Limit on Coding and Modulation Gains in Fiber-Optic Communication Systems

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Introduction

- A fundamental question for fiberoptic communication systems: "How close is the actual performance to the fundamental capacity limit?"
- The fiberoptic channels studied here are channels dominated by Amplified Spontaneous Emission Noise (ASEN), hereafter referred to as ASEN channels
- We extend the capacity formulae for Additive White Gaussian Noise (AWGN) channels to ASEN channels by taking into account two orthogonal polarizations
- Based on the evaluated capacities of ASEN channels, we discuss possible gains from different coding and modulation techniques

Definition of Channel Capacity

- Channel capacity is defined as

  $C = \lim_{T\to\infty} (\log_2 M) / T$ bits/s, where M is the number of different signal functions of duration T on the channel that can be reliably distinguished

- Claude Shannon derived the AWGN channel capacity as

$$\frac{C}{W} = \log_2\left(1 + \frac{C}{W}\frac{E_b}{N_0}\right)$$

  bits/s/Hz, where W is the channel bandwidth, and E_b/N_0 is the signal to noise ratio per information bit (SNR/bit)

- For ASEN channel capacity evaluation, we assume an ideal receiver detects a channel's full optical field rather than just the intensity

ASEN Channel vs. AWGN Channel

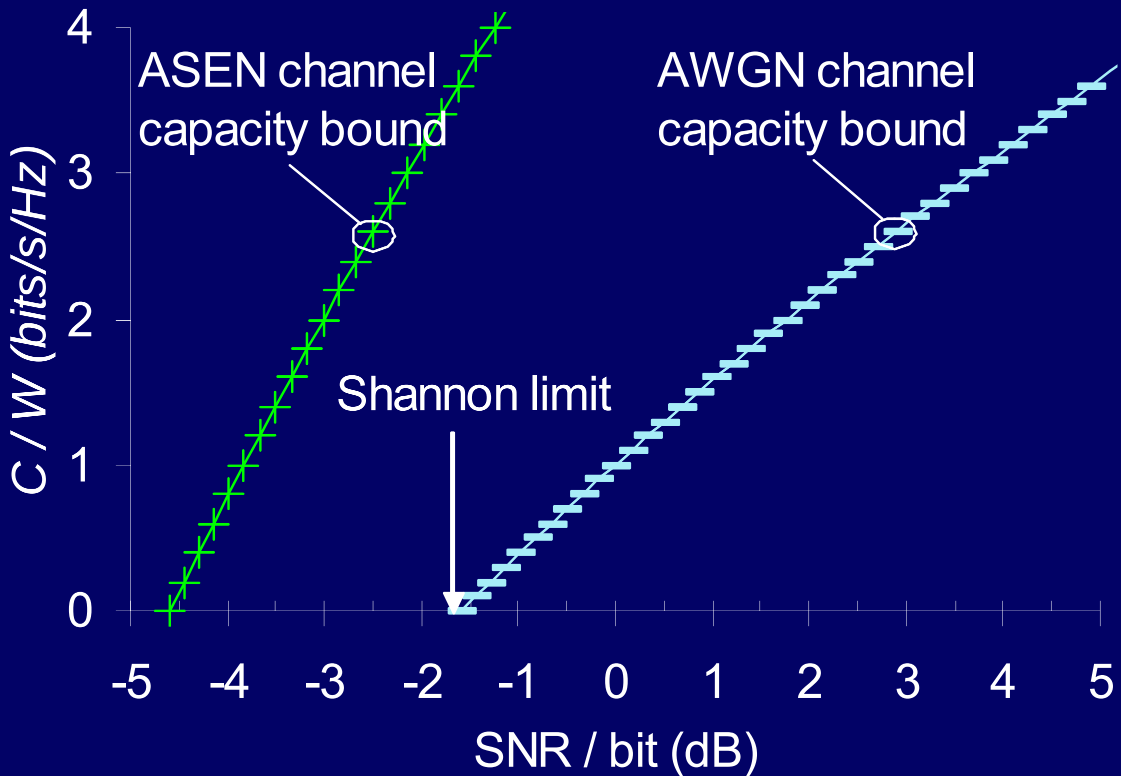
- AWGN Channel
  - One white Gaussian noise source
  - Noise is additive to signal
- ASEN Channel
  - Two orthogonal polarization modes in the same frequency band
  - Noises in the two polarizations are independent white Gaussian noises
  - Only noise component parallel in polarization to the signal is additive, and orthogonal noise component can be eliminated by polarizer

An ASEN channel comprises two independent AWGN channels in the same frequency band

Capacity of ASEN Channels

- ASEN channel capacity can be evaluated by combining the capacities of two independent AWGN channels **in the same frequency band**
  - Double the AWGN channel capacity
  - Shift the doubled capacity curve towards lower Eb/N0 (SNR/bit) by 3dB
- An ASEN channel can achieve two times as much as an AWGN channel capacity with a 3-dB lower SNR/bit
- Note that combining two independent AWGN channels occupying different frequency bands does not increase the channel capacity

Capacity Bound: ASEN Channels vs AWGN Channels

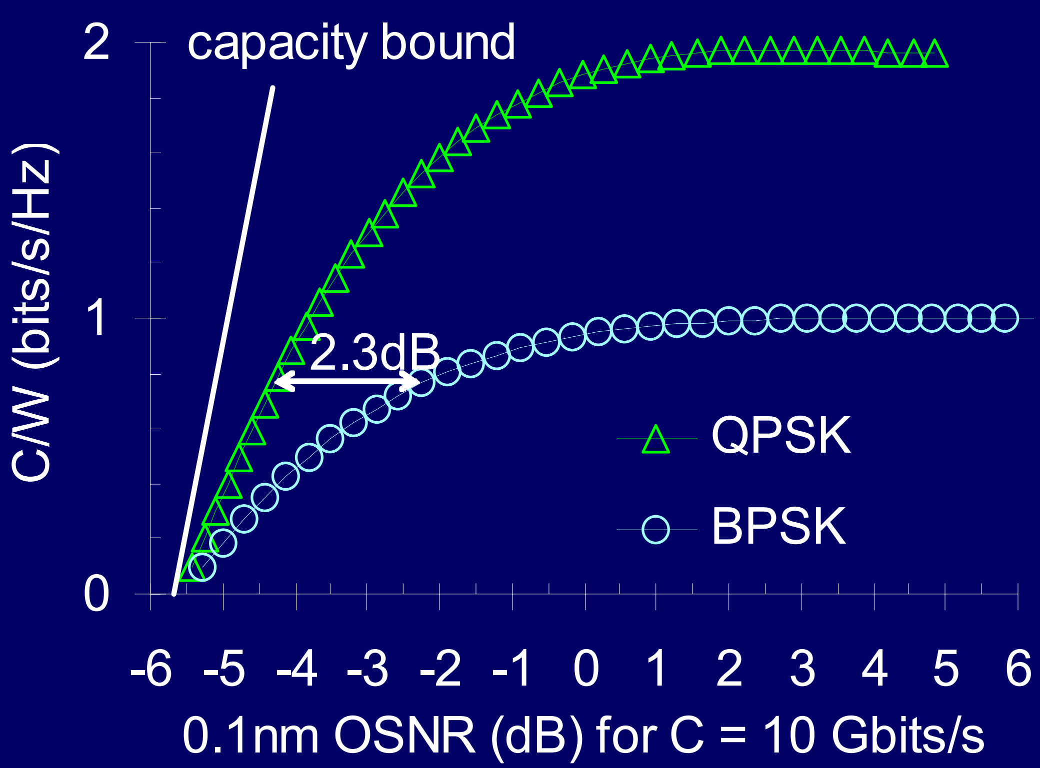


Shannon limit can be "broken" by ASEN channels

Shannon limit on AWGN channels is at –1.6 dB, below which no error-free information can be possibly transmitted

The limit on ASEN channels is at –4.6dB

Capacities of BPSK and QPSK ASEN Channels



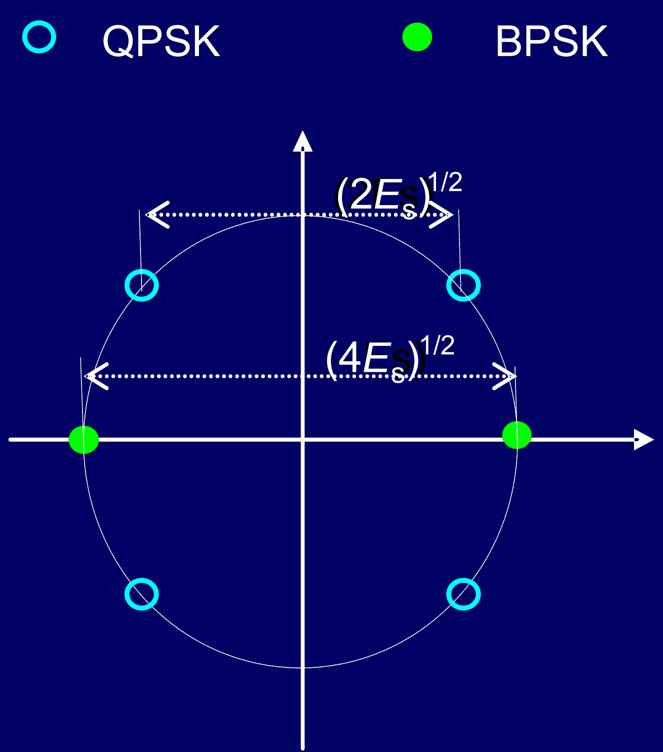
Capacity without Polarization Division Multiplexing

- QPSK system has twice the capacity of BPSK system
- The larger channel capacity can be utilized to save signal power
- At 0.8bit/s/Hz, QPSK should give 2.3dB OSNR benefit over BPSK

Q: **How to get the OSNR gain?**

A: **Use large overhead FEC**

Understanding the OSNR Benefit of QPSK over BPSK



Constellation of QPSK and BPSK

QPSK 100%OH

10G symbols/s → 10G bits/s

BPSK 0%OH

10G symbols/s → 10G bits/s

To achieve the same error probability

- If discard the 100% overhead

  SNR_QPSK = SNR_BPSK + 3dB

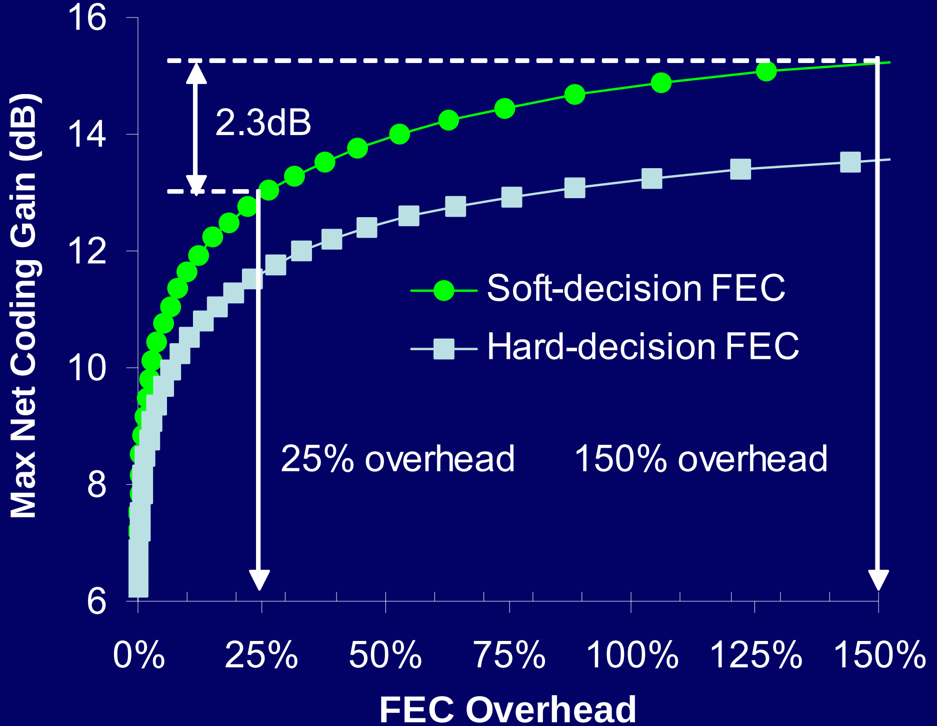
- If use the 100% overhead for signal averaging

  SNR_QPSK = SNR_BPSK

- **If use the 100% overhead for FEC**

  SNR_QPSK = SNR_BPSK – Net Coding Gain

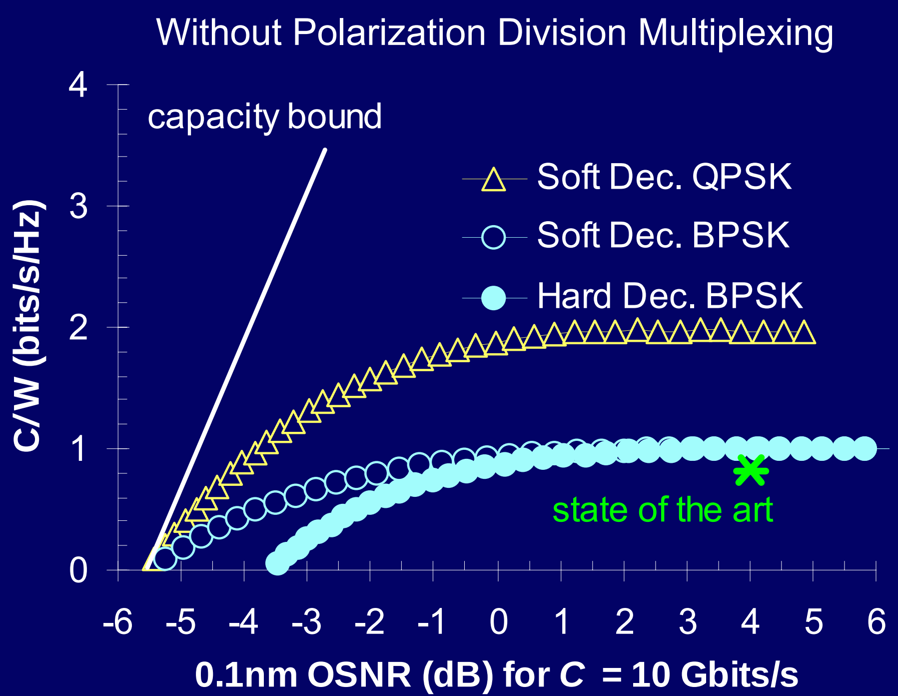
Get the OSNR Benefit of QPSK over BPSK

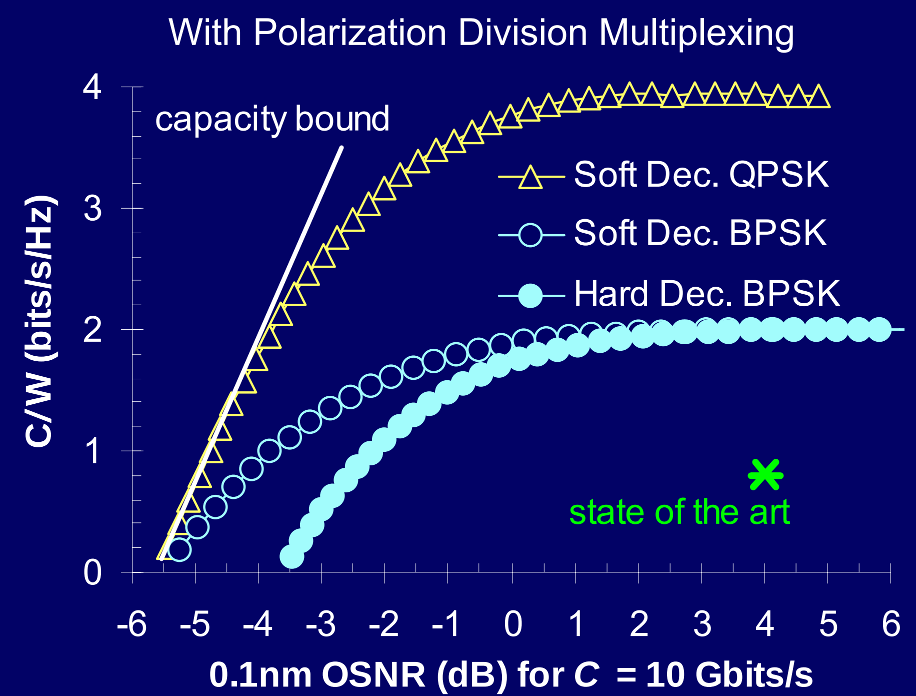


Maximum FEC net coding gain at 10^{-15} BER

- At 0.8bit/s/Hz, BPSK and QPSK have 25% and 150% overhead, respectively
- From 25% to 150% FEC overhead, the max net coding gain increases by 2.3 dB
- **QPSK requires large overhead FEC to get the full OSNR benefit over BPSK**

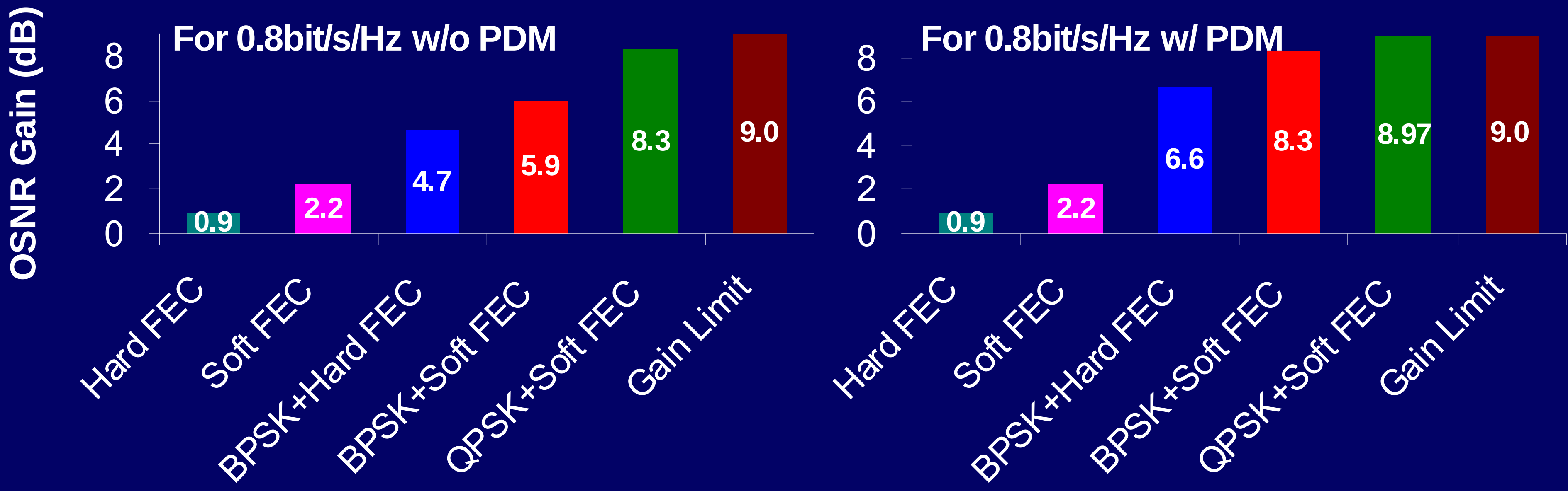
Capacity of ASEN Channels Employing Different Techniques





- The state of the art in research corresponds to a linear RZ-DBPSK system with a 25% overhead TPC having 10.7dB net coding gain at 10^{-15} BER
- The possible gains from different techniques can be evaluated against the current art in the field

Possible Gain From Different Techniques



- Significant gain can be obtained by using QPSK + large overhead FEC
- Employing QPSK + soft-decision FEC + PDM, fiberoptic channels can be as close as 0.03dB to the capacity bound at 0.8bit/s/Hz

Conclusions

- At 3dB lower SNR/bit, 2-polarization fiberoptic channels have twice the capacity of AWGN channels.
- Significant OSNR gain can be potentially obtained by employing advanced modulation, PDM, and large overhead FEC techniques