Photonic spiking reinforcement learning for intelligent routing

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Intelligent routing is critical for data centers and 6G but limited by high power and latency. A photonic spiking reinforcement learning architecture with PPO was proposed for intelligent routing. Evaluated on fat-tree SDN, it outperforms Dijkstra in throughput, latency, packet loss and load balance. A hardware-software framework using MZI and DFB-SA chips achieves consistent accuracy. This low-latency, high-efficiency paradigm has broad prospects in data centers, satellite networks and 6G.

Driven by the rapid development of cloud computing, big data, artificial intelligence, and the Internet of Things, global data traffic has grown explosively, imposing unprecedented stringent requirements on the real-time performance, throughput, and energy efficiency of communication networks. In contrast to traditional routing algorithms, which rely on static link weights, lack dynamic awareness, and suffer from slow convergence, intelligent routing based on deep reinforcement learning can perceive network states in real time. It features multi-objective collaborative optimization and adaptive decision-making, showing broad application prospects in data centers, computing power networks, and future 6G scenarios.

However, neural networks implemented on conventional electronic platforms face bottlenecks such as high power consumption and large decision latency, which can hardly meet the demands of edge real-time control and large-scale high-speed, highly dynamic networks.

Photonic computing has become a key technical route to break through the bottlenecks of electronic computing due to its ultra-high speed, large bandwidth, low power consumption, and parallelism. Furthermore, spiking neural networks (SNNs) inspired by biological brain mechanisms further improve energy efficiency through event-driven computation. How to combine photonic spiking neural computing with reinforcement learning to build an intelligent routing system with ultra-low latency and ultra-high energy efficiency has become a critical scientific issue at the intersection of optical communications and artificial intelligence.

The authors of this article propose a novel software-defined networks (SDN) intelligent routing architecture based on photonic spiking reinforcement learning, providing a novel technical path for next-generation intelligent networks.

This approach aims to construct a low-latency, high-efficiency, and adaptive intelligent routing system. The research group proposes and implements a photonic spiking reinforcement learning-based intelligent routing system for SDN, which deeply integrates SNN, proximal policy optimization (PPO), and photonic computing chips, with systematic verification carried out on a fat-tree data center topology. A three-tier architecture including data plane, control plane, and intelligent decision-making plane is designed. By employing photonic computing hardware to perform core routing decision computations, the system achieves real-time perception of network states and dynamic optimization of routing strategies, successfully overcoming the poor adaptability of traditional routing algorithms as well as the high latency and power consumption of electronic solutions.

With the MZI-based photonic synapse chip and DFB-SA-based photonic spiking neuron chip, they built a hardware-software collaborative inference platform, where the spiking Actor network is deployed on photonic hardware to maximize the speed and energy efficiency advantages of photonic computing while ensuring training stability. Experimental results on 640 state-action pairs show that the inference accuracy of the hardware-software collaborative framework is fully consistent with that of the pure software algorithm. Under various traffic loads, the proposed photonic spiking PPO routing significantly outperforms the classical Dijkstra algorithm in four key metrics: throughput, packet loss rate, average latency, and load balance, especially under high-load conditions. The system also exhibits strong robustness and fast re-convergence capability under topology changes such as link failures.

This achievement represents the first full integration of photonic spiking reinforcement learning and SDN intelligent routing, establishing a novel paradigm for routing optimization with ultra-low latency and ultra-high energy efficiency. It is expected to be applied in large-scale data centers, computing power networks, satellite Internet, and future 6G networks, providing key technical support for space-air-ground integrated real-time network optimization and advancing interdisciplinary research at the interface of photonic intelligence and communication networks.

Keywords: photonic spiking neural network, spiking reinforcement learning, intelligent routing, SDN

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