Decoupling Label Shift and Surrogate Gradient Errors for Robust Federated Spiking Neural Networks

Zouquan Chen, Yifei Yang, Lidong Zheng, Zhiming Fang, Yuchen Zheng

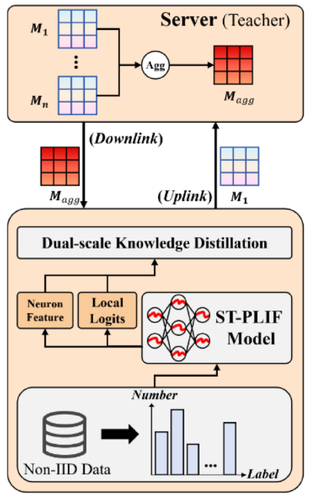
chenzouquan@stu.shzu.edu.cn
ouczyc@outlook.com

College of Information Science and Technology, Shihezi University, Shihezi, China

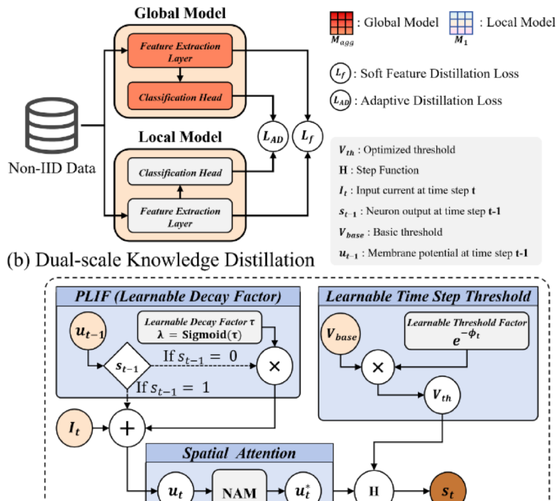
Abstract

Federated Spiking Neural Networks (FedSNNs) offer a promising approach to edge intelligence, but their robustness is limited by label shift and surrogate gradient errors. Under heterogeneous data, label shift distorts membrane potential distributions and drives neurons away from gradient-sensitive regions, amplifying gradient errors and destabilizing federated optimization. We propose Spatio-Temporal Spiking Adaptive Thresholds (ST-SAT) to mitigate this coupling through neuronal adaptation and client–server knowledge alignment. ST-SAT integrates Spatio-Temporal Parametric Leaky Integrate-and-Fire (ST-PLIF) neurons, which adapt firing thresholds, membrane potentials, and decay dynamics, with Dual-Scale Knowledge Distillation, which aligns class predictions and neuronal activity statistics. Experiments on three benchmark datasets demonstrate improvements in global and client-model accuracy under severe label shift, supporting the effectiveness of ST-SAT for robust federated SNN learning.
The code is available at https://github.com/ZouquanChen/ST-SAT_code.

Methods



(a) Overall Framework Process



(b) Dual-scale Knowledge Distillation

(c) ST-PLIF Neuron

Overall architecture of ST-SAT. The framework consists of the ST-PLIF neuron for stabilizing spiking dynamics under label shift and the Dual-Scale KD mechanism for aligning client- server knowledge at both logit and feature levels.

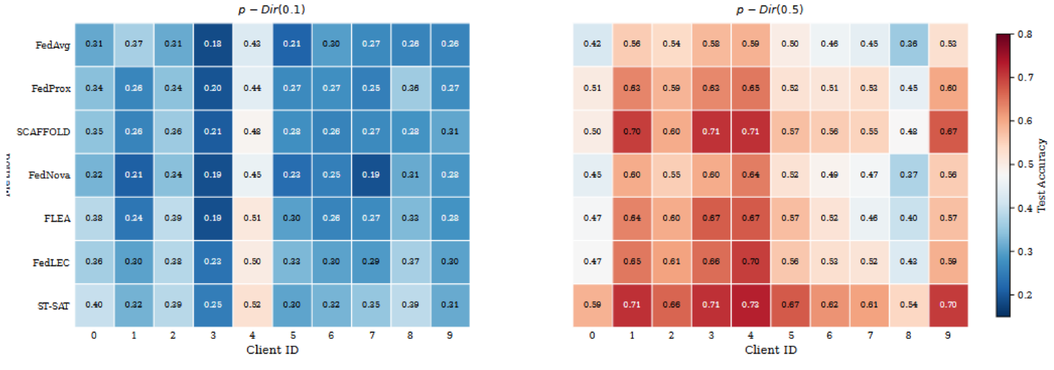
Experiments

Best global model test accuracy (%) of different federated learning methods with the VGG-S backbone on CIFAR-10, CIFAR-100, and CIFAR10-DVS under Dirichlet label skew. Results are reported as mean ± sample standard deviation over the three experiment groups (n = 3). The highest mean in each column is shown in bold

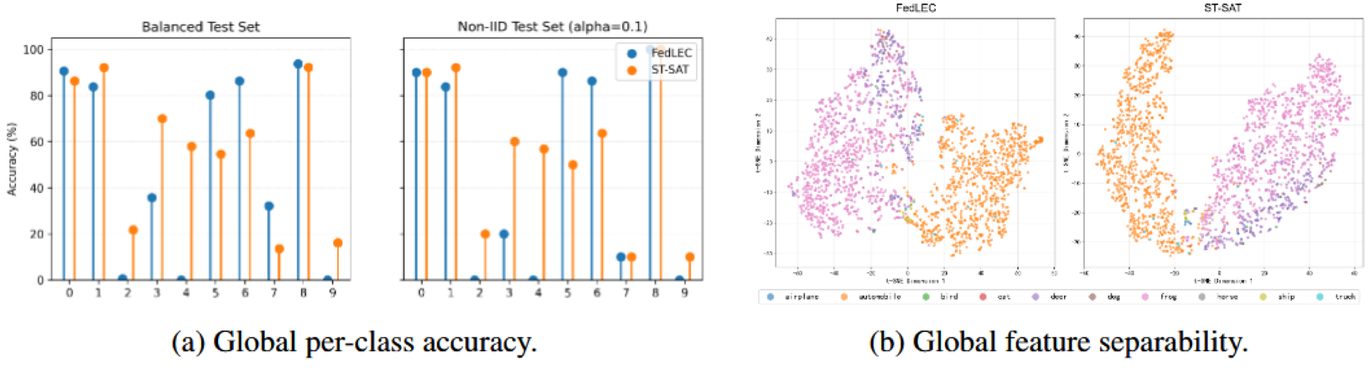
Method	CIFAR-10		CIFAR-100		CIFAR10-DVS	
	$\alpha = 0.1$	$\alpha = 0.5$	$\alpha = 0.1$	$\alpha = 0.5$	$\alpha = 0.1$	$\alpha = 0.5$
FedAvg	42.02 ± 1.81	63.10 ± 0.66	21.87 ± 0.54	36.94 ± 0.53	28.90 ± 5.54	36.43 ± 1.03
FedConcat	43.59 ± 0.94	72.77 ± 1.63	36.05 ± 1.26	43.58 ± 0.53	32.58 ± 0.43	40.00 ± 0.41
FedLEC	50.10 ± 0.29	74.55 ± 0.71	34.13 ± 0.46	48.00 ± 0.54	39.70 ± 1.31	46.92 ± 2.36
FedNova	43.20 ± 0.56	67.18 ± 0.48	16.98 ± 0.10	28.76 ± 0.35	33.93 ± 4.65	45.45 ± 0.28
FedProx	45.33 ± 0.64	70.31 ± 0.65	30.69 ± 0.40	42.38 ± 0.61	29.52 ± 2.36	37.10 ± 2.48
FLEA	52.55 ± 2.23	70.77 ± 0.93	37.30 ± 1.30	46.64 ± 0.47	35.18 ± 0.10	44.30 ± 3.74
SCAFFOLD	44.90 ± 1.27	**77.68 ± 0.91**	34.59 ± 0.37	50.83 ± 0.38	30.77 ± 2.08	**50.17 ± 1.10**
ST-SAT	**55.61 ± 2.43**	76.11 ± 0.15	**42.02 ± 0.74**	**52.18 ± 0.29**	**41.62 ± 4.03**	49.57 ± 1.29

Average best client accuracy (%) of different federated learning methods with the VGG-S backbone on CIFAR-10, CIFAR-100, and CIFAR10-DVS under Dirichlet label skew. For each experiment group, the best test accuracy of each client is averaged across clients. Results are reported as mean ± sample standard deviation over the three experiment groups (n = 3). The highest mean in each column is shown in bold.

Method	CIFAR-10		CIFAR-100		CIFAR10-DVS	
	$\alpha = 0.1$	$\alpha = 0.5$	$\alpha = 0.1$	$\alpha = 0.5$	$\alpha = 0.1$	$\alpha = 0.5$
FedAvg	28.81 ± 0.19	49.46 ± 0.28	16.20 ± 0.19	31.81 ± 0.31	21.81 ± 2.82	29.36 ± 0.71
FedLEC	33.33 ± 0.41	56.84 ± 0.68	22.55 ± 0.21	38.83 ± 0.19	25.32 ± 0.76	33.30 ± 1.47
FedNova	28.42 ± 0.54	52.70 ± 0.30	12.05 ± 0.12	21.30 ± 0.36	23.16 ± 2.25	34.25 ± 0.14
FedProx	30.57 ± 0.73	55.66 ± 0.81	18.92 ± 0.13	32.42 ± 0.30	21.50 ± 0.77	27.53 ± 1.67
FLEA	31.86 ± 0.26	56.13 ± 0.37	23.77 ± 0.30	41.23 ± 0.17	24.14 ± 0.84	29.07 ± 3.98
SCAFFOLD	29.84 ± 0.48	60.67 ± 0.54	21.46 ± 0.02	41.32 ± 0.28	22.84 ± 0.87	34.92 ± 0.46
ST-SAT	**38.34 ± 0.63**	**64.79 ± 0.43**	**32.82 ± 0.25**	**46.45 ± 0.48**	**27.42 ± 1.85**	**38.38 ± 1.00**



Client test accuracy on CIFAR-10 under Dirichlet label skew with α = 0.1 (left) and α = 0.5 (right). Results are from a single run for each setting. Accuracy is shown on a scale from 0 to 1.



(a) Global per-class accuracy.

(b) Global feature separability.

Global model comparison on CIFAR-10 under severe label shift. Compared with FedLEC, ST-SAT improves per-class accuracy and learns more separable global feature representations when α = 0.1.