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Training time minimization for federated edge learning with optimized gradient quantization and bandwidth allocation

Key words: Federated edge learning; Quantization optimization; Bandwith allocation; Training time minimization

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Motivation

1. In edge networks, computation resources of the edge devices and wireless resources of the network are limited. Therefore, training an artificial intelligence (AI) model by federated edge learning (FEEL) is usually time-consuming and expensive.
2. To reduce the total training time, we should not only bring down the number of communication rounds, but also shorten the per-round latency.
3. With the goal of minimizing the total training time, we focus on how to balance the number of communication rounds and the per-round latency via joint quantization level and bandwidth allocation optimization.

Main idea

1. We consider quantized FEEL, whereby a stochastic quantization scheme is adopted for updated gradient compression.
2. We make a comprehensive analysis of the total training time by taking into account the communication time, computation time, and number of communication rounds, based on which the intrinsic trade-off between the number of communication rounds and the per-round latency is characterized.
3. A joint quantization and bandwidth allocation optimization problem is formulated and solved.

Method

1. We propose a joint data-and-model-driven fitting method to yield an accurate estimate of the number of required communication rounds.
2. We adopt the alternating optimization technique to decompose the original problem into two sub-problems, and each optimizes one of the two control variables with the other variable fixed.

Simulation results

- **Experiment I**: ℓ_2 regularized logistic regression with synthetic dataset

- Total training time vs. quantization level

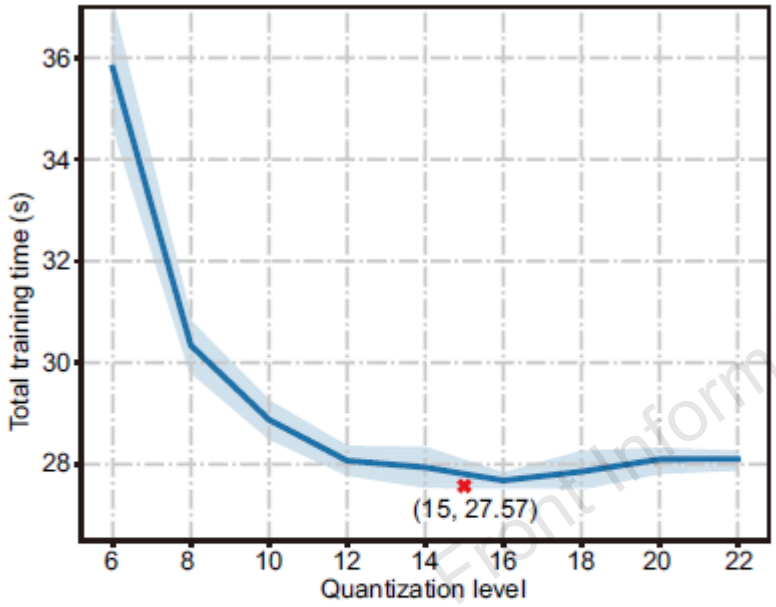

Fig. 4 Total training time vs. the quantization level q in simulation 1 when the bandwidth allocation is optimal (The point with the optimal quantization level and the corresponding training time from Algorithm 3 in theory is annotated by "x")

- Bandwidth allocation & CPU frequency

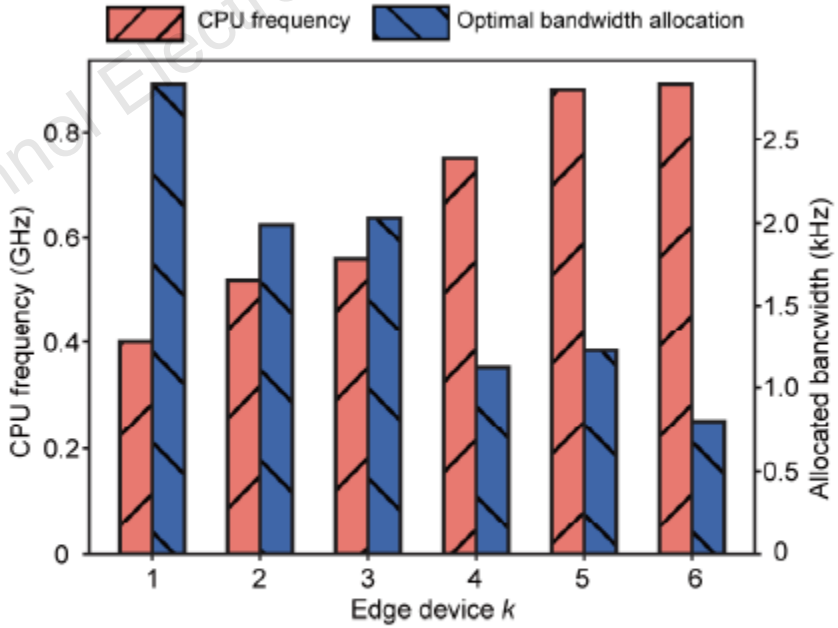

Fig. 5 Optimal bandwidth allocation (bars on the right) and CPU frequency (bars on the left) of each edge device in simulation 1

Simulation results

- **Experiment I**: ℓ_2 regularized logistic regression with synthetic dataset
  - Optimality gap & test accuracy vs. training time

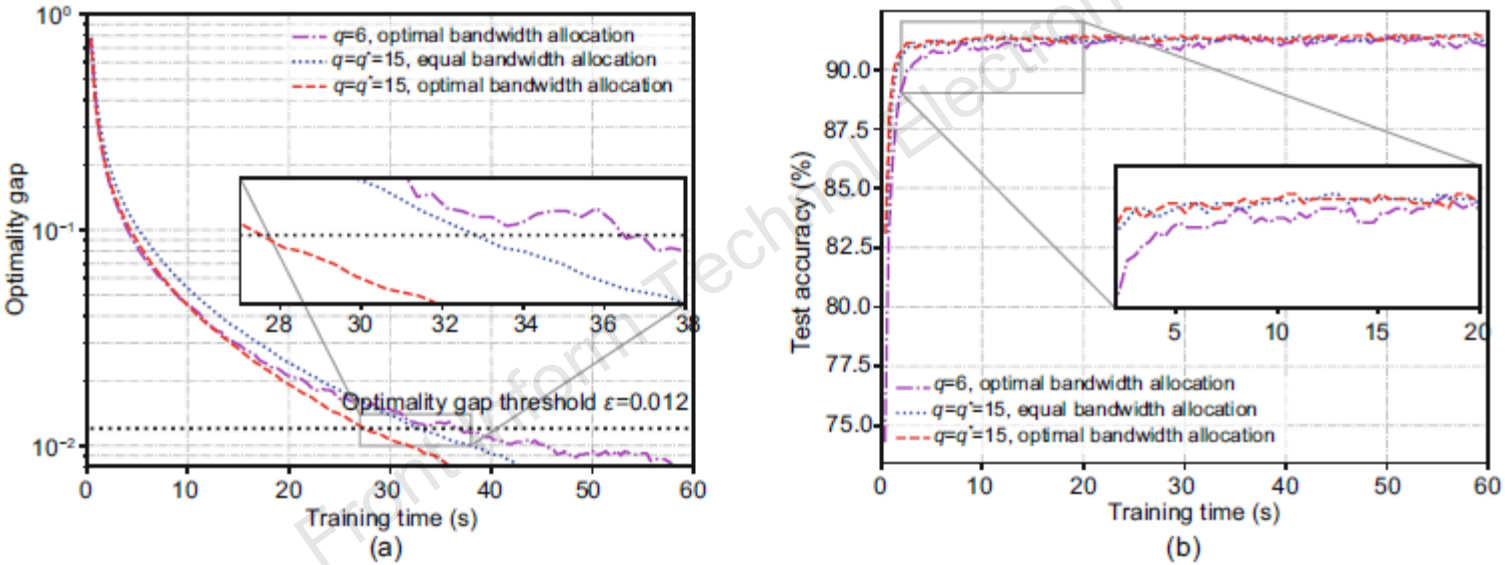

Fig. S1 Optimality gap (a) and test accuracy (b) in simulation 1

Major results

- **Experiment II**: CIFAR-10 dataset image classification with ResNet20

  - Simulation setup

Edge devices	Radius of network area	r	500m
	Number of devices	K	6
	Transmit power	p_k	1 dBm
	CPU frequency	f_k	[100MHz, 1GHz]
	Cycles for executing a batch of sample	$\mathcal{V}$	10^8
Wireless propagation	Path loss	$[PL]_{dB}$	$128.1 + 37.6\log_{10} l$ (l in Km)
	Shadow fading variance	σ_ζ^2	8 dB
	Noise power spectral density	N_0	-174 dBm/Hz
	Total bandwidth	B	10 KHz
Learning	Learning rate	η_n	$5/(n+10)$, $100/(n+1000)$
	Batch size	m_b	100
	Model size	d	1024
	Threshold of optimality gap	ϵ	0.015

Major results (Cont'd)

- **Experiment II**: CIFAR-10 dataset image classification with ResNet20
  - Total training time vs. quantization level

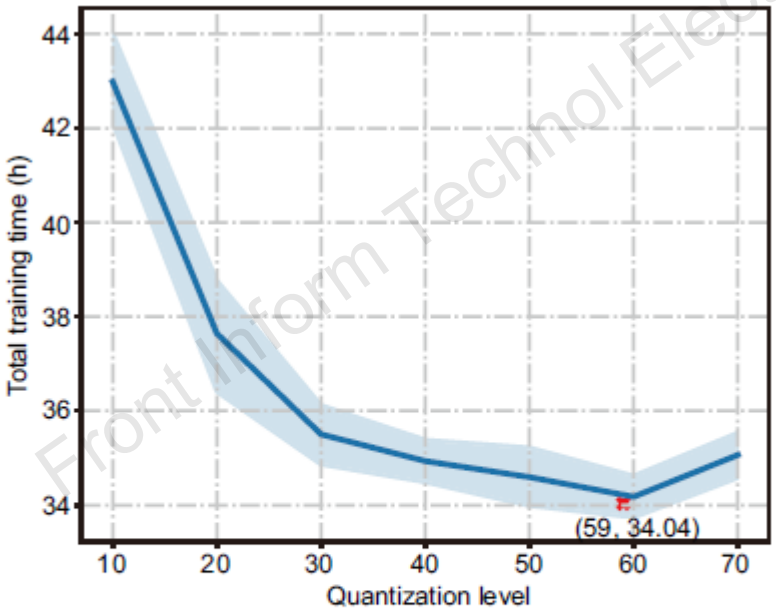

Fig. 6 Total training time vs. quantization level q in simulation 2 when the bandwidth allocation is optimal (The point with the optimal quantization level and the corresponding training time from Algorithm 3 in theory is annotated by "x")

Major results (Cont'd)

- **Experiment II**: CIFAR-10 dataset image classification with ResNet20
  - Optimality gap & test accuracy vs. training time

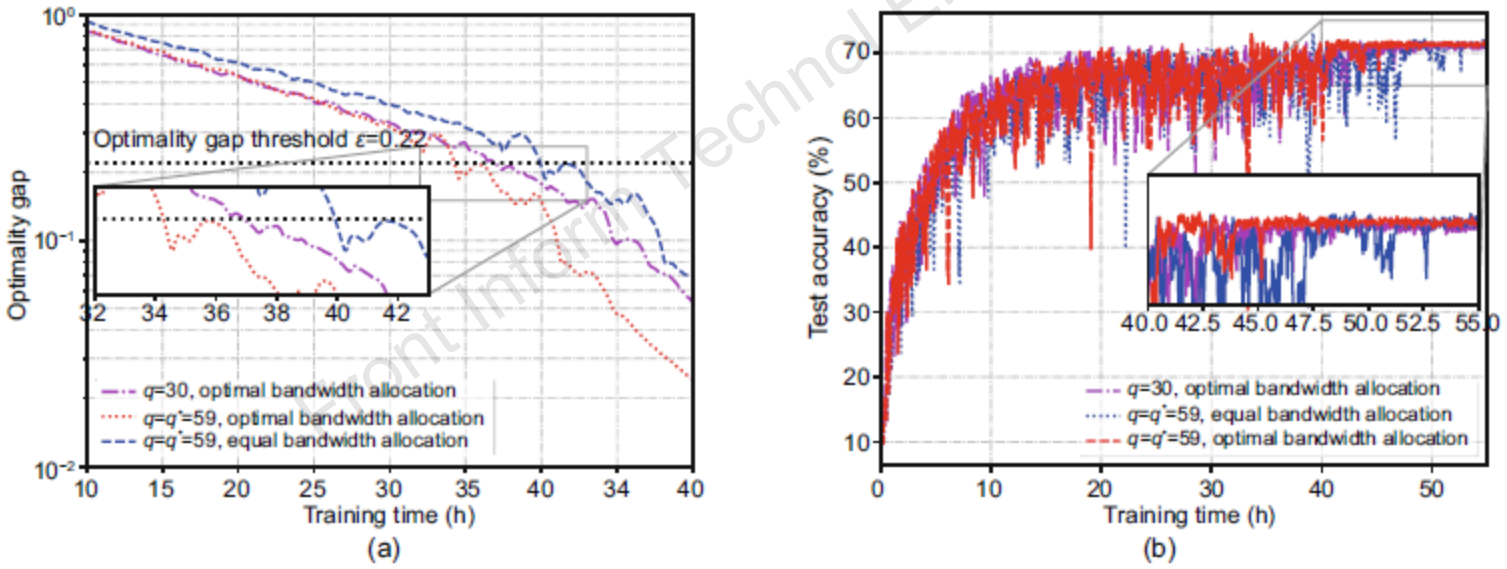

Fig. S2 Optimality gap (a) and test accuracy (b) in simulation 2

Conclusions

1. We studied the minimization of training time for quantized FEEL with optimized quantization level and bandwidth allocation.
2. The theoretical results developed can be used to guide system optimization and contribute to the understanding of how a wireless communication system can properly coordinate resources to accomplish learning tasks.

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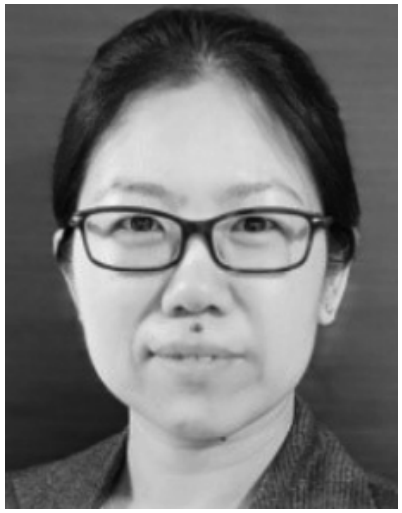

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