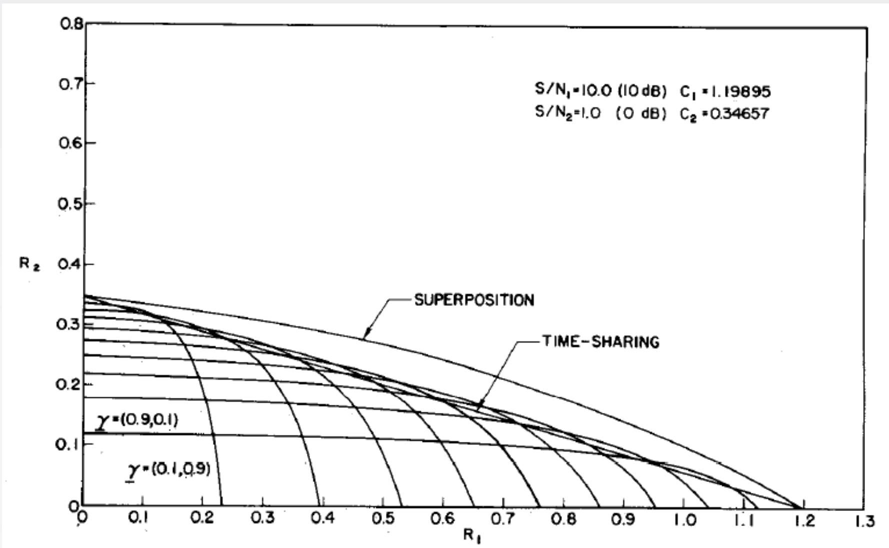
On Enhancing Hierarchical Modulations

Shu Wang, Byung K. Yi and Soon Y. Kwon
LG Electronics Mobile Research, USA

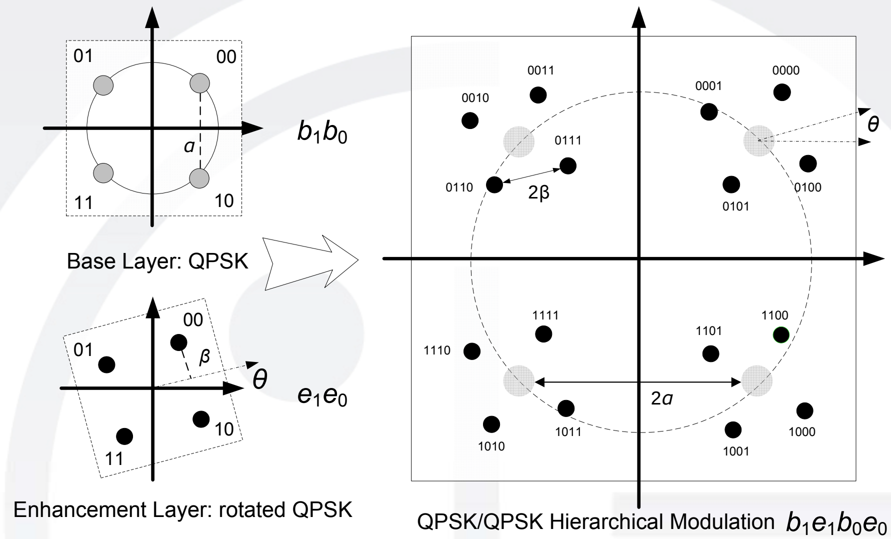
Introduction

- Hierarchical modulations are widely used in digital broadcast system design such as
  - Dedicated network: DVB-T, Media-FLO, UMB-BCMCS.
  - Hierarchical network: DVB Multiplexing.
- Hierarchical modulations can help
  - provide different QoS's to users with different profiles, e.g. higher throughput for users with advanced receiver.
  - provide unequal protection on different contents, e.g., video, audio, text.
  - update system to provide better service to new users with advanced receiver with keeping existing users unchanged.
- The enhanced hierarchical modulation scheme by rotating enhancement layer(s) is investigated here for the next generation system in terms of
  - an information theoretic perspective: achievable throughputs
  - a signal-processing perspective: inter-layer interference, effective SNR, effective power, modulation efficiency.
  - an implementation perspective: peak-to-average power ratio (PAPR)
- These criteria can be used for optimizing and evaluating layered/hierarchical transmissions in the future too.

Superposition Precoding and Hierarchical Modulation

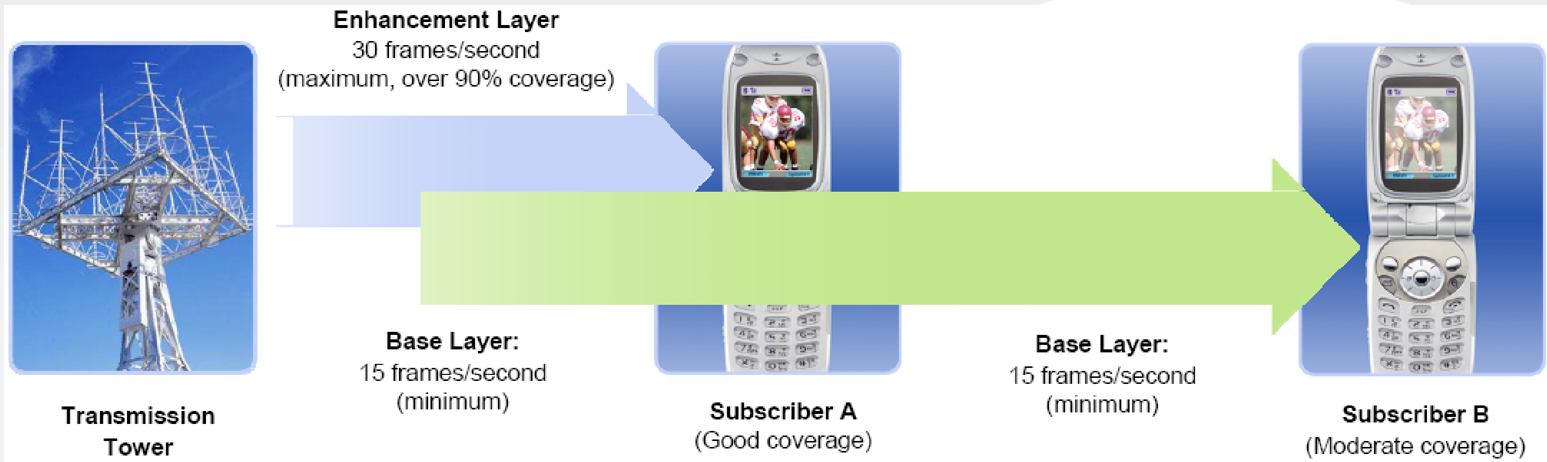


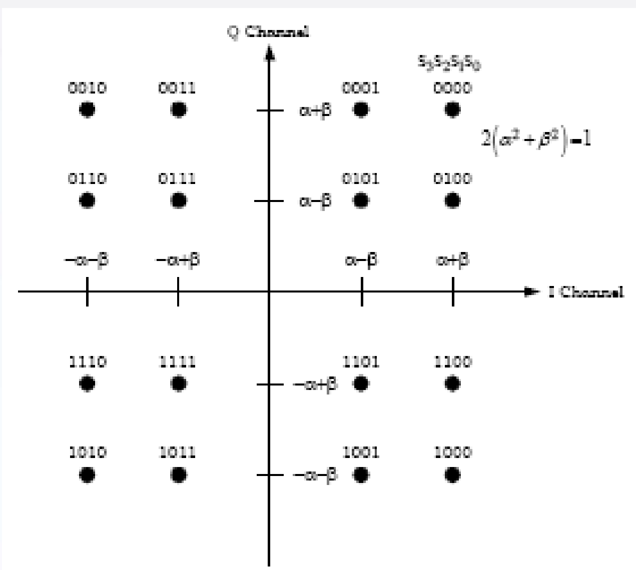
Achievable rates, (Bergmans and Cover, 1974).



- Optimal broadcast channel capacity is achievable by superposing two users’ signal together.
- Superposition precoding with interference cancellation outperforms TDM and FDM schemes in most time.
- Hierarchical modulation is one of the popular implementations of superposition precoding.

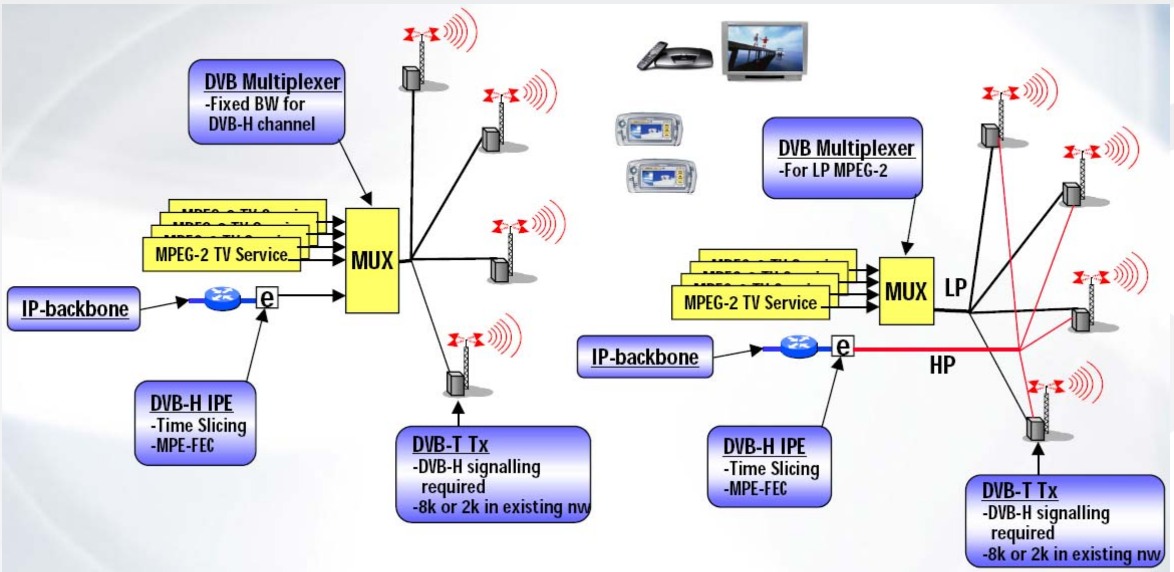
Hierarchical Modulation in Standards (1/2)

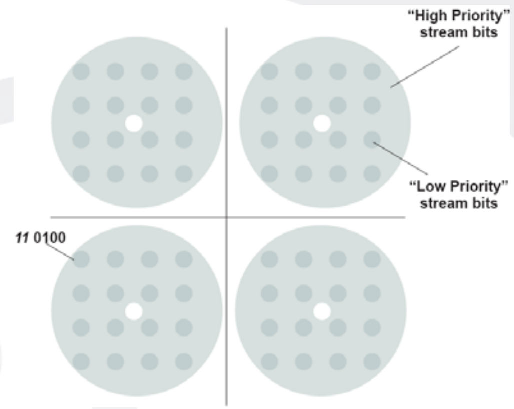




- Media-FLO supports hierarchical transmission of base/enhancement layers
  - Extends coverage with layered source coding
  - Provides a more graceful degradation of reception.

Hierarchical Modulation in Standards (2/2)

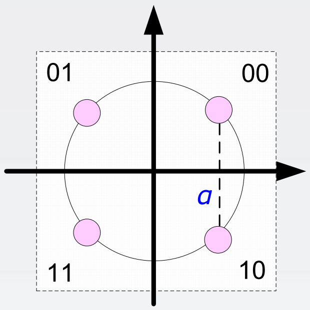




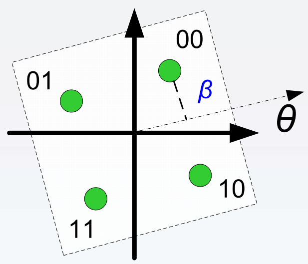
DVB-T -- QPSK/64QAM, 13.6/4.5Mbps with coding rate ¾ and ½.

- Besides using a dedicated DVB-H network, DVB-H service can also be embedded into DVB-T network using hierarchical modulation.
    - DVB-H service use the HP input while DVB-T services use LP.
    - The HP input can offer increased robustness in mobile environment over the LP input
    - The LP input can serve higher bit-rate for fixed reception service

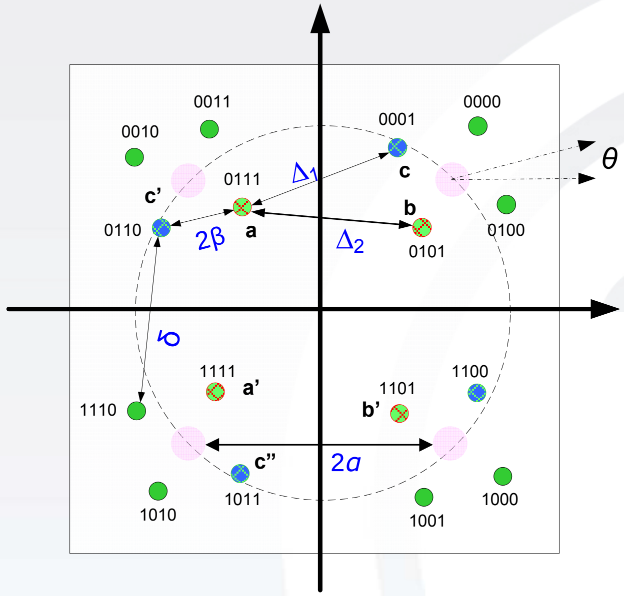
Enhanced Hierarchical Signal Constellation



Base Layer: QPSK

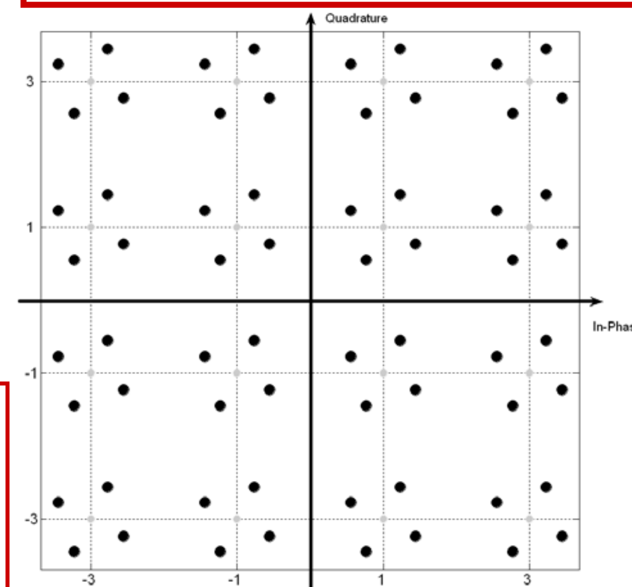


Enhancement Layer: rotated QPSK



Enhanced QPSK/QPSK Hierarchical Modulation

- The key advantage: minimum complexity increase.
- The major gain: higher throughput on the base layer
- The extra benefit: lower bit-error rate on the enhancement layer



QPSK/16QAM Hierarchical Modulation

There are a couple of ways to find the best rotation angle:

- if the target SNR's are known, maximizing the sum capacity of the two layers.
- if only the power splitting ratio is known, optimizing Euclid distance profile.
- another practical approach is to find the best angle by simulations.

Channel Capacity using N-ary Modulation

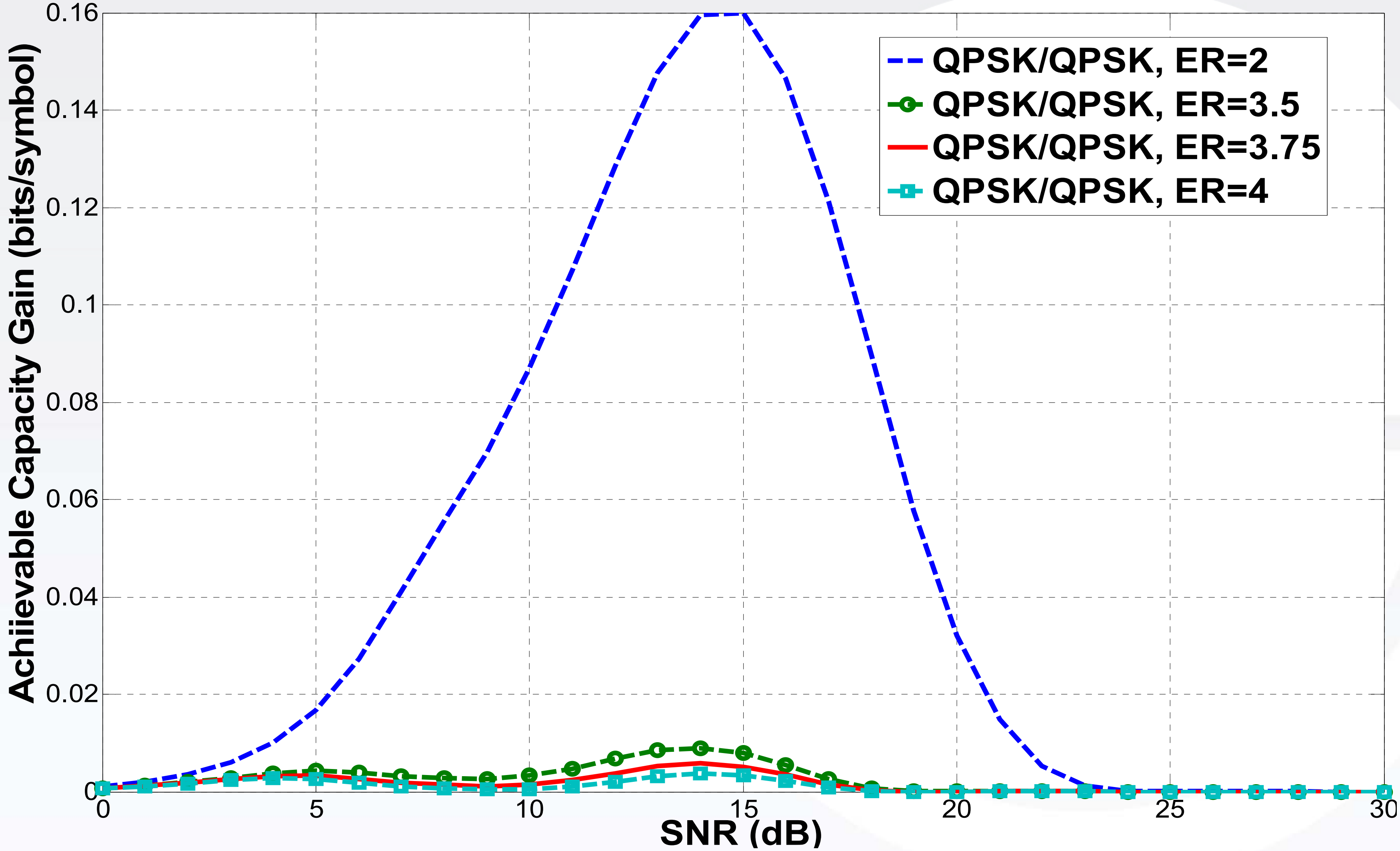
- The capacity of a general N-ary modulation can be written by

Signal Constellation and Euclid Distances Profile

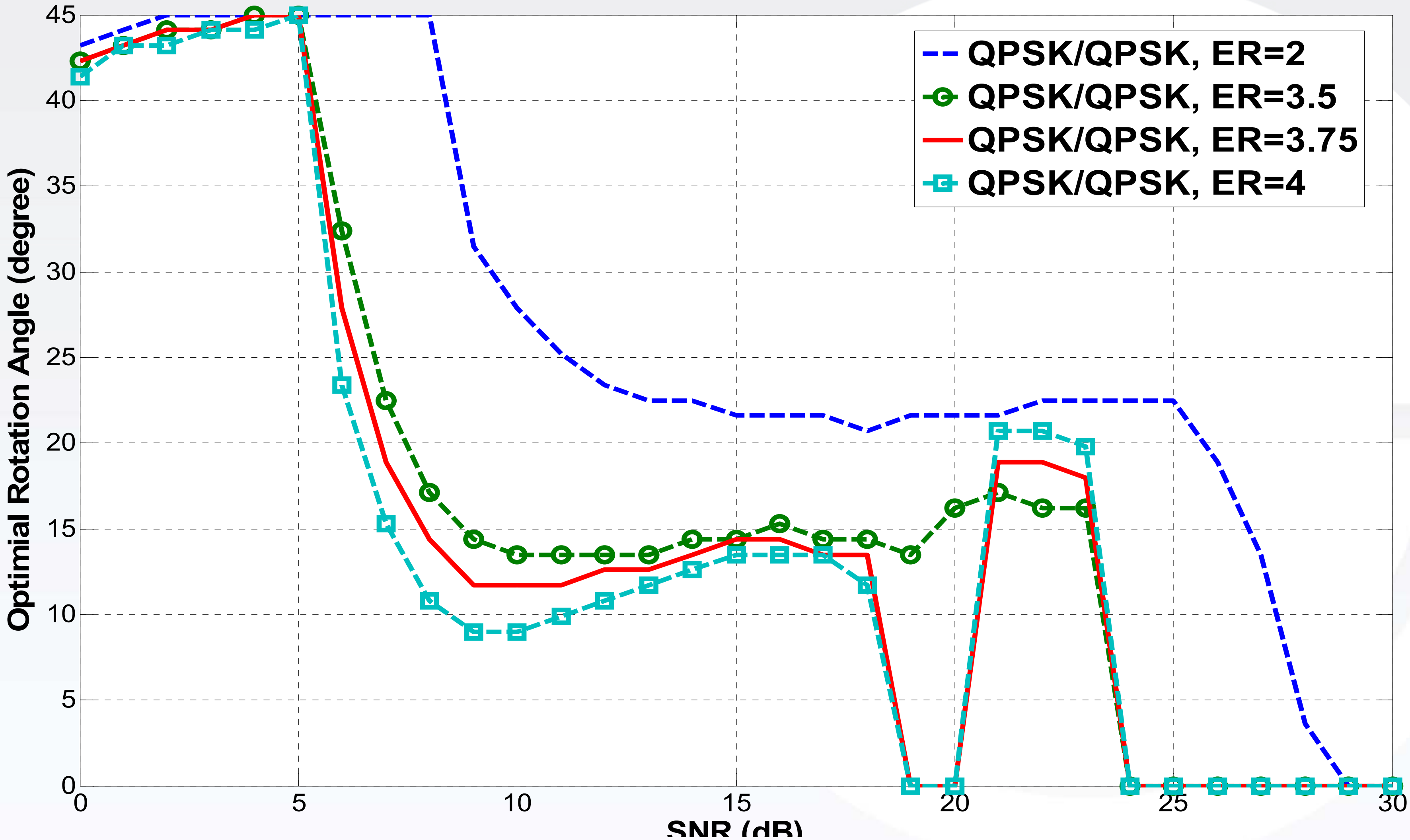
$$C_N = \log_2(N) - \frac{1}{N}\sum_{j=0}^{N-1} E\left\{\log_2\left[\sum_{i=0}^{N-1}\exp\left(-\frac{|s_j+n-s_i|^2 - |n|^2}{2\sigma^2}\right)\right]\right\}$$

n denotes normally distributed complex-valued noise with variance σ^2

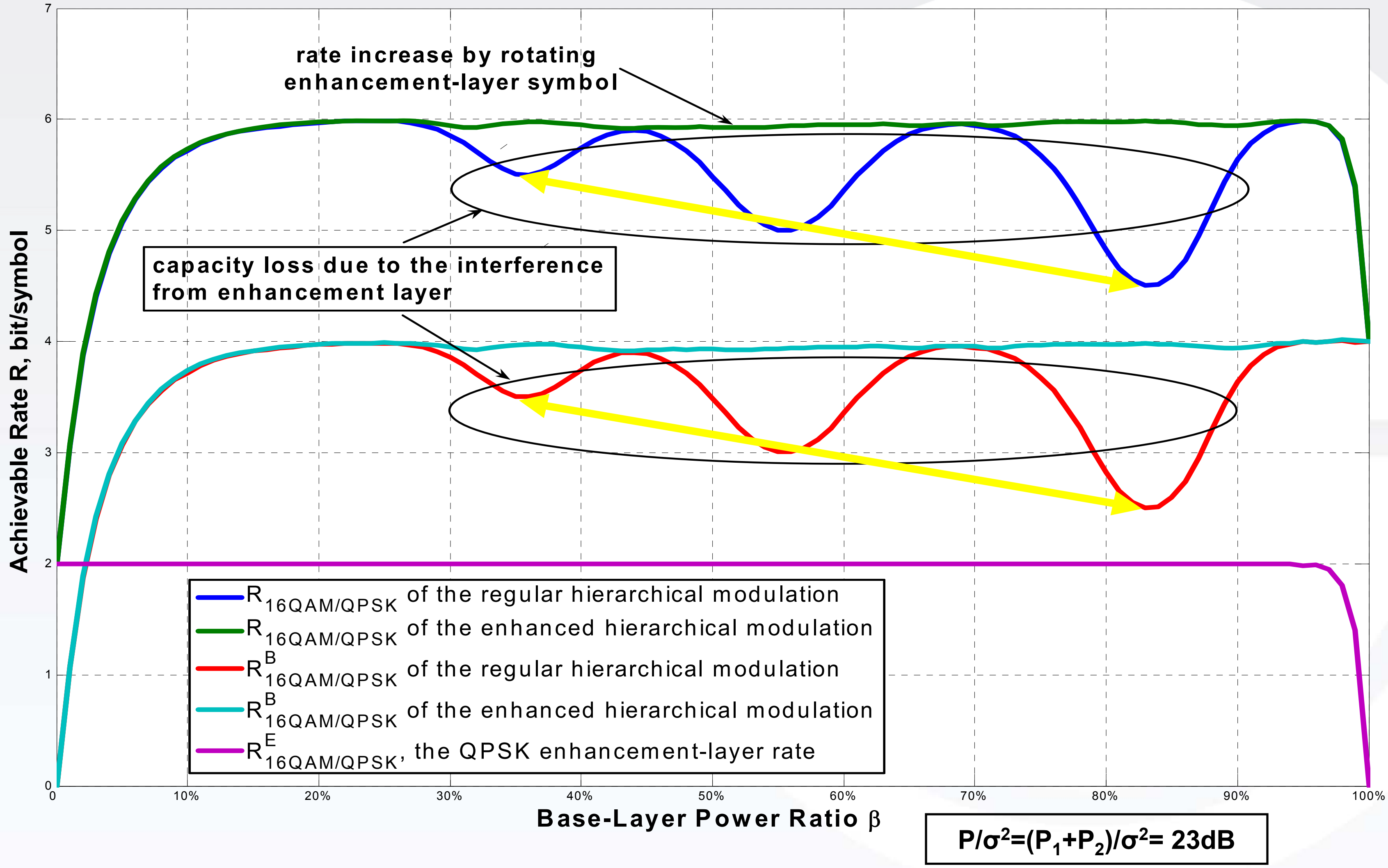
Achievable Gains (1/2)



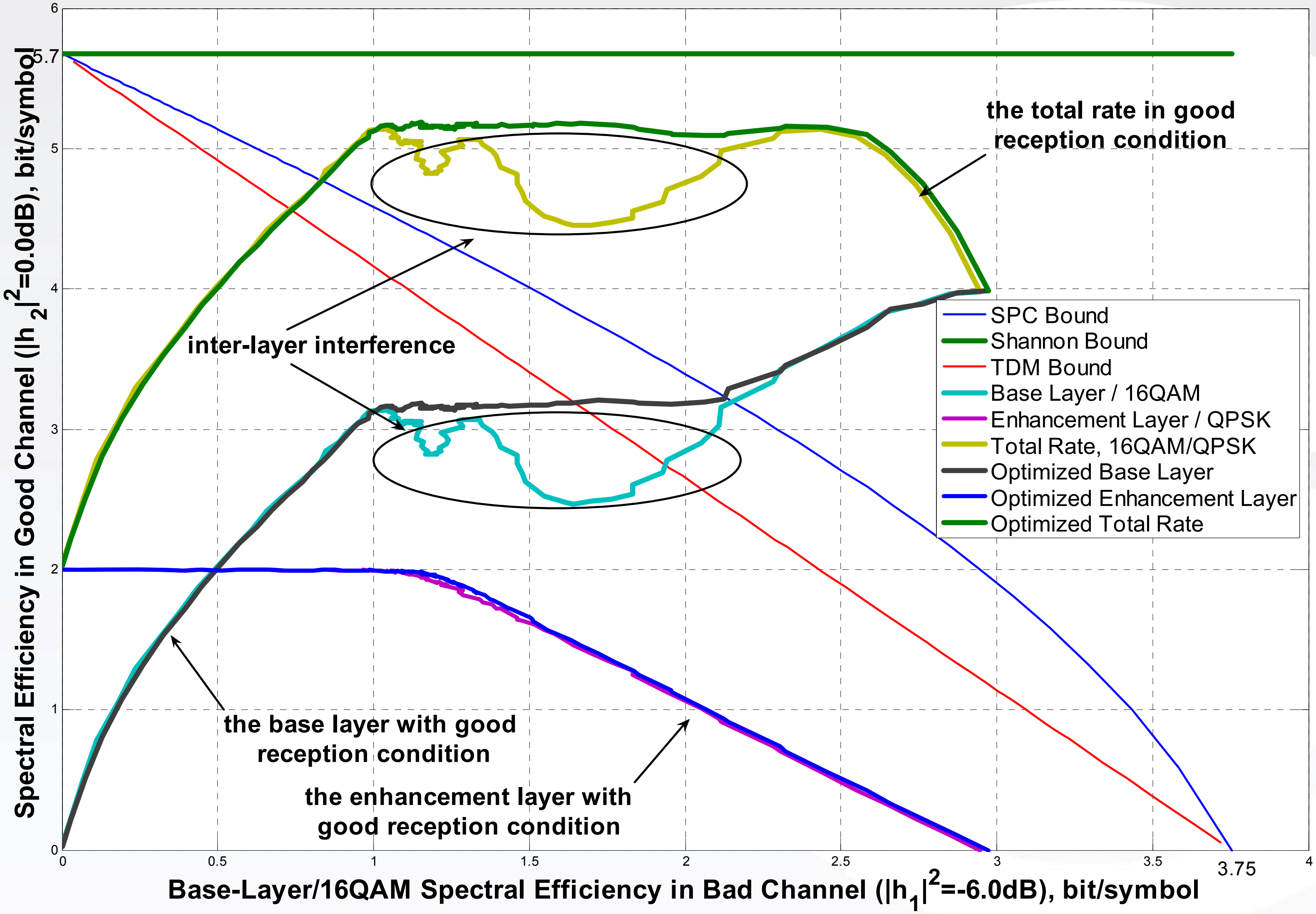
Achievable Gains (2/2)



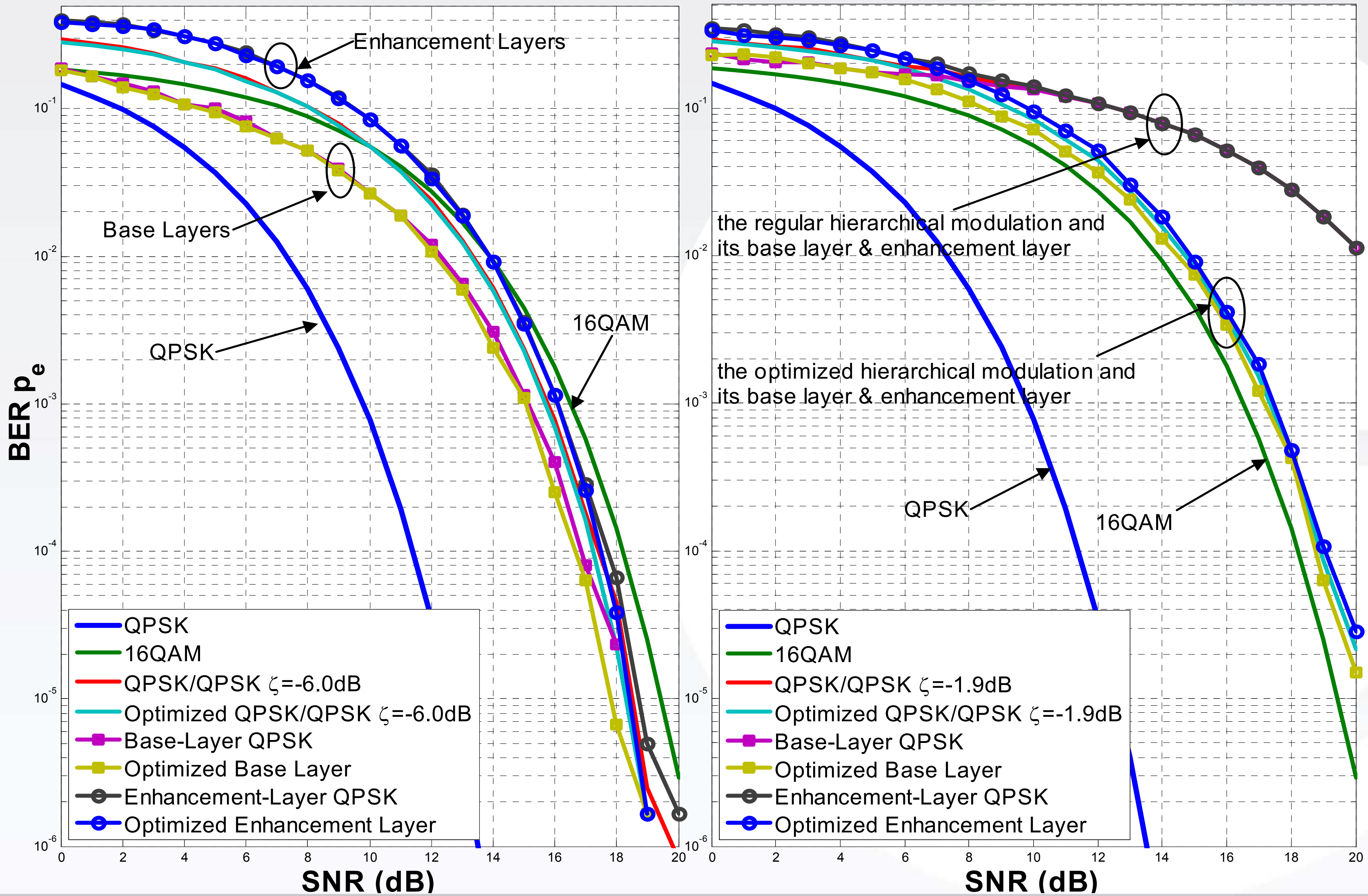
Achievable Rates: 16QAM/QPSK



Constrained Throughput of Hierarchical Modulations



Inter-Layer Interference



Effective Signal-to-Noise Ratio

- Effective SNR γ_{eff} is defined as the SNR necessitated when the base layer signal is sent alone with the same power.
  - Effective SNR always is less than the actual SNR.
  - The required symbol energy for achieving the same BER is called effective power, which is smaller than actual base-layer signal power.
  - For example, For QPSK/QPSK hierarchical modulation, the effective SNR of base-layer BER p_e is given by

$$\gamma_{\text{eff}}\left(\sigma^2\right) = \frac{\varepsilon_{\text{eff}}\left(\sigma^2\right)}{\sigma^2} = \mathrm{P}_{\text{QPSK}}^{-1}\left(p_e\right) \leq \gamma = \frac{\varepsilon_{\text{base}}}{\sigma^2}$$

Due to inter-layer interference, effective SNR or effective power is less than actual SNR or power. Stronger inter-layer interference is and smaller effective SNR/power becomes

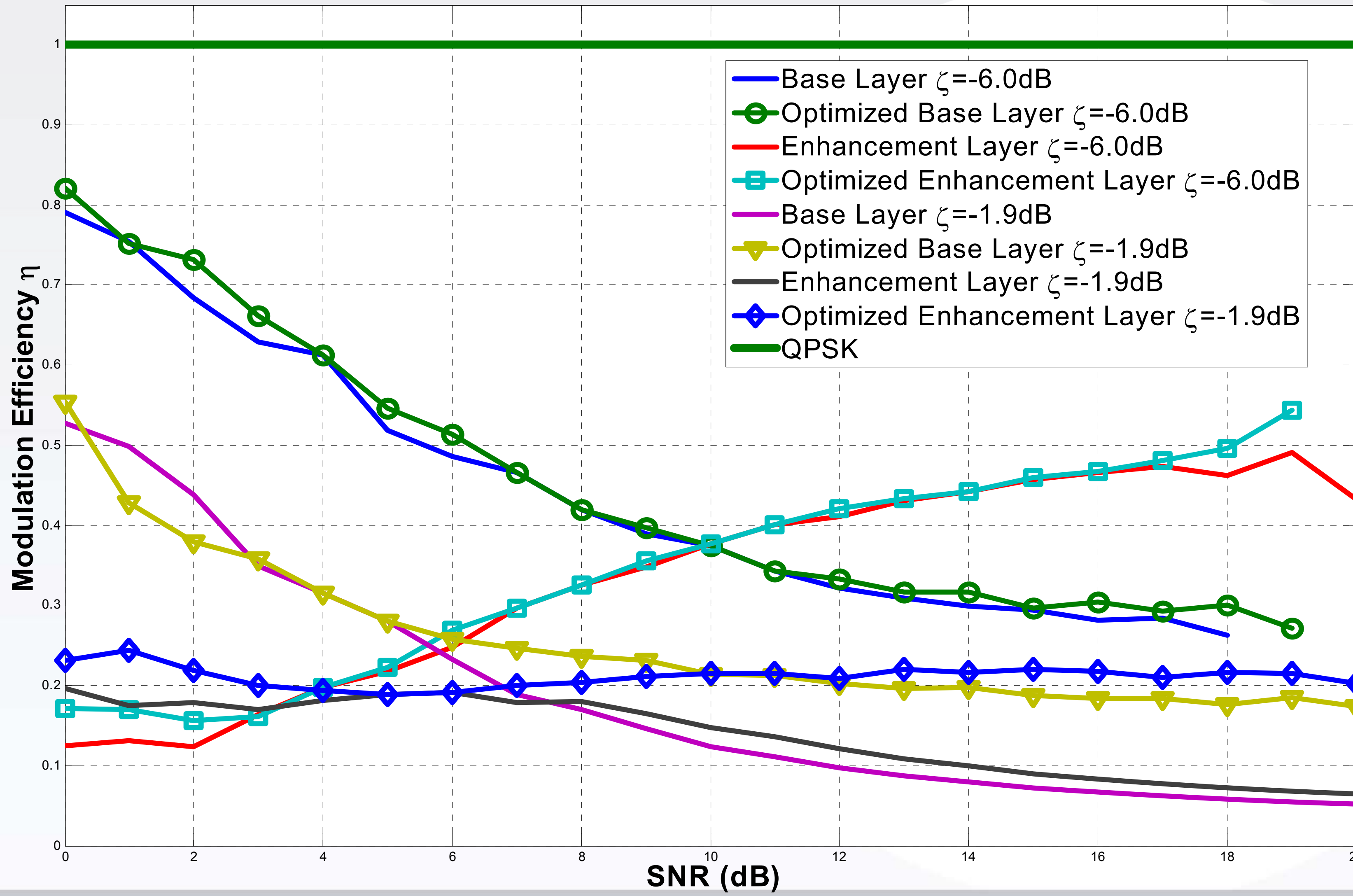
Modulation Efficiency (1/2)

$$\eta = \gamma_{\text{eff}} \frac{\sigma^2}{\varepsilon_{\text{base}}} = \frac{\varepsilon_{\text{eff}}\left(\sigma^2\right)}{\varepsilon_{\text{base}}}$$

$$\eta_{\infty} = \lim_{\sigma^2 \to 0} \eta$$

- Modulation efficiency of a modulated signal is defined by the ratio between effective SNR and actual SNR.
- Modulation efficiency is not greater than 1.
- Modulation efficiency, as well as effective SNR and effective power, is the parameter proposed by us for evaluating the performance of the whole transceiver chain, including modulation and demodulation.
- Asymptotic modulation efficiency is the ratio when the SNR becomes very large and interference becomes dominant.
- Asymptotic modulation efficiency is proposed by us for evaluating the interference resistance capability of both hierarchical modulation scheme and demodulation scheme.

Modulation Efficiency (2/2)



PEP and Minimum Euclid Distance

- A upper bound for pairwise error probability (PEP) can be derived with assuming
  - The Hamming distance is d << K: two codeword c and c' differ in d bits.
  - Perfect interleaving.

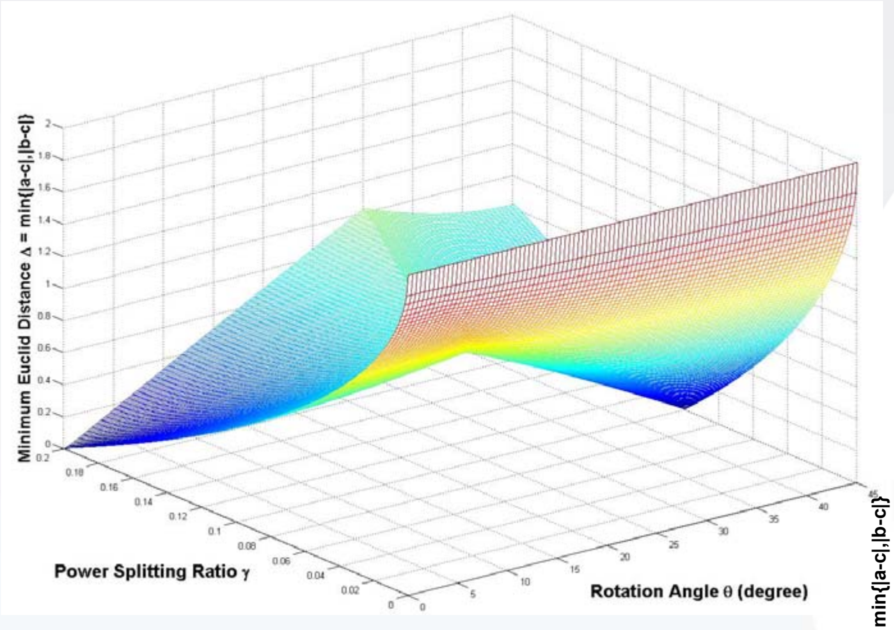
pairwise error probability

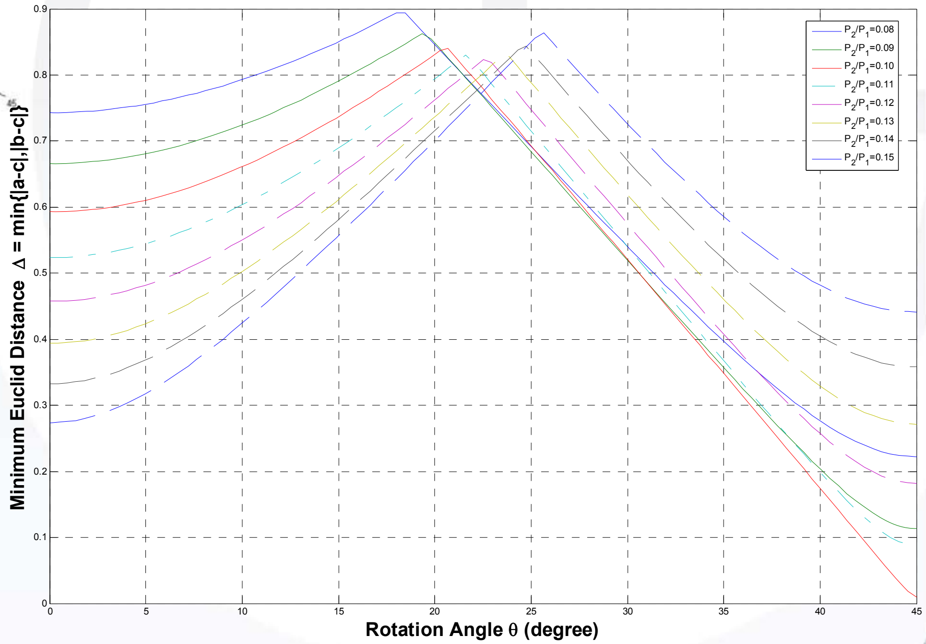
Minimum Euclid distance

$$\Pr\{\mathbf{c} \to \mathbf{c}' \mid \mathbf{c}\} = Q\left(\frac{1}{\sqrt{2}\sigma} \sum_{i=1}^{d} \left\| \mathbf{s}_{k_i} - \mathbf{s}'_{k_i} \right\|^2 \right) \le \prod_{i=1}^{d} e^{-\frac{1}{4\sigma^2}\left\| \mathbf{s}_i - \mathbf{s}'_i \right\|^2} \le e^{-\frac{d}{4\sigma^2}\Delta_{\min}^2}$$

Observation: PEP is dominated by the terms with the smallest squared Euclid distance in high SNR region

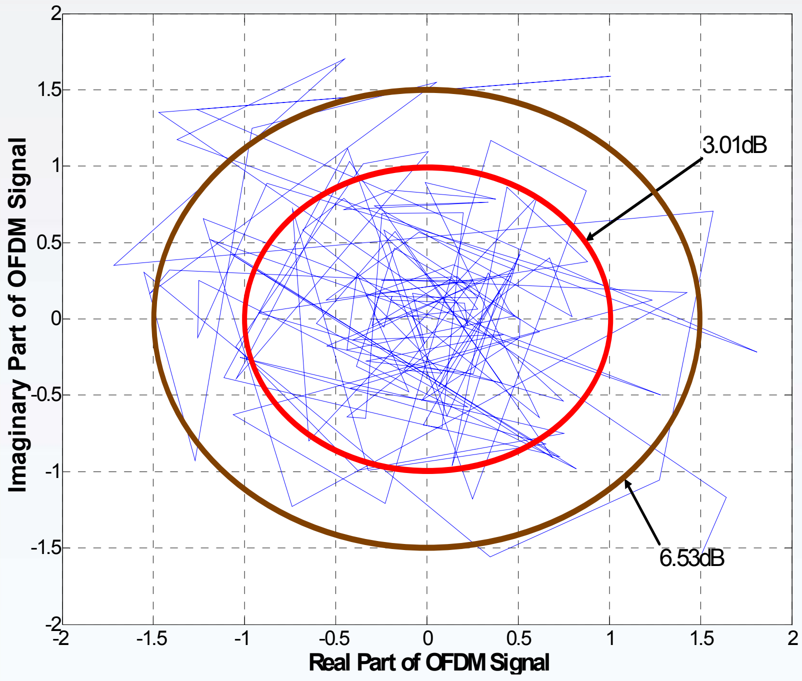
Minimum Euclid Distance: QPSK/16QAM

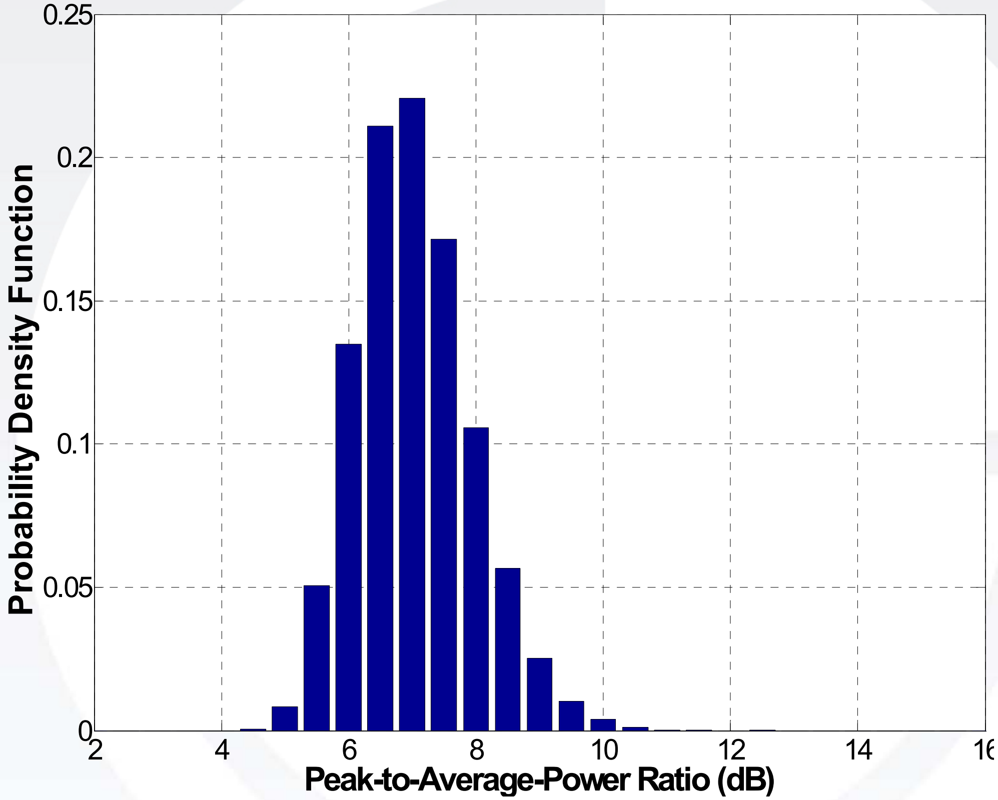




PAPR of OFDM

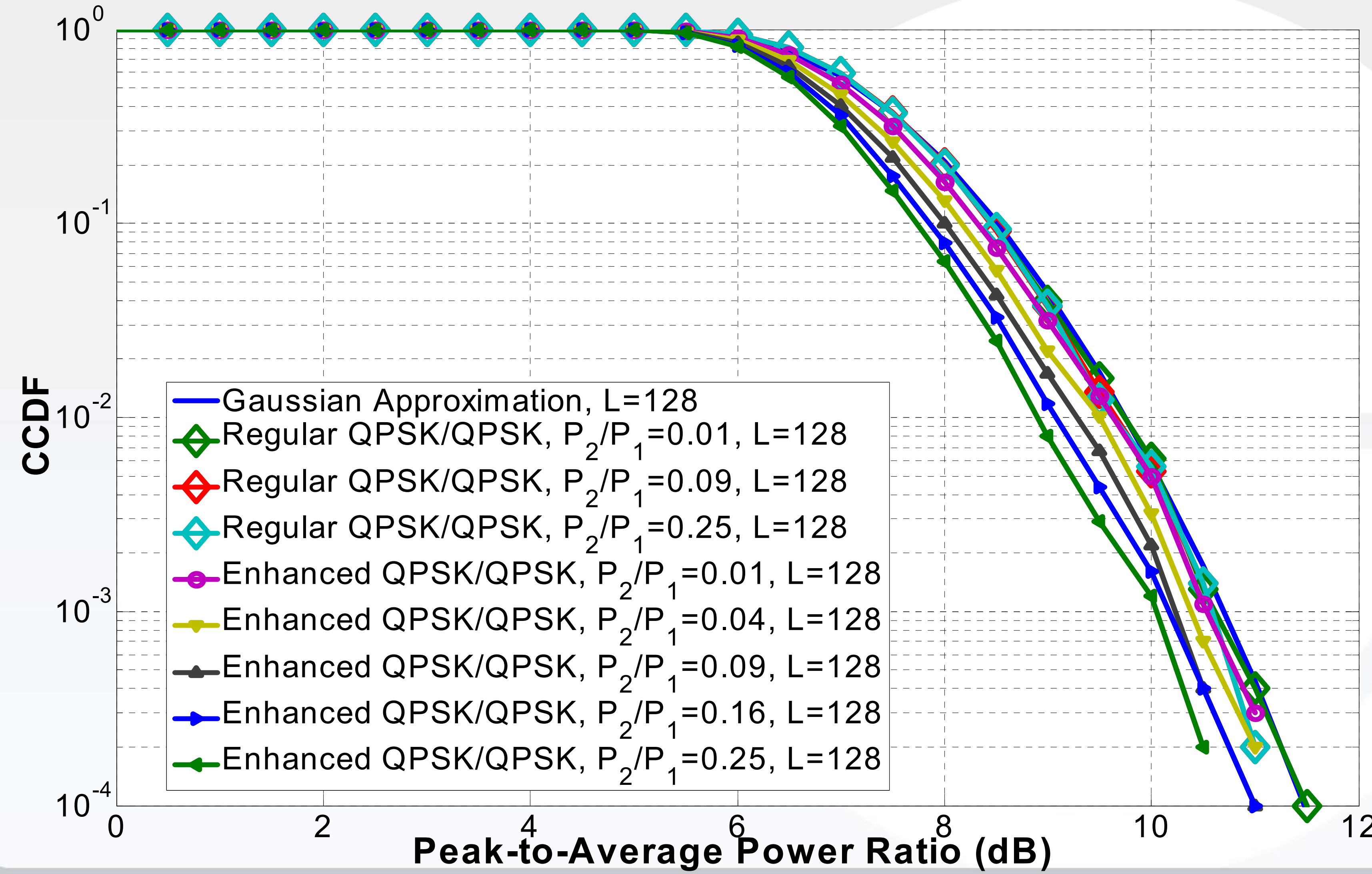
$$PAPR = \frac{\max|s(t)|^2}{E|s(t)|^2} \approx O(L)$$



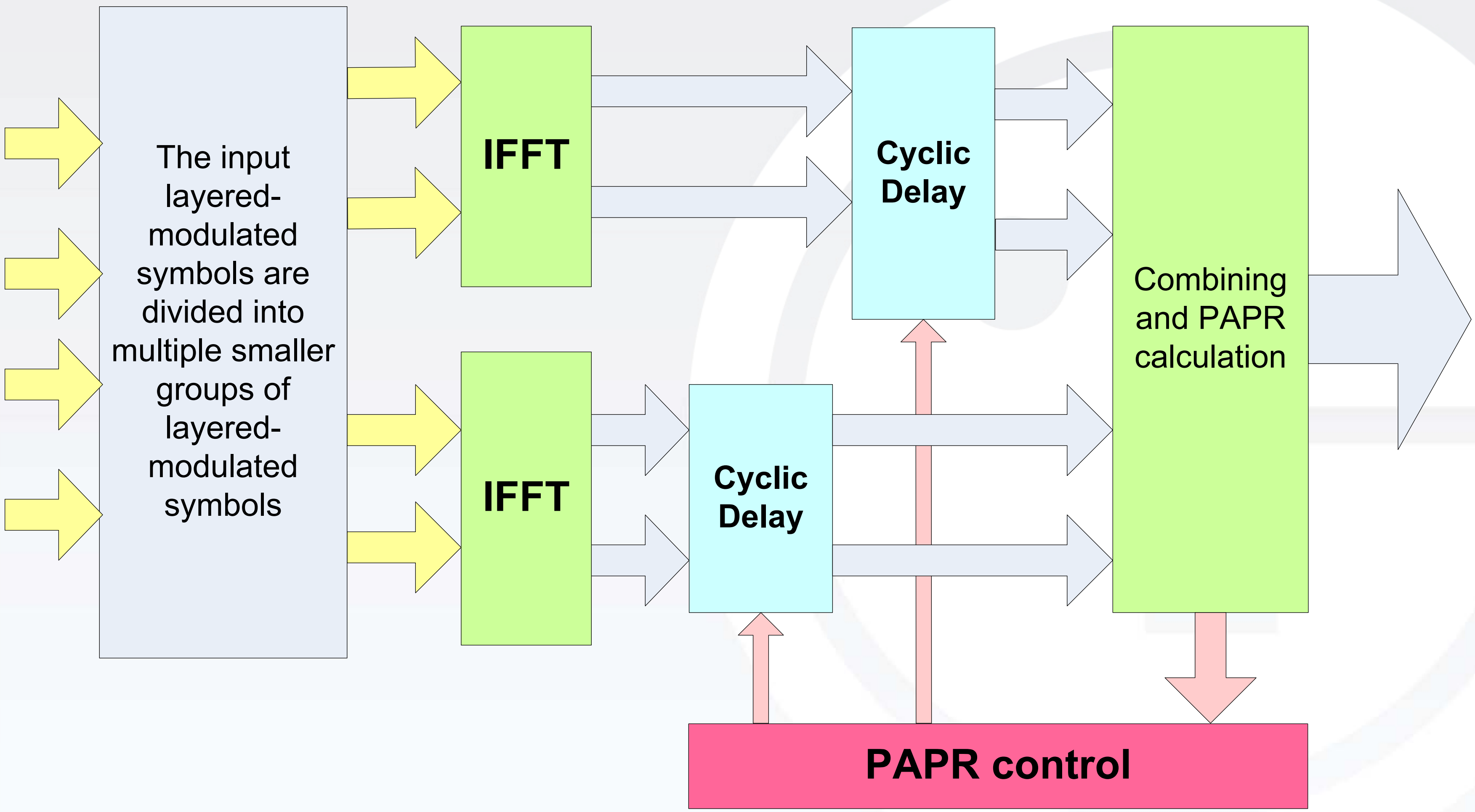


8PSK, L=128

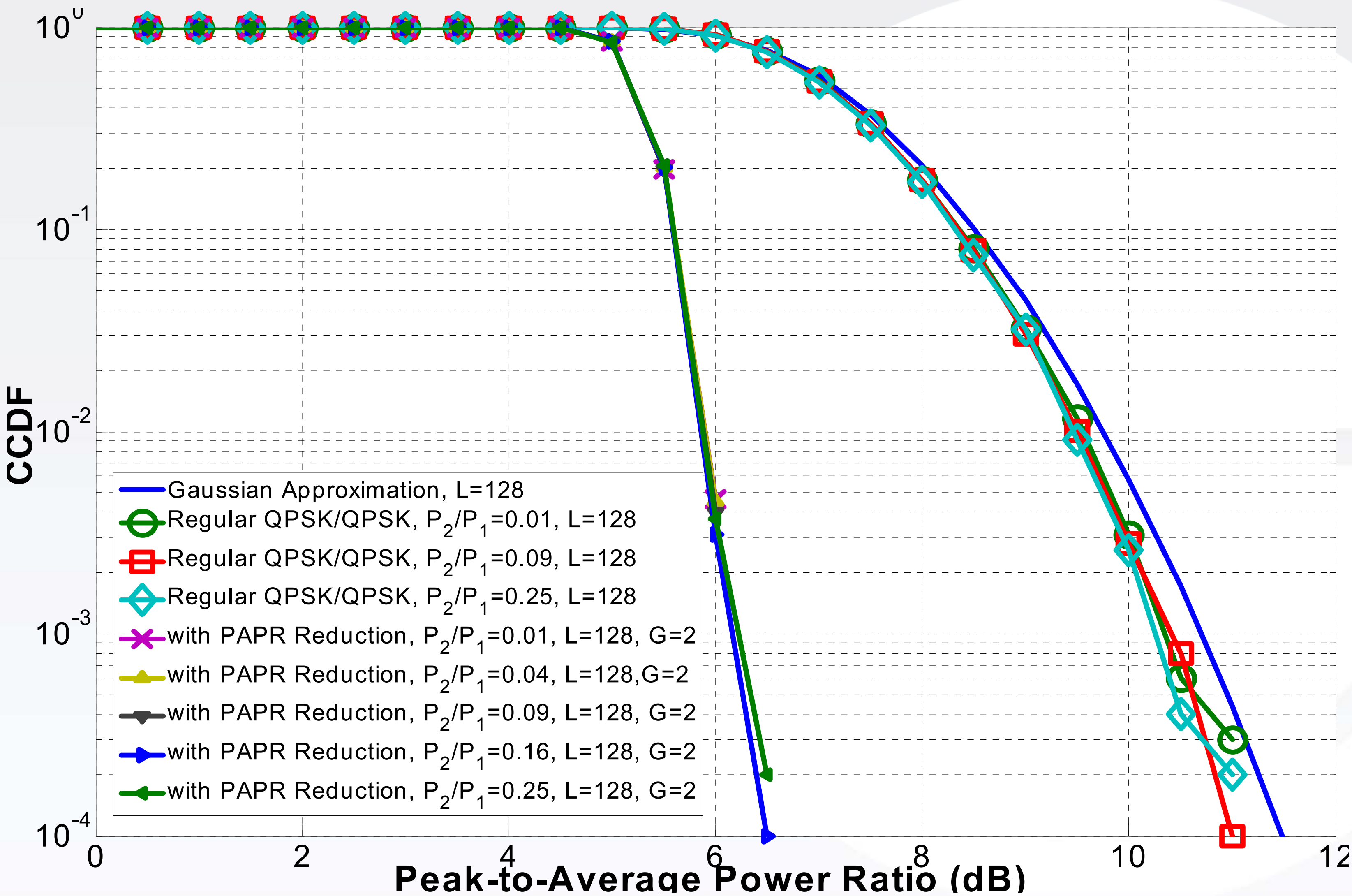
Hierarchical Modulation with Rotation



PAPR Reduction with Group-Based Cyclic Delay (1/2)



PAPR Reduction with Group-Based Cyclic Delay (2/2)



Conclusions

- Hierarchical modulation has been adopted in various standards including MediaFLO, DVB-H and UMB.
- The enhance hierarchical modulation is adopted in UMB, the salient features of which include
  - minimum modulation/demodulation complexity increase.
  - high bps: channel capacity gain on lower layer(s)
  - lower BER: signal processing gain.
- The enhanced hierarchical modulation is investigated in terms of
  - achievable throughputs
  - inter-layer interference
  - asymptotic modulation efficiency
  - peak-to-average power ratio
- The enhanced hierarchical modulation is recommended for the next-generation standards.

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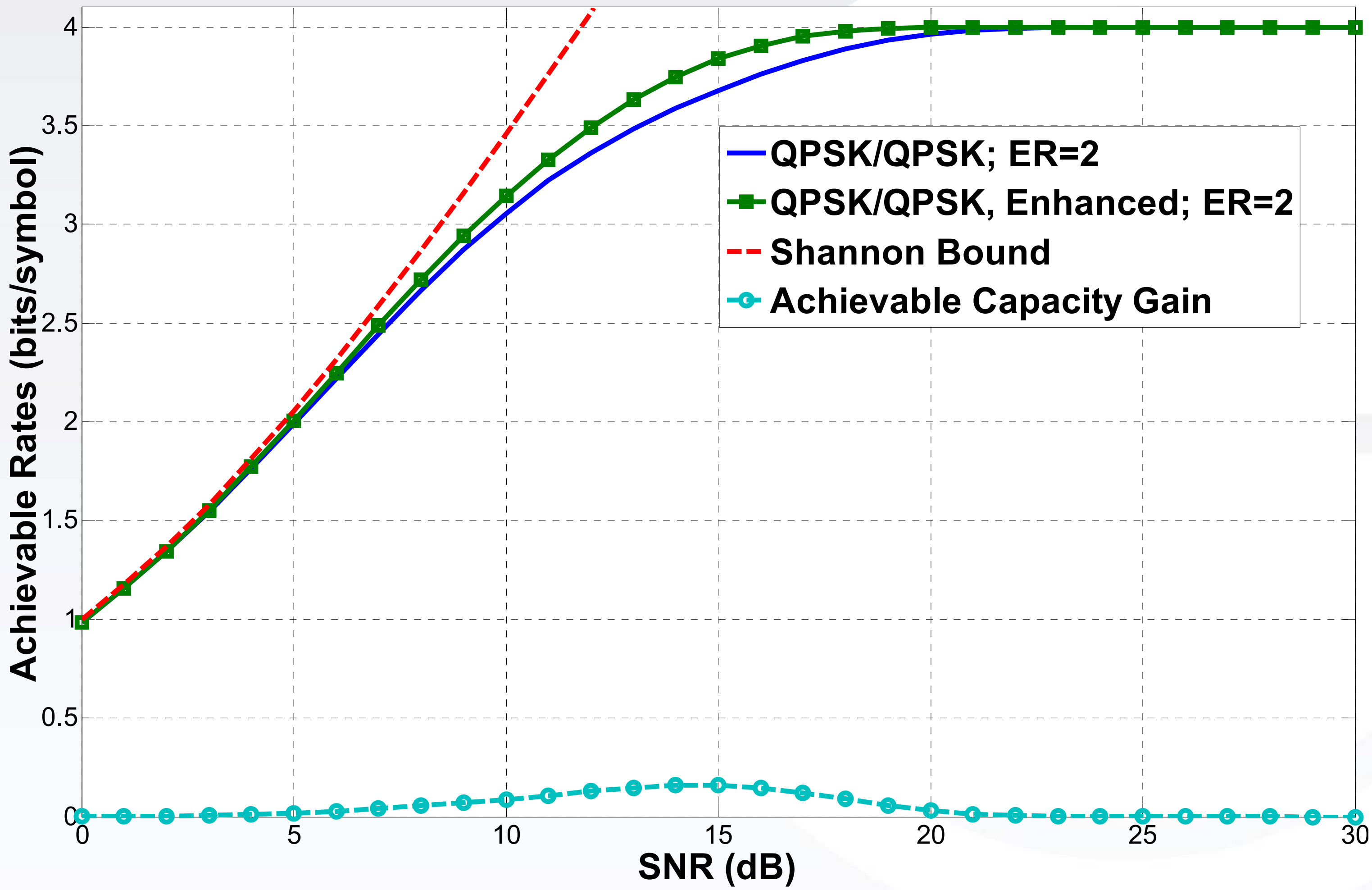
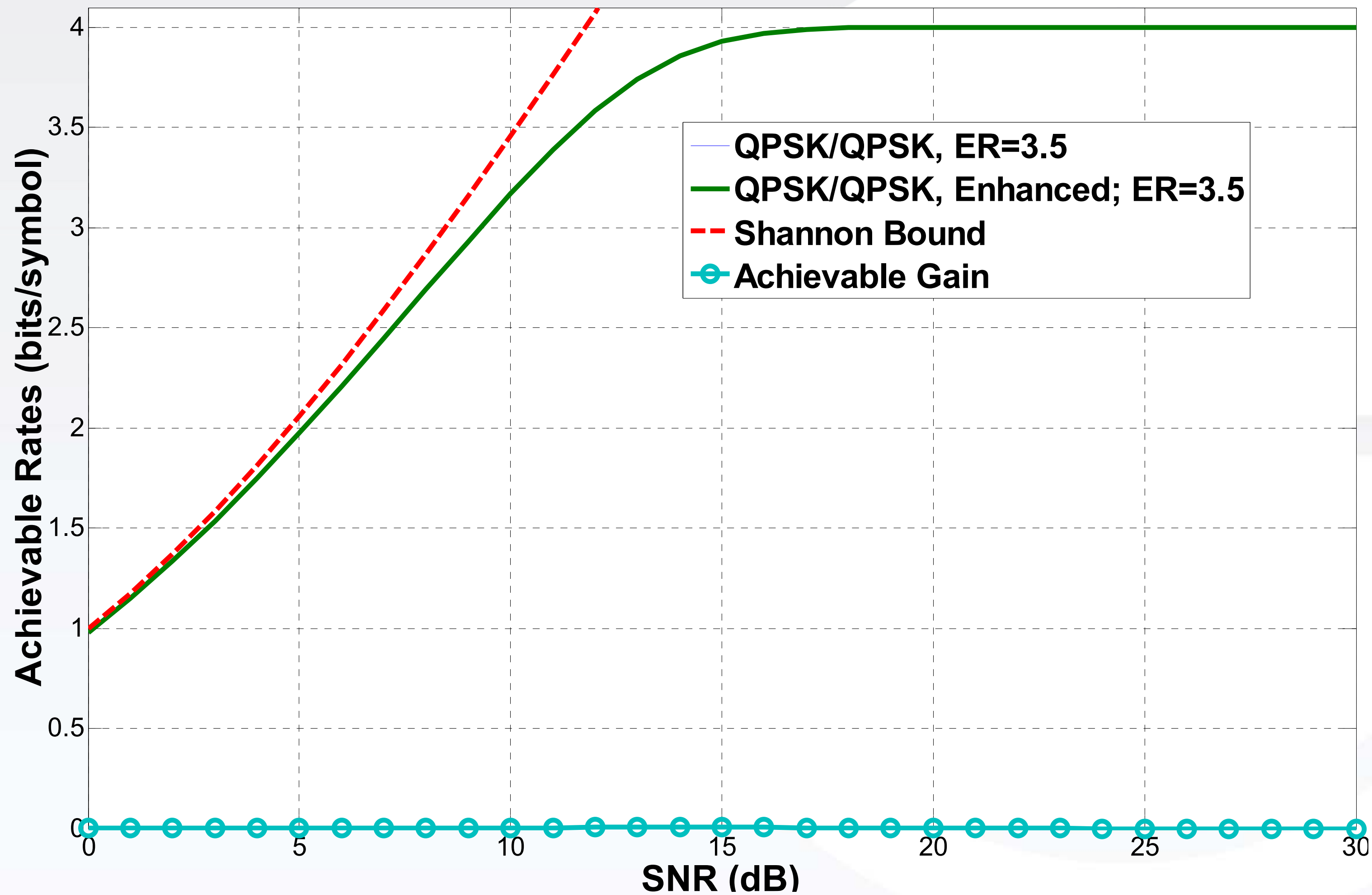
Appendix

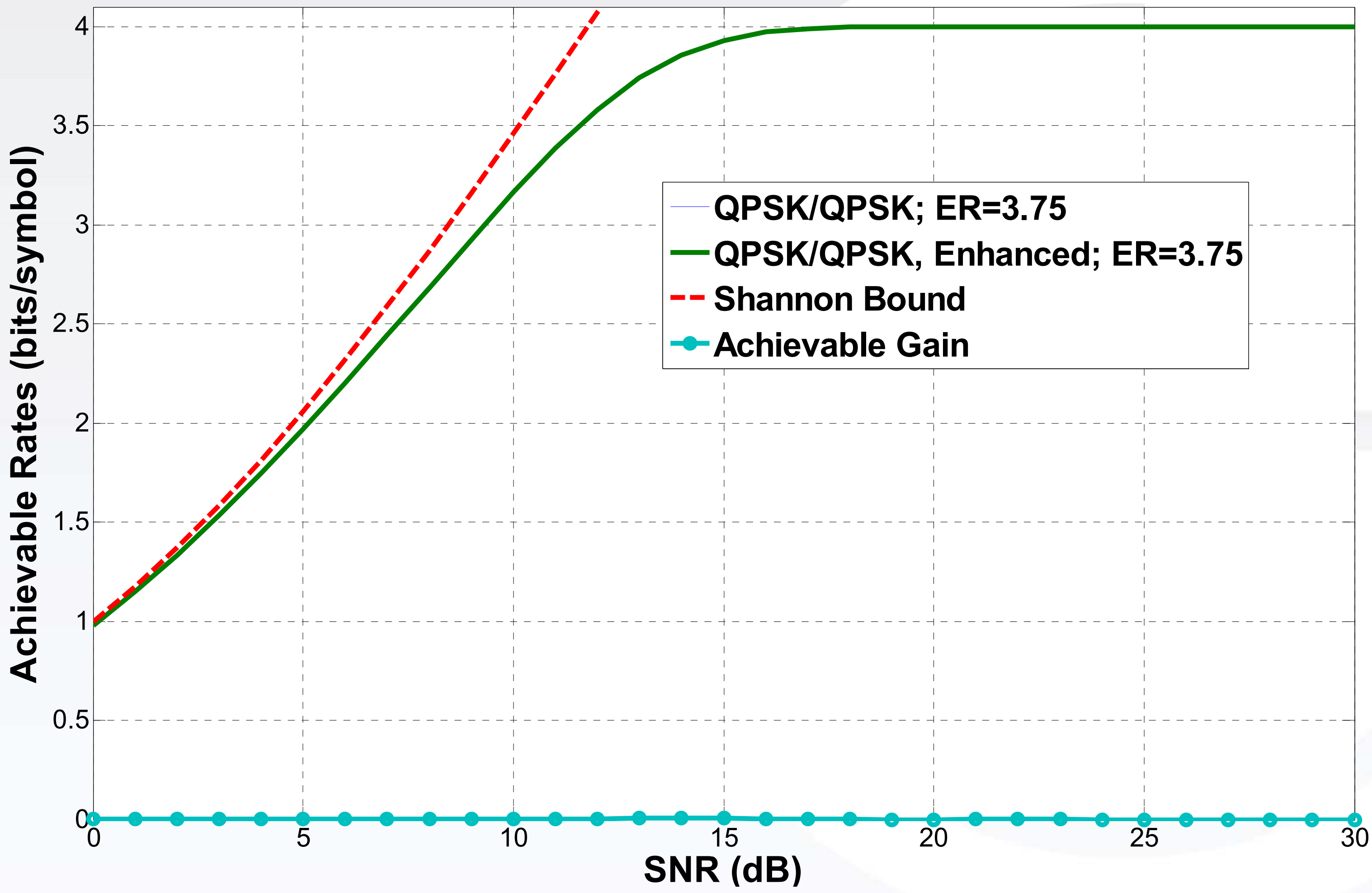


Achievable Rates (bits/symbol)
SNR (dB)
QPSK/QPSK; ER=2
QPSK/QPSK, Enhanced; ER=2
Shannon Bound
Achievable Capacity Gain
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30

Achievable Rates for QPSK/QPSK, ER=3.5



Achievable Rates for QPSK/QPSK: ER=3.75



Achievable Rates for QPSK/QPSK, ER=4