Design of APSK Constellations for Coherent Optical Channels with Nonlinear Phase Noise

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Abstract

We study the design of amplitude phase-shift keying (APSK) constellations for a coherent fiber-optical communication system where nonlinear phase noise is the main system impairment. A practical two-stage detection scheme is analyzed and we optimize APSK constellations in terms of symbol error probability (SEP) under two-stage detection. Performance gains of 3.2 dB can be achieved at a SEP of 10^-7 compared to 16-QAM. We also demonstrate that in the presence of severe nonlinear distortions, it may become beneficial to sacrifice a constellation point or an entire constellation ring to reduce the average SEP.

Motivation

• Higher order modulation formats are crucial to increase spectral efficiency of optical fiber communication systems.
• The optical channel suffers from distortions that are absent for example in wireless channels, in particular nonlinear phase noise.
• Practical question: How much can we gain by optimizing the constellation compared to standard QAM?
• Theoretical question: How do optimal constellations look like for very strong nonlinearities?

Problem Statement

• APSK constellations can be regarded as a union of phase-shift keying (PSK) signal sets with different amplitude levels. Example: (1,6,5,3,1)-APSK

Points-per-Ring Optimization

• We optimize the number of rings and points per ring for P between -14 and 10 dBm in steps of 2 dBm assuming uniform radii.
• More rings are optimal for increasing input power due to high nonlinear phase noise (see markers in the above figure).
• The optimized constellations for low input power are almost as good as 16-QAM in a Gaussian channel.

Radius Optimization

• For (1,6,5,3,1)-APSK, we optimize the radii of the rings.
• For high input power, it is optimal to move the point in the last ring far away from the remaining constellation points.

Channel Model and Detection

• Fiber length L = 5000 km, parameters c, a_0 from [1]
• K segments, Δr = L/K, noise N ~ C(0, σ^2/K)
• Probability density function (PDF) of Y defined piecewise.

Examples:

- (4, 4, 4, 4)-APSK
- (1, 4, 4, 4)-APSK
- (4, 4, 4, 4, 4)-APSK

References


Conclusion

1. Significant gains can be obtained by choosing an optimized APSK constellation compared to regular 16-QAM.
2. High nonlinearities and an average power constraint may lead to counterintuitive optimization results.

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