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High-spectral-efficiency optical transmission with high-order QAM and probabilistic shaping

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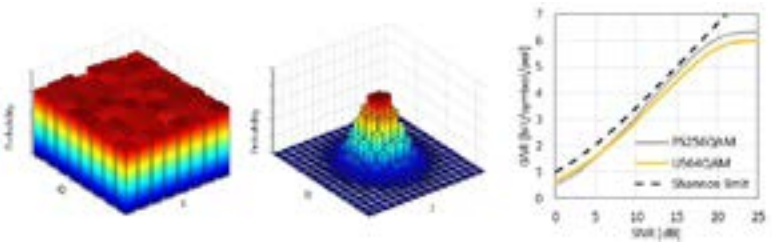
Due to the introduction of digital coherent technology which enables us to employ multi-level modulation such as High-spectral-efficiency (SE) quadrature amplitude modulation (QAM), the capacity over the single mode optical fiber has dramatically increased in limited wavelength resources. In a deployed network, polarization-division-multiplexed (PDM) 16QAM signal of which amplitudes modulated with 4 levels began to be widely used using the real-time digital signal processor (DSP) and the SE was 5.3bit/s/Hz. As for the highest-order QAM transmission in the laboratory, the PDM-4096QAM signal was successfully transmitted using an optical phase-locked loop (OPLL) technique and the potential SE was reached 15.8bit/s/Hz. Further higher SE can be realized by utilizing the higher-order QAM, however, it needs much finer amplitude modulation level and results in the reduced noise tolerance. Meanwhile, the probabilistic shaping (PS) or constellation shaping has been intensively investigated because it offers ultimate shaping gain of 1.53dB and enables to reach the Shannon limit in additive white Gaussian noise channel. PS modifies the probability of the amplitude points on the QAM constellation into approximately Gaussian distribution, thus the lower power points are generated more often than the points with a higher power. The amplitude probabilities of PS-256QAM and uniformly-shaped (US) 64QAM signals and is the generalized mutual information (GMI) which represents the transmission rate per received symbol in each polarization. The GMI of the PS-256QAM exceeded that of the US-64QAM and can realize the close performance with Shannon limit. In order to realize a high SE transmission with a high noise tolerance, the combination of the high-order QAM and the PS technology has attracted much attention. A single channel 82 Gbaud PS-256QAM transmission with SE of 8bit/s/Hz was achieved over 400km by precisely compensating the frequency response of the transceiver. As the highest-order PS-QAM experiments, single channel 3 Gbaud PS-4096QAM with SE of 15.3bit/s/Hz was firstly demonstrated over 160km. Then, 10 wavelength-division-multiplexed (WDM) 3 Gbaud PS-4096QAM transmission with SE of 17.3bit/s/Hz was realized over 50km. In this paper, we review the recent transmission techniques to generate the signal applied with the high-order QAM and the PS. Then the numerical performance comparison between PS and US constellations in terms of phase noise is presented. We also describe the experimental results of 80 Gbaud PS-256QAM transmission with precise calibration technique as the transmission with the large capacity and 3 Gbaud PS-4096QAM transmission with OPLL as the transmission employing largest constellations. The SE of each transmission was 8 and 15.3bit/s/Hz, respectively. Lastly, we discuss the challenges to further increase the SE.



Biography

Seiji Okamoto received the BE, MS and PhD in Electrical Engineering from Tohoku University in 2009, 2011 and 2018 respectively. In 2011, he joined NTT Network Innovation Laboratories, Yokosuka, Japan, where he has been engaging in the research and development of the large capacity and low power digital coherent optical transmission systems with high-speed digital signal processing.

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