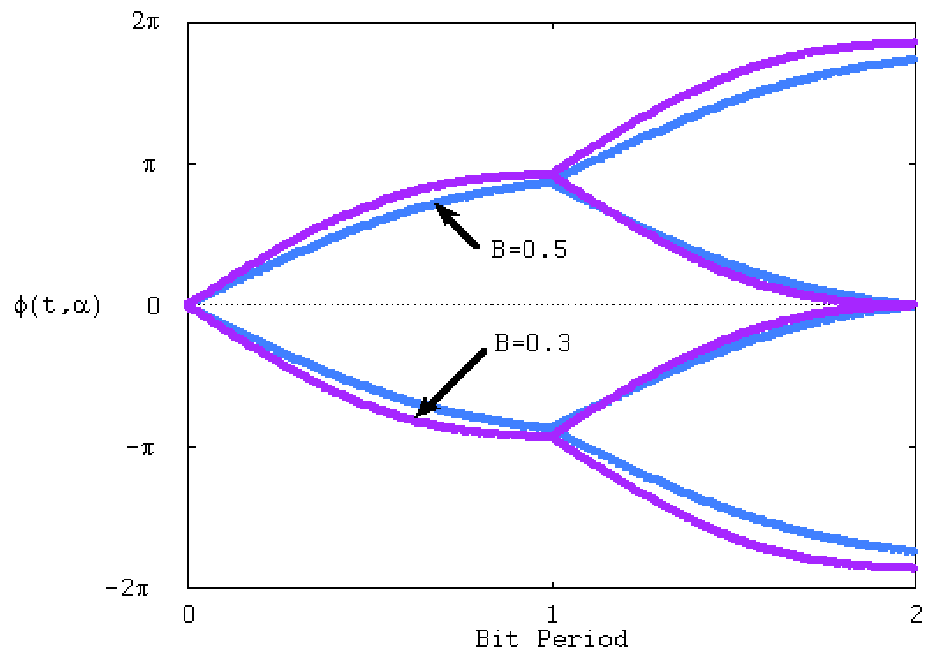
- Gaussian frequency pulses, resulting in arced trellis transitions.





GMSK

- GMSK standards established for
  - Global System for Mobile (GSM) Communications [B=0.3]
  - Digital European Cordless Telephone (DECT) [B=0.5]
  - Digital Communication System (DCS) [B=0.3]
- Compare our error performance results with these systems.

GMSK Performance

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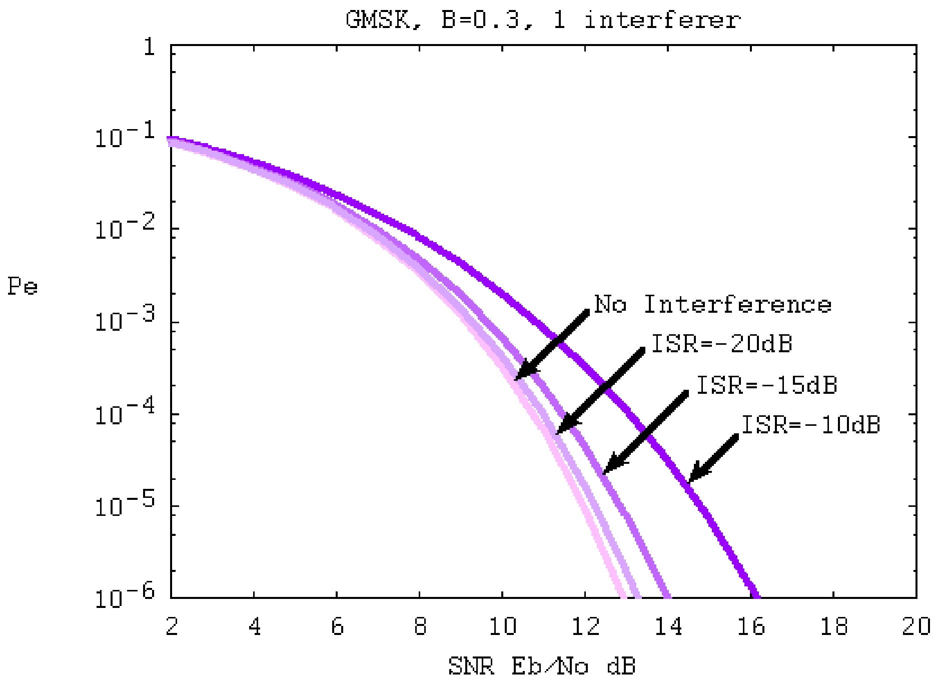

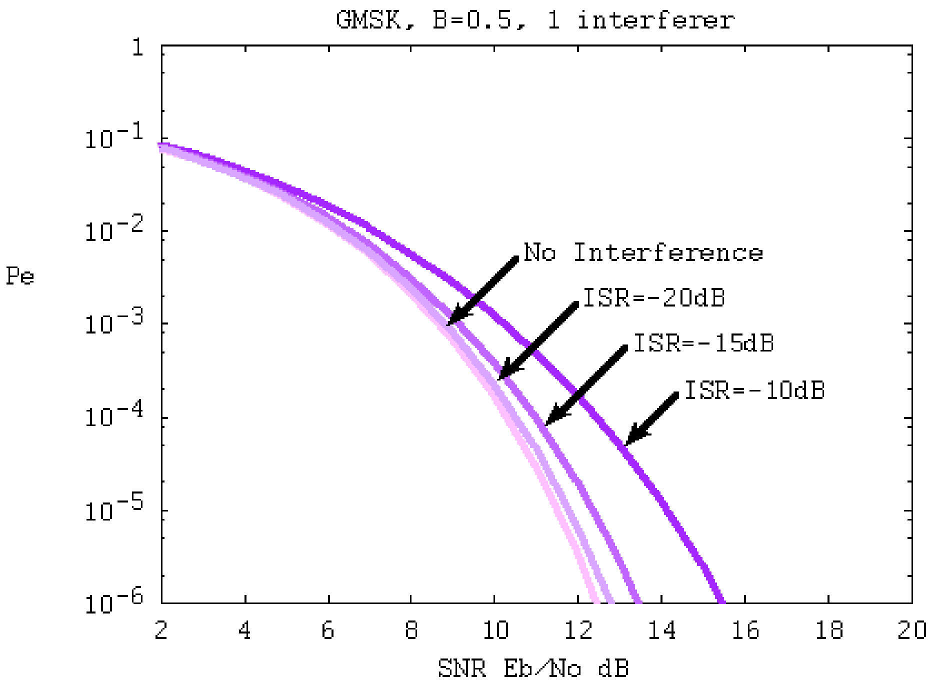

$$ISR = \frac{P_1}{P}$$

Monte-Carlo Integration

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- If $\{x_1, x_2, \ldots, x_N\}$ are independent random variables with density p(x) then

$$\int f(x)p(x)dx = E[f(x)] \approx \frac{1}{N}\sum_{n=1}^{N} f(x_n)$$

- Extension to multidimensional integrals results in rapid computation.
- The accuracy is independent of the integration dimension.

Two Interferers

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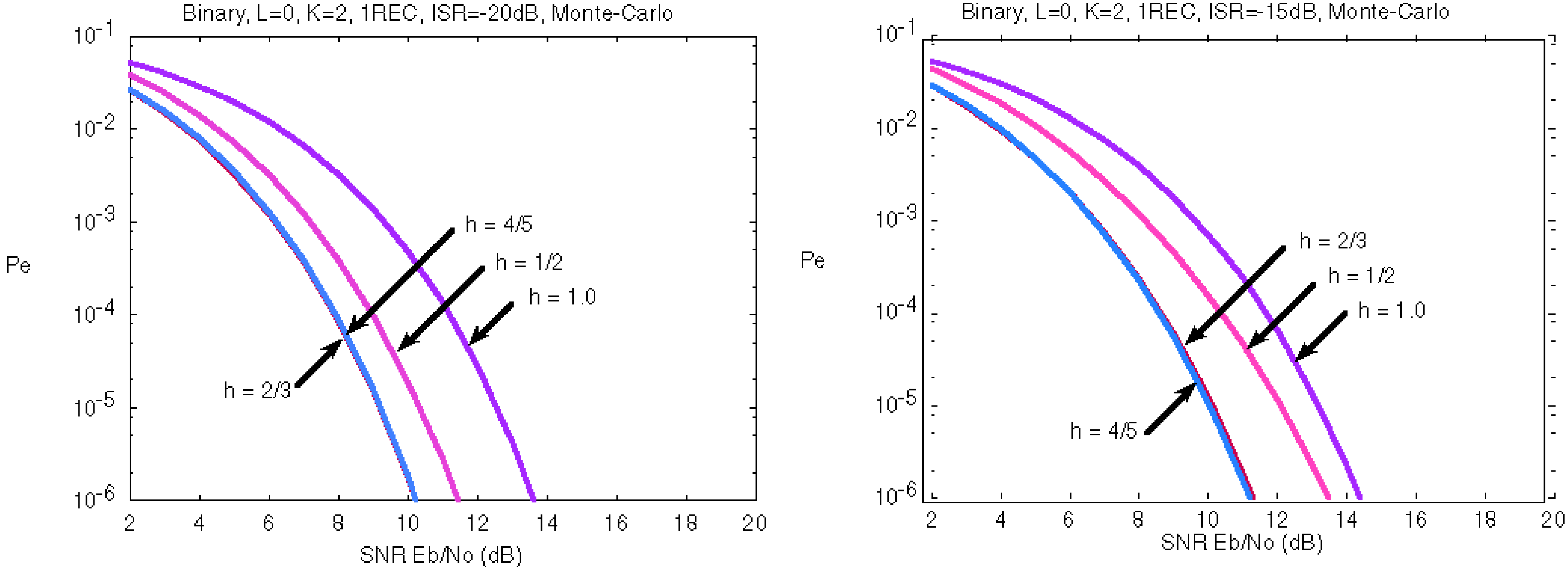

$$ISR = \frac{P_k}{P}, k = 1,2 \quad P_1 = P_2$$

Three Interferers

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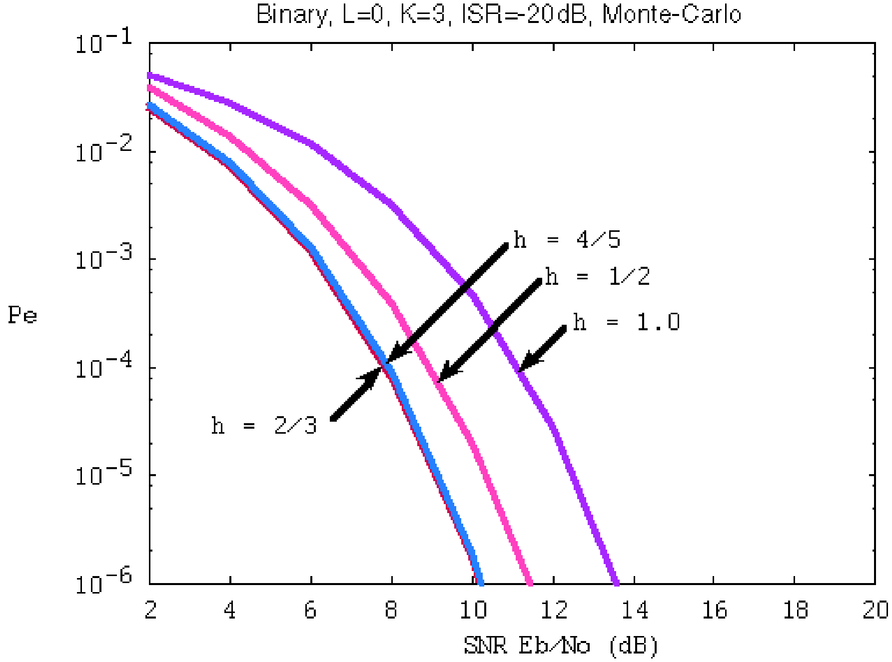

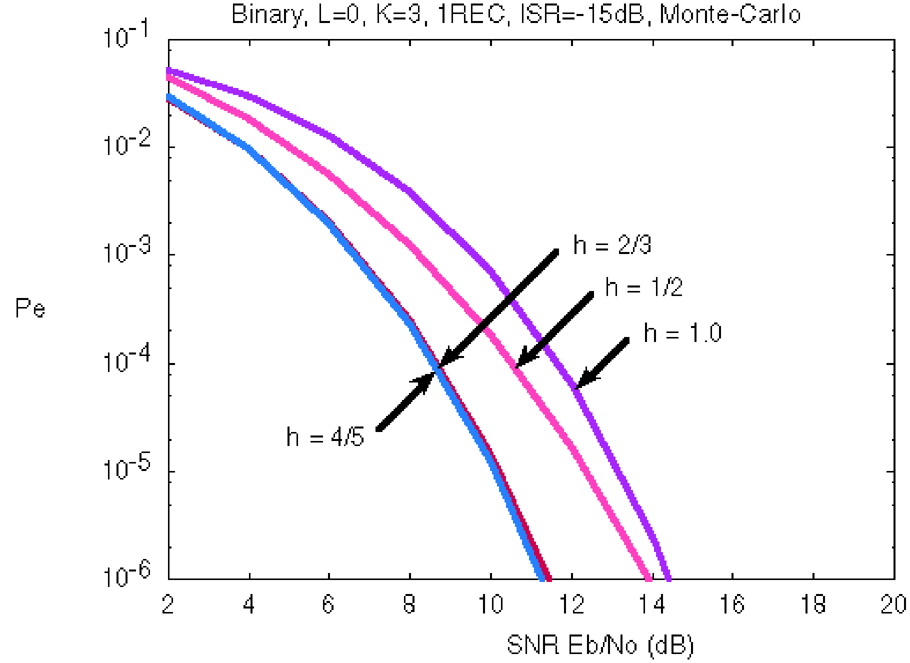

$$ISR = \frac{P_k}{P}, k = 1,2,3 \quad P_1 = P_2 = P_3$$

Conclusions

- Complete error performance expression obtained.
- Reduced computation by using the Monte-Carlo integration method.
- “Best” modulation index is h=2/3 under a variety of conditions, and has a simple three state MLSE decoder.