

Enhanced Hierarchical Modulation for IEEE 802.16m

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For discussion and approval by TGM

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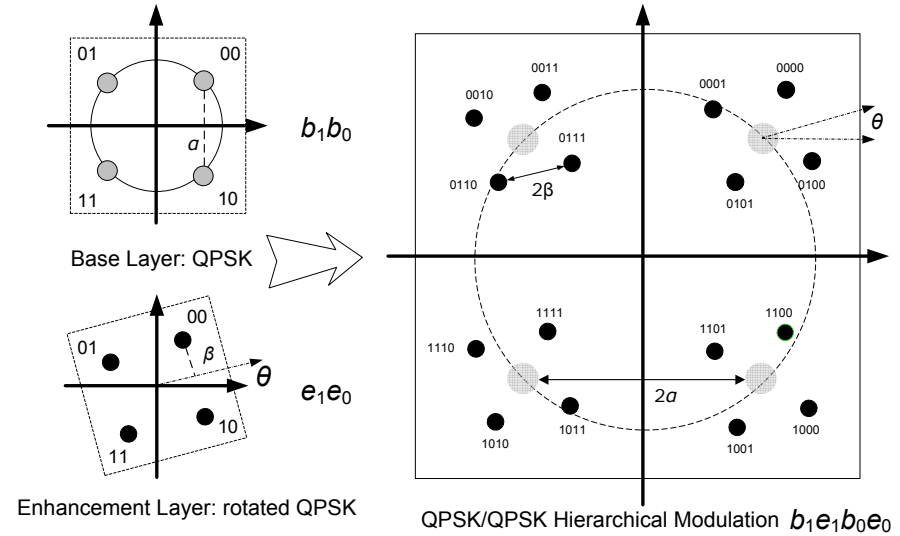
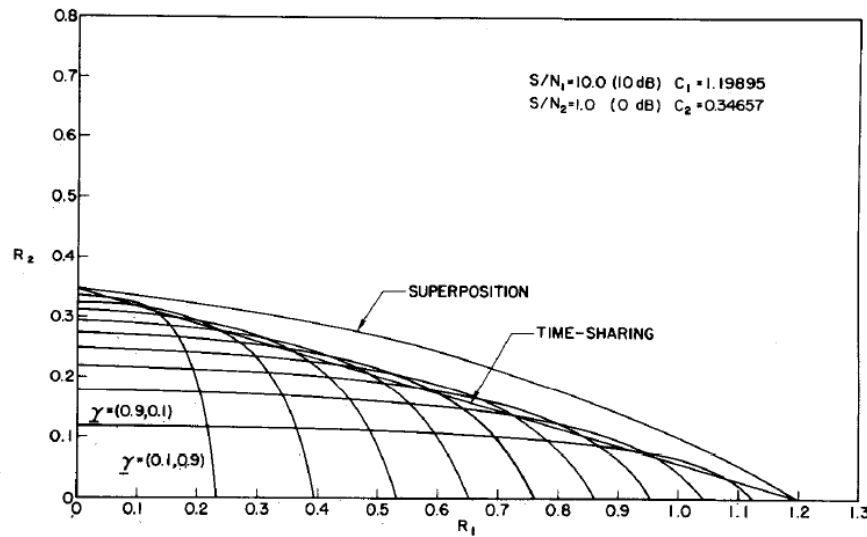
<<http://standards.ieee.org/guides/bylaws/sect6-7.html#6>> and <<http://standards.ieee.org/guides/opman/sect6.html#6.3>>.

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Introduction

- Hierarchical modulations are used for digital broadcast system design as well as multiuser access multiplexing
 - Dedicated network: DVB-T, Media-FLO, UMB-BCMCS.
 - Hierarchical network: DVB Multiplexing.
- Hierarchical modulations can help
 - provide different QoS or UEP to users with different profiles, e.g. higher throughput for users with advanced receiver,
 - multiplexing users in a high efficient way,
 - upgrade 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.

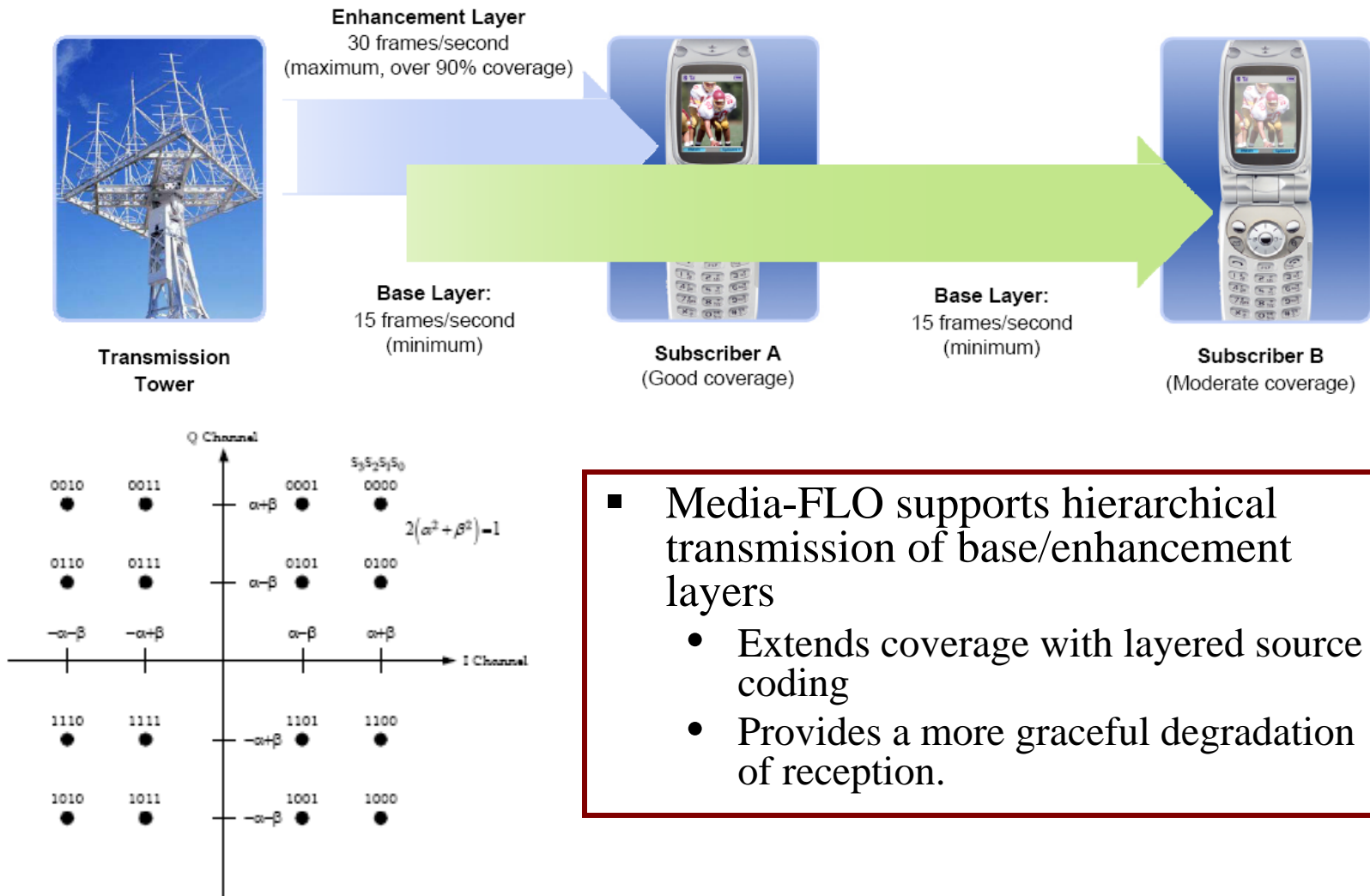
Superposition Precoding and Hierarchical Modulation



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.

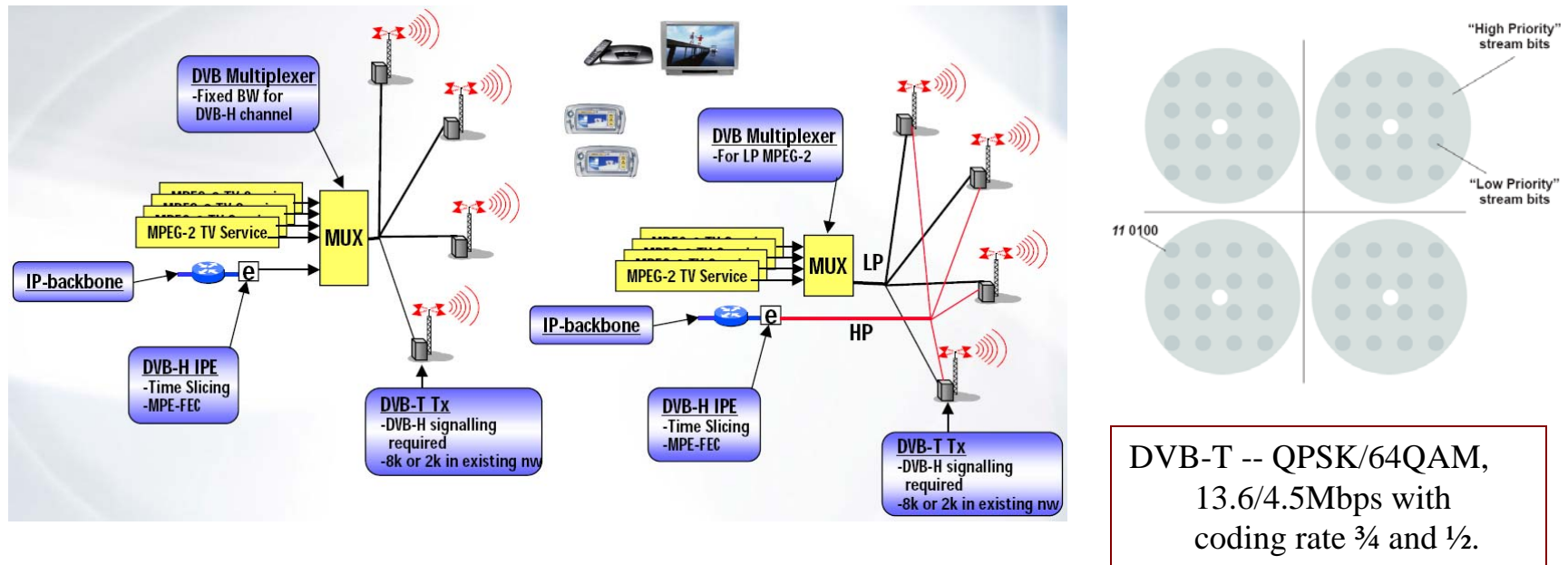
Hierarchical Modulation in Standards (1/2)



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

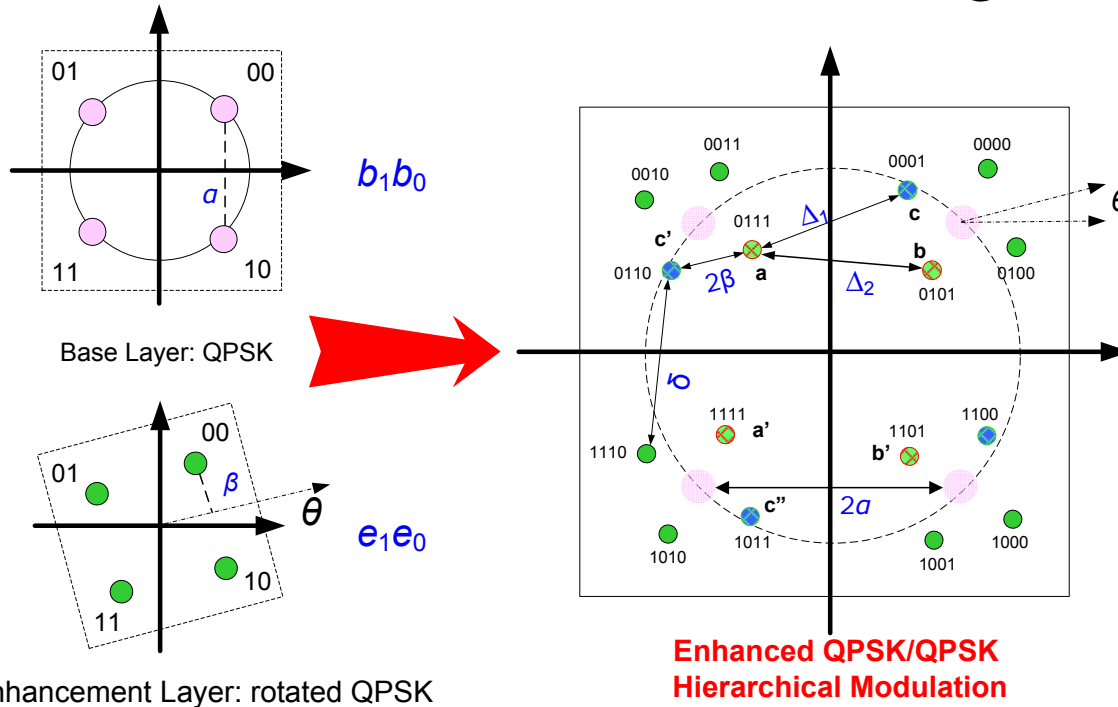
Hierarchical Modulation in Standards (2/2)

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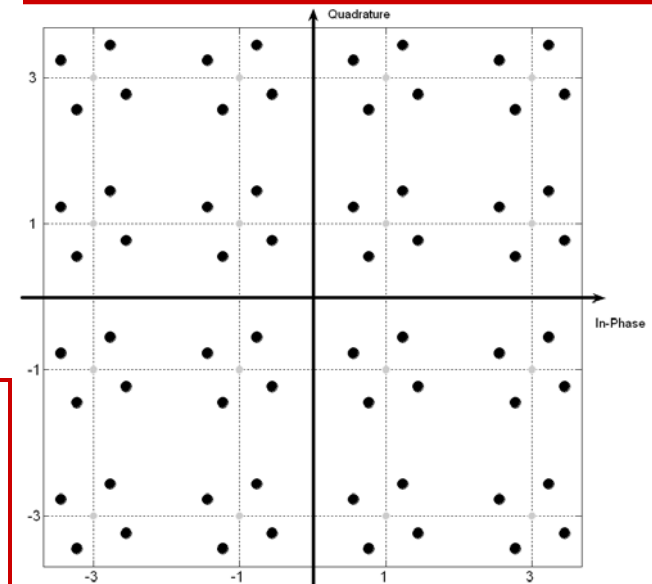


- Besides using a dedicated DVB-H network, DVB-H service can also be embedded into DVB-T network using hierarchical modulation.
 - DVB-H service use the HP input while DVB-T services use LP.
 - The HP input can offer increased robustness in mobile environment over the LP input
 - The LP input can serve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

Enhanced Hierarchical Signal Constellation



- 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

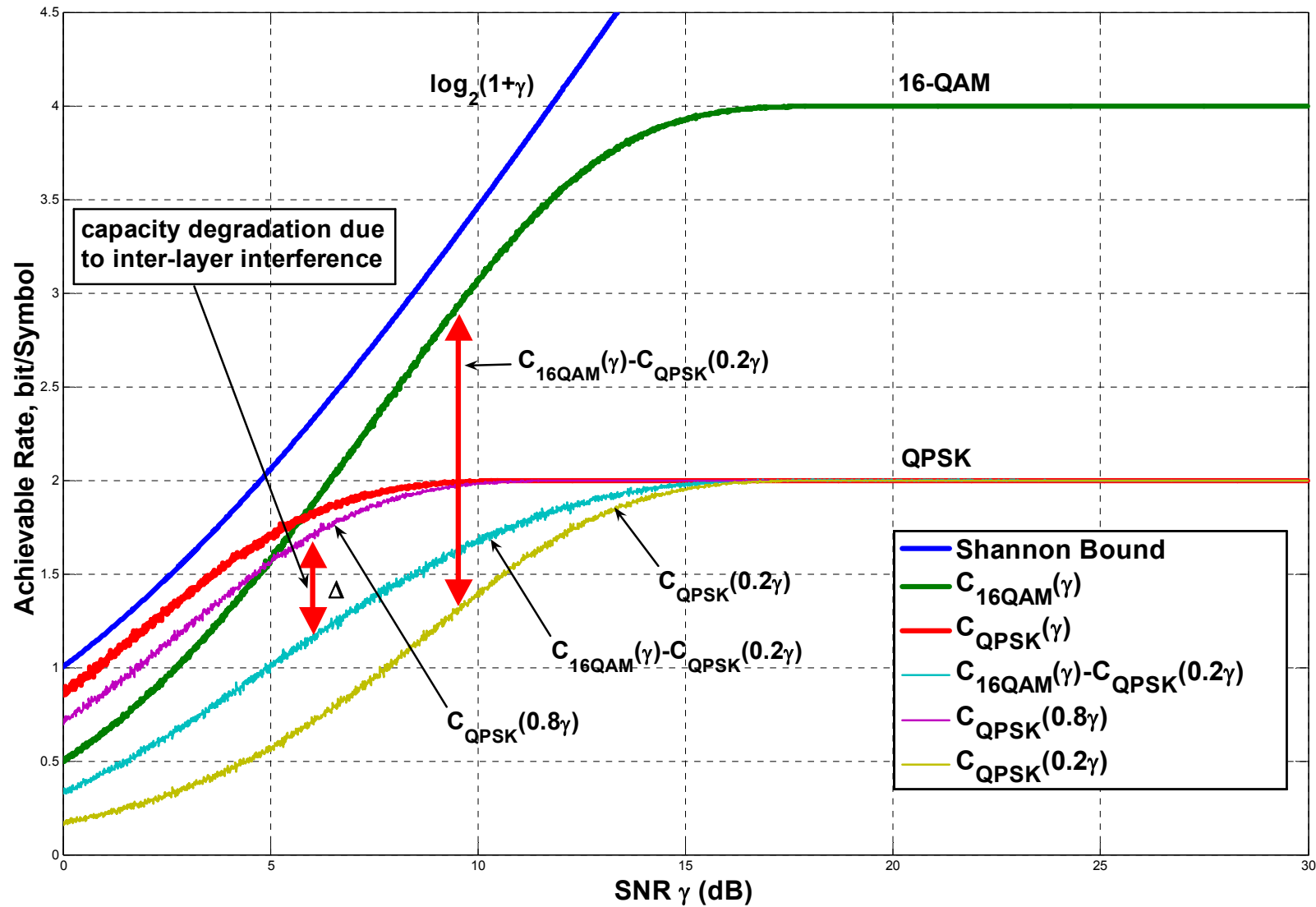
- The capacity of a general N-ary modulation can be written by

Signal Constellation and Euclid Distances Profile

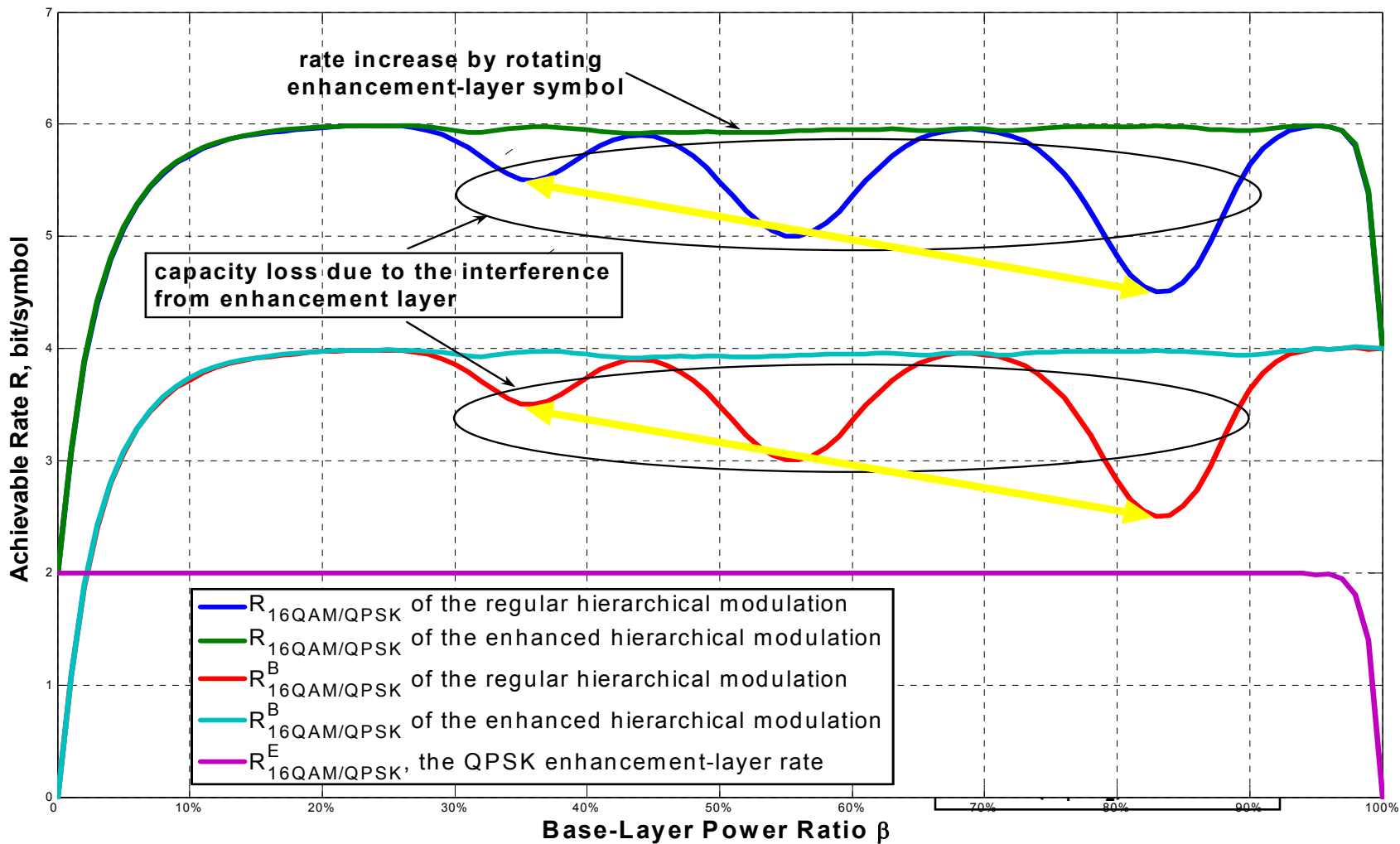
$$C_N = \log_2(N) - \frac{1}{N} \sum_{j=0}^{N-1} E \left\{ \log_2 \left[\sum_{i=0}^{N-1} \exp \left(-\frac{|s_j + n - s_i|^2 + |n|^2}{2\sigma^2} \right) \right] \right\}$$

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

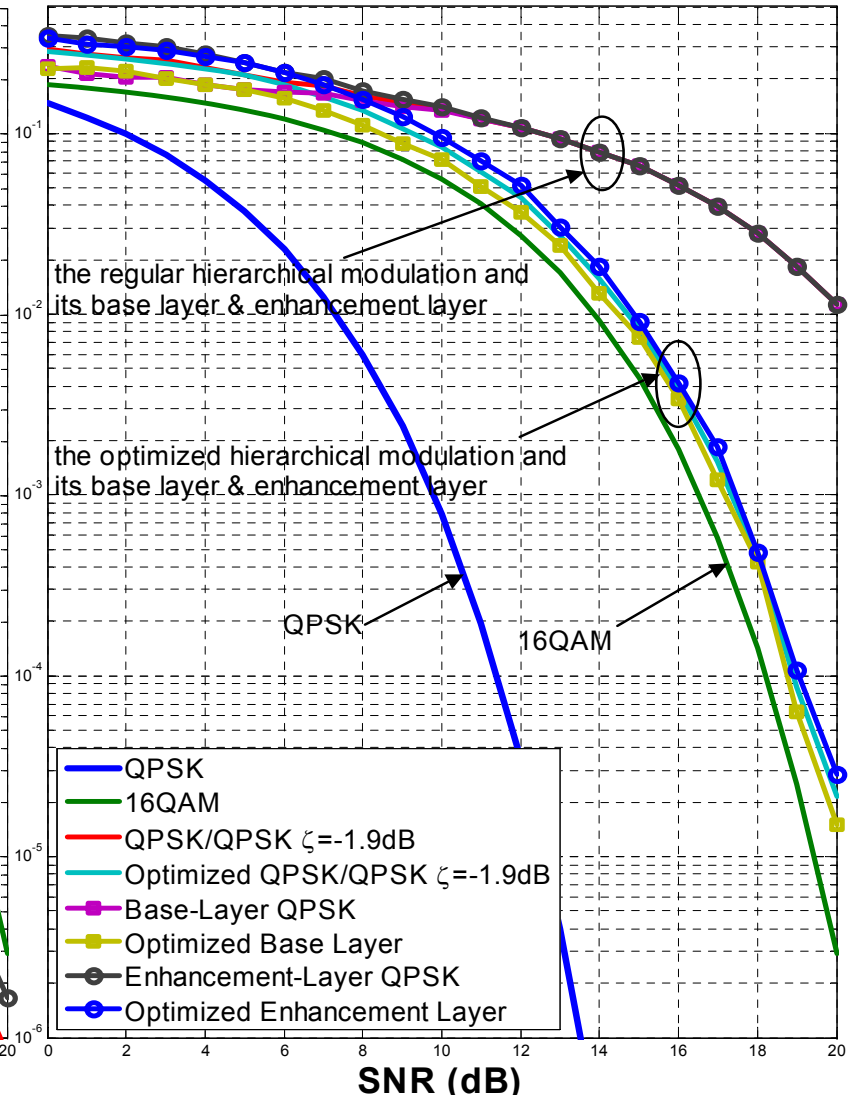
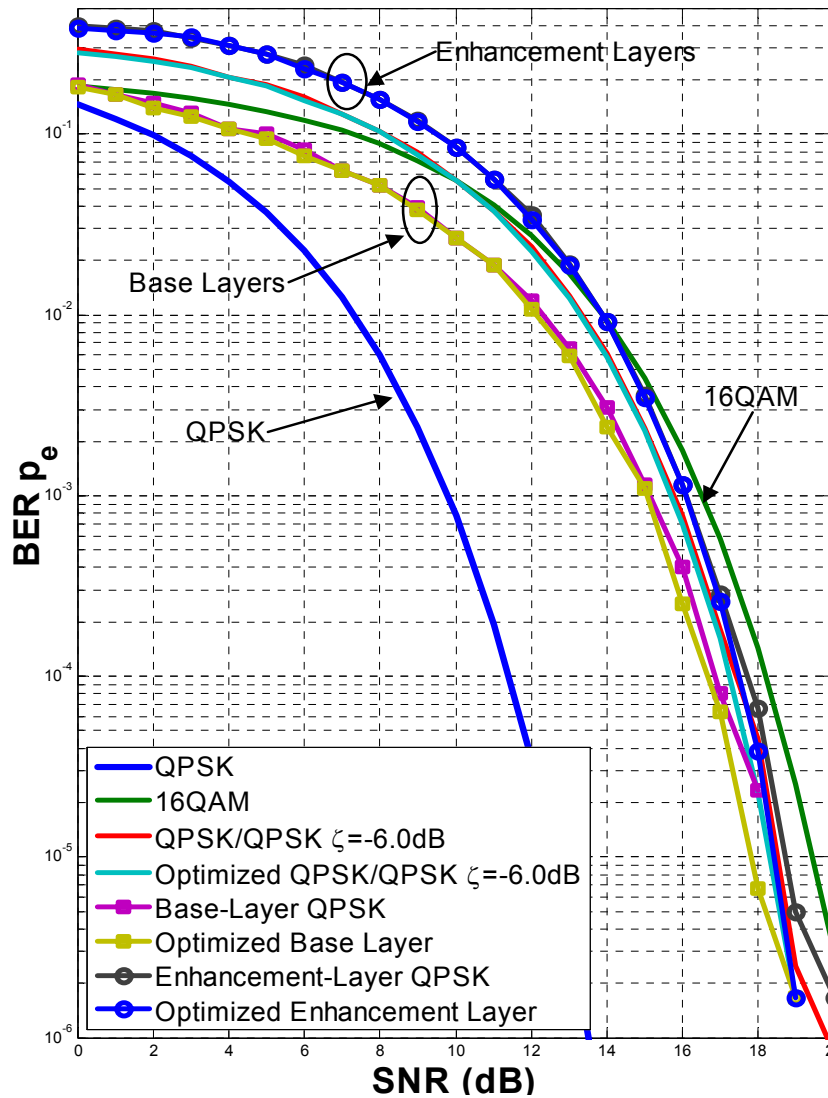
16QAM: Hierarchical Modulation Perspective



Achievable Rates: 16QAM/QPSK



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

$$\gamma_{\text{eff}}(\sigma^2) = \frac{\varepsilon_{\text{eff}}(\sigma^2)}{\sigma^2} = P_{\text{QPSK}}^{-1}(p_e) \leq \gamma = \frac{\varepsilon_{\text{base}}}{\sigma^2}$$

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

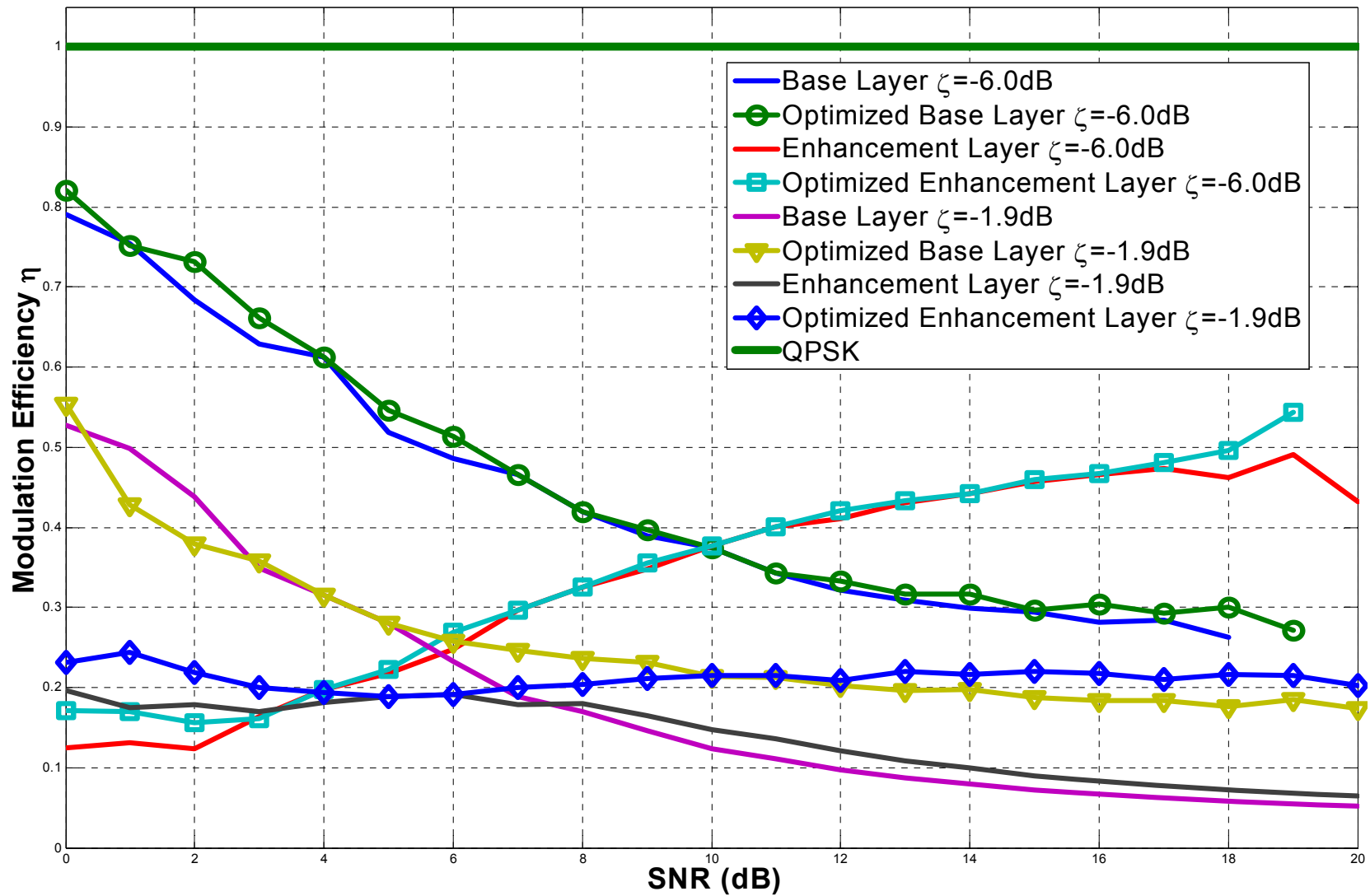
Modulation Efficiency (1/2)

$$\eta = \gamma_{\text{eff}} \frac{\sigma^2}{\mathcal{E}_{\text{base}}} = \frac{\mathcal{E}_{\text{eff}}(\sigma^2)}{\mathcal{E}_{\text{base}}}$$

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

- **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 $d \ll K$: two codeword \mathbf{c} and \mathbf{c}' differ in d bits.
 - Perfect interleaving.

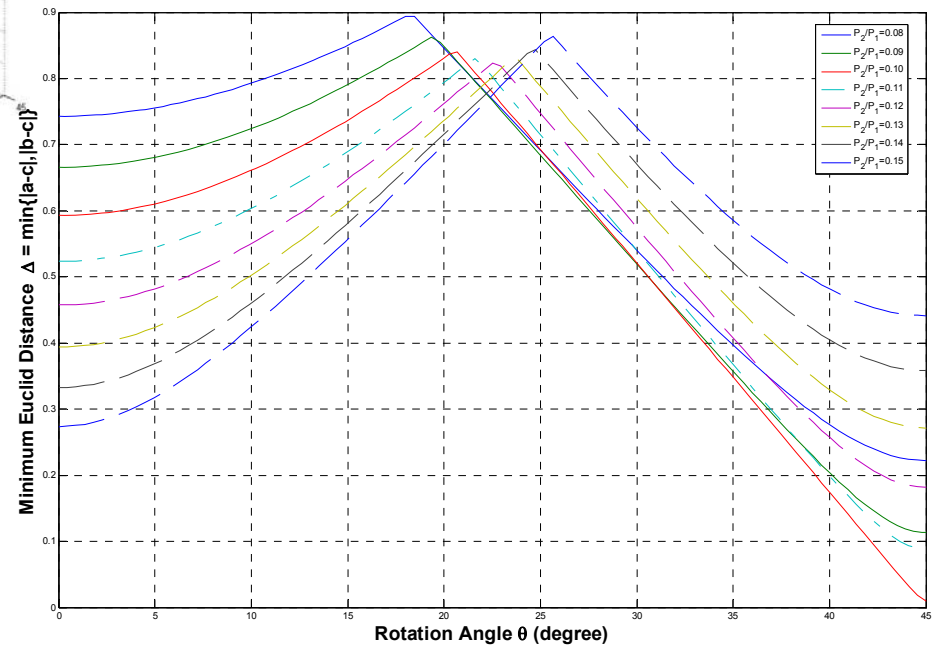
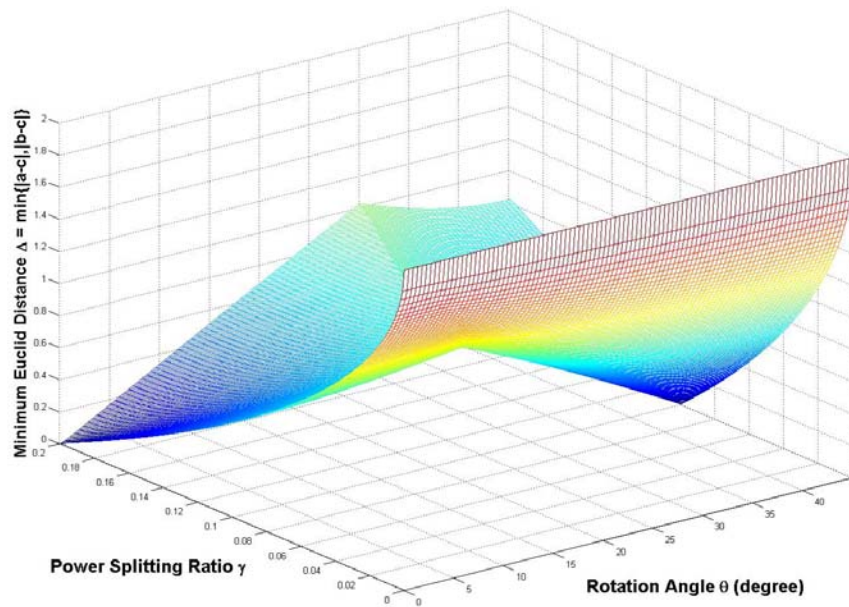
pairwise error probability

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

Minimum Euclid distance

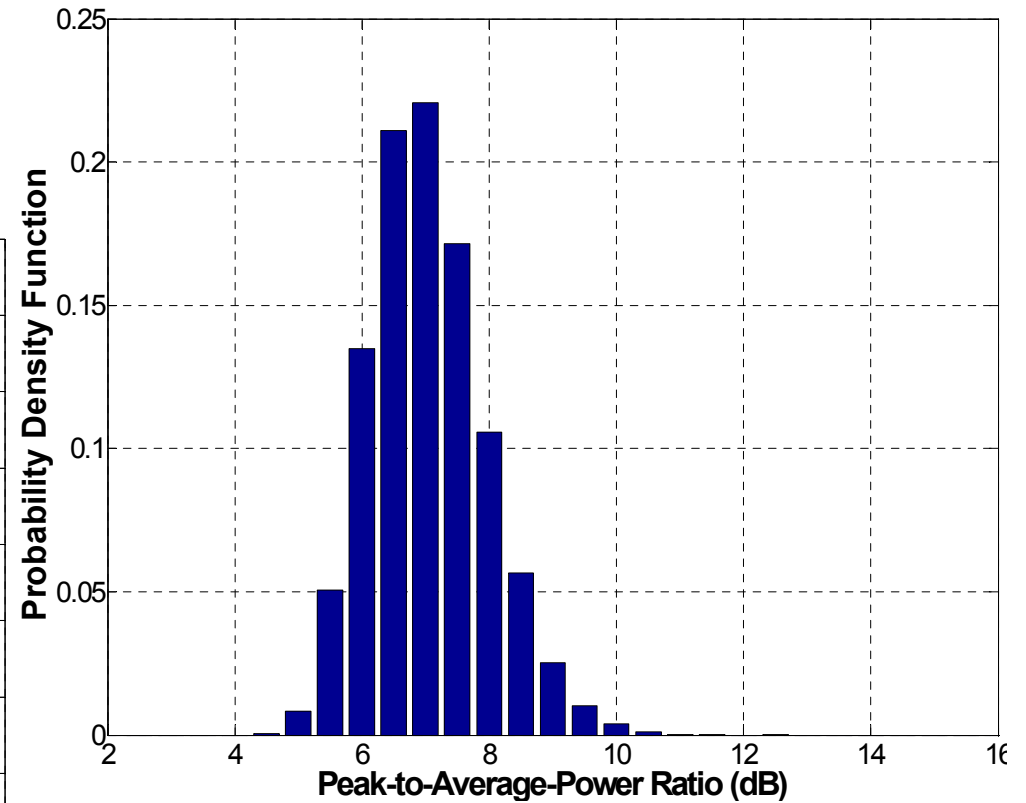
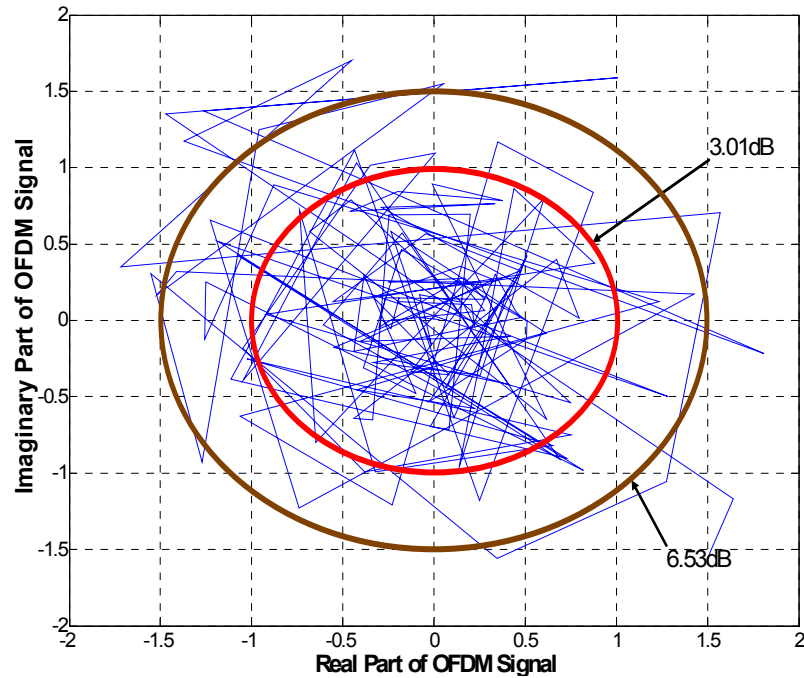
Observation: PEP is dominated by the terms with the smallest squared Euclid distance in high SNR region

Minimum Euclid Distance: QPSK/16QAM



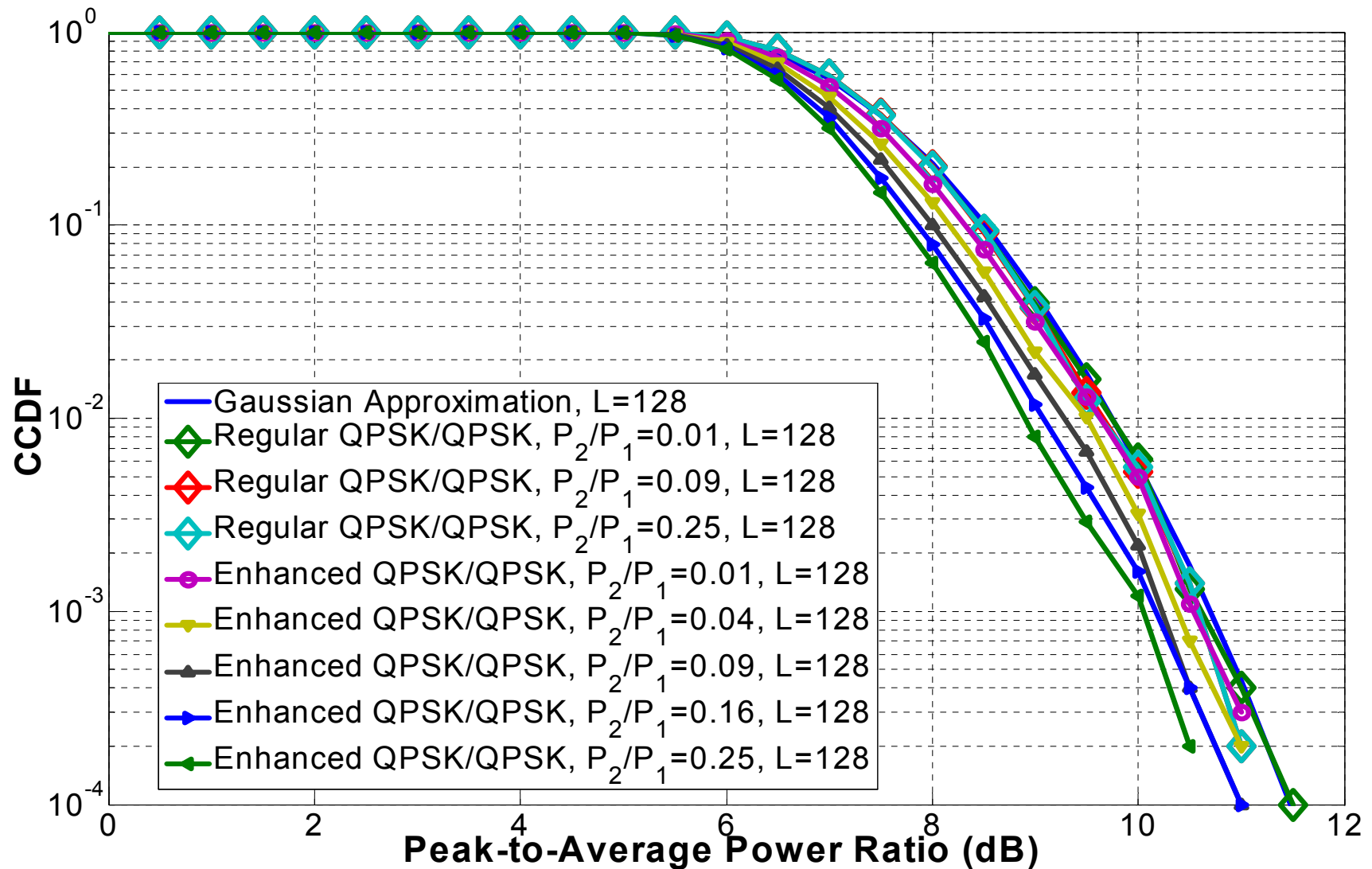
PAPR of OFDM

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



8PSK, L=128

Hierarchical Modulation with Rotation



Conclusions

- Hierarchical modulation has been adopted in various standards including MediaFLO, DVB-H and UMB.
- The enhanced 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 16m