Mobile Device Training Strategies in Federated Learning: An Evolutionary Game Approach

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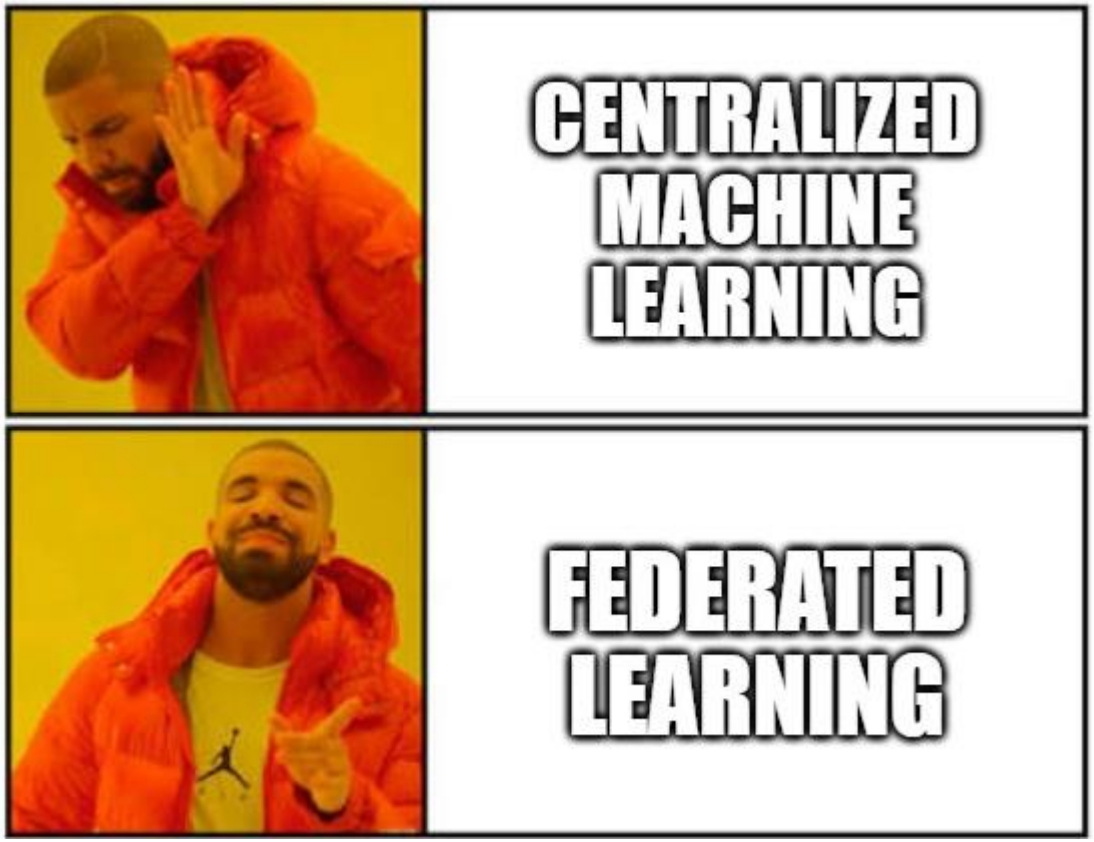
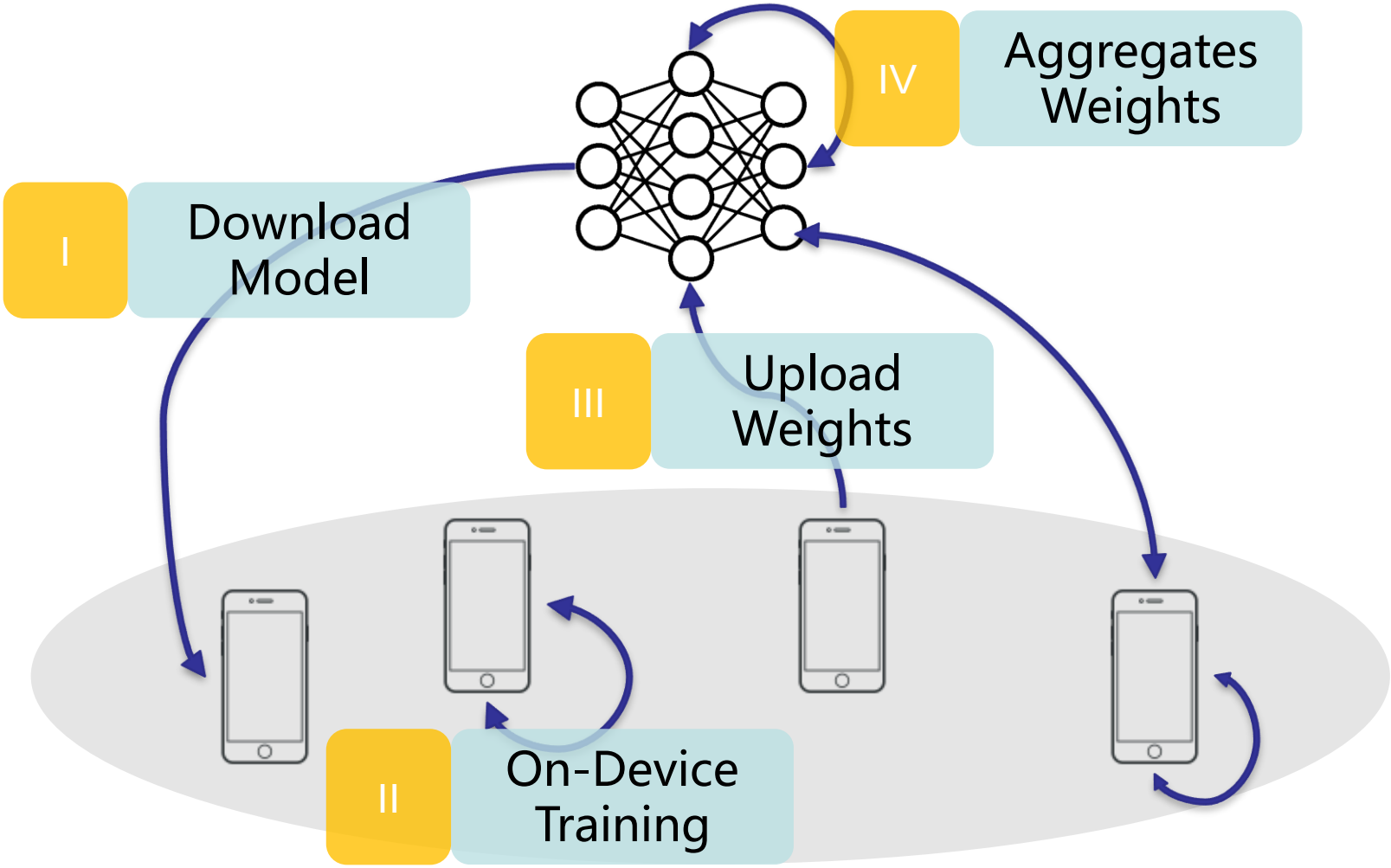
- System Description
- Evolutionary Game Formulation
- Performance Evaluation

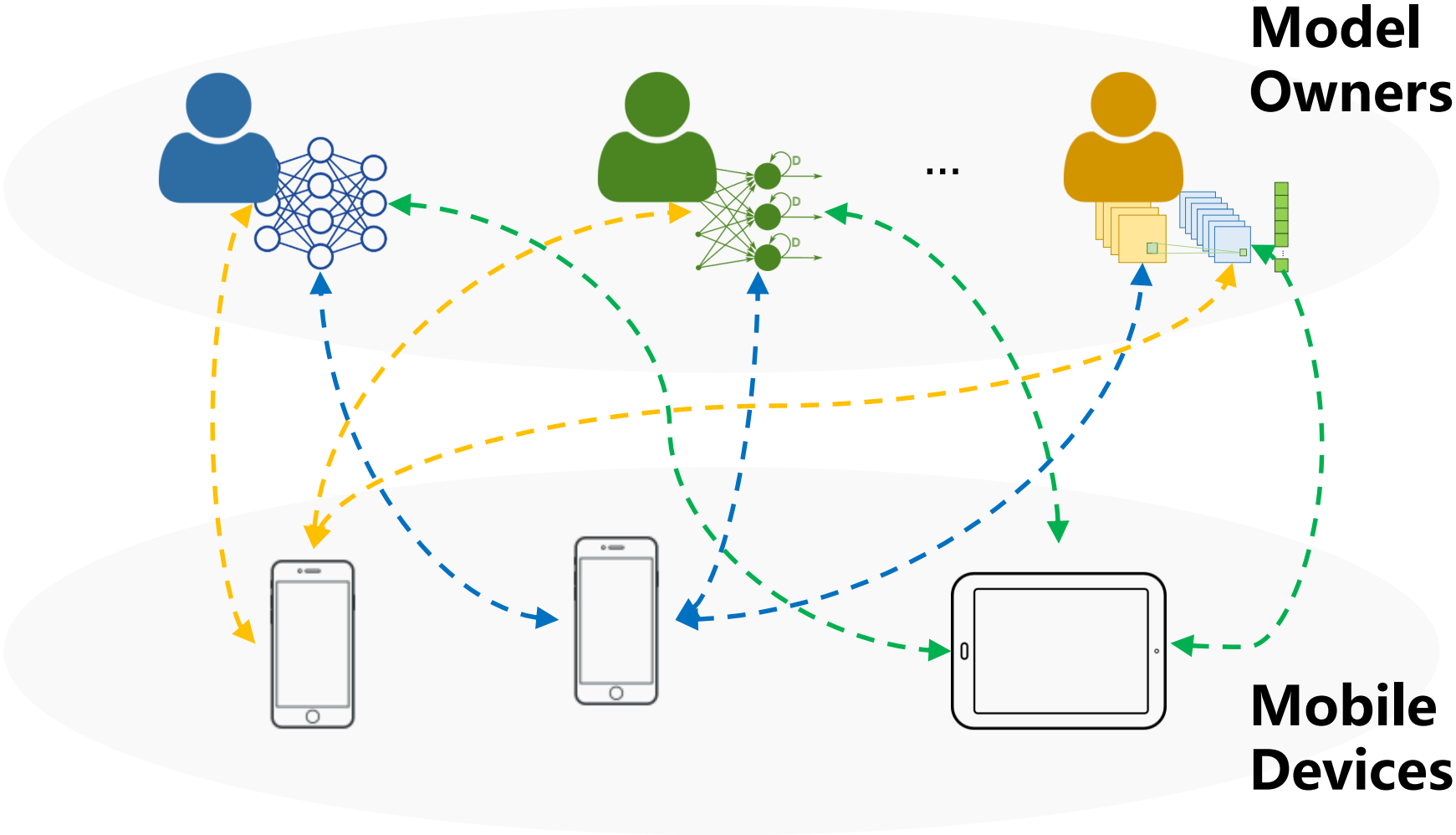
Introduction



Introduction

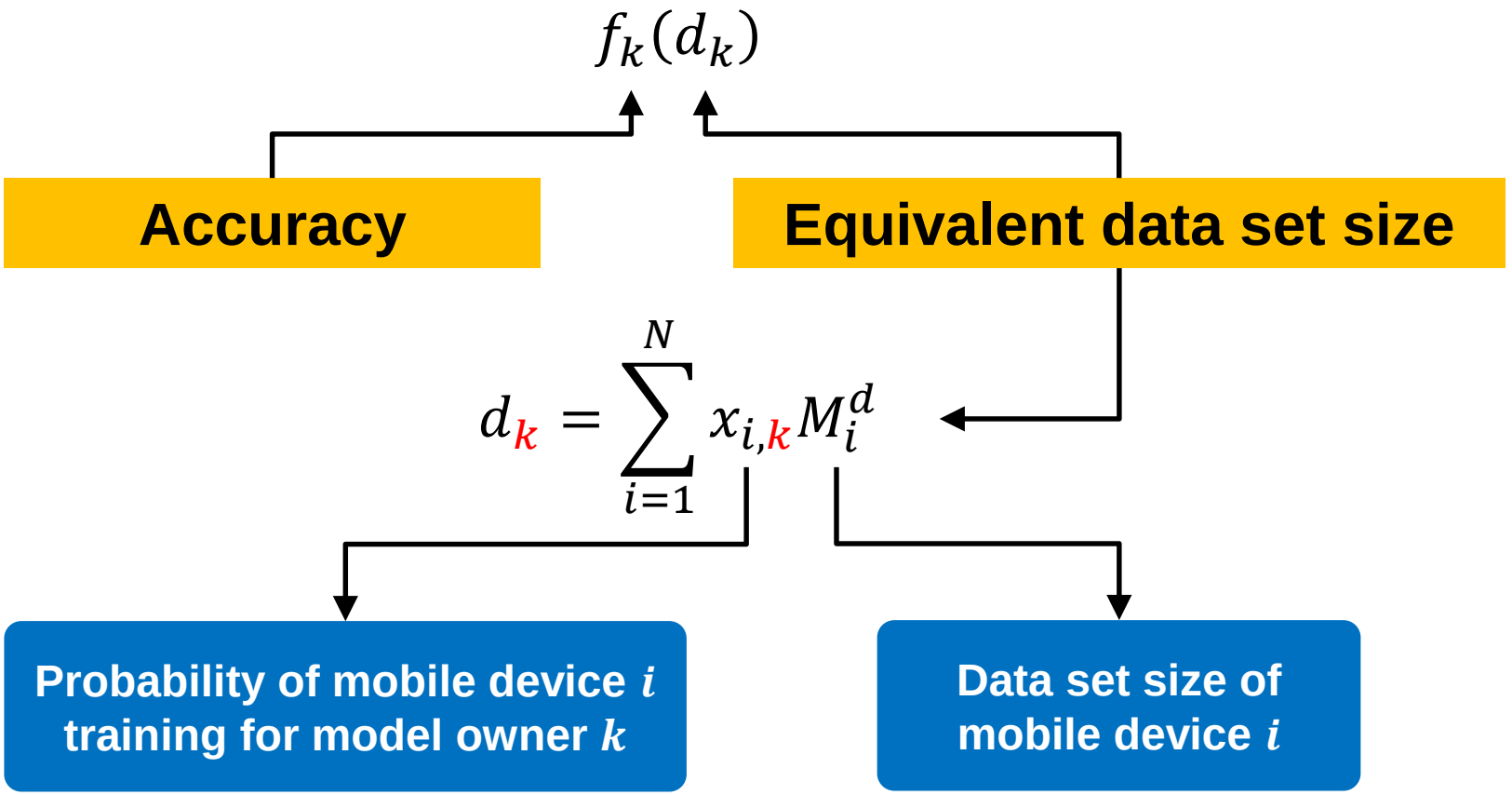


System Description



System Description

- Accuracy of machine learning model

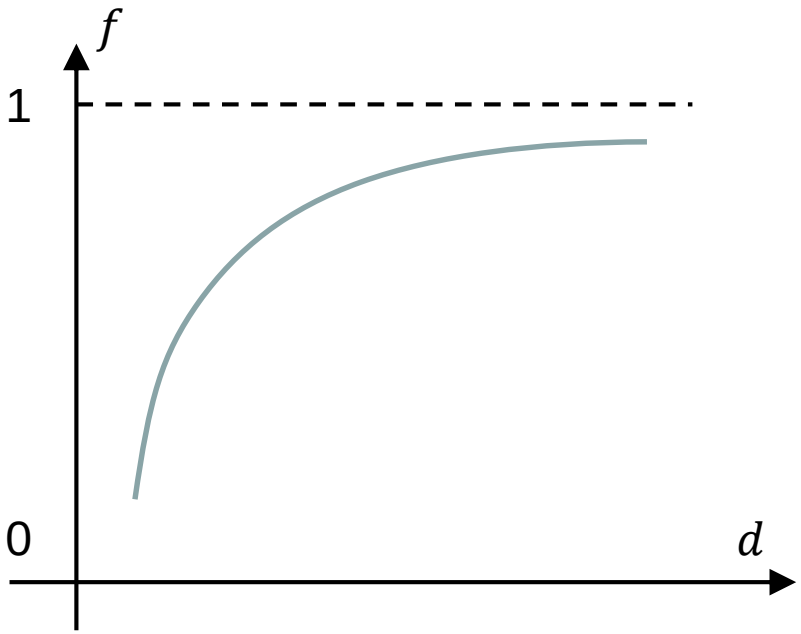


System Description

- Accuracy of machine learning model

$$f_k(d_k)$$

- Properties of $f(d)$
  - Non-decreasing
  - Concave
  - Bounded



System Description

- Utility of mobile device
  - **Payoff**

$$\gamma_{i,k}\frac{x_{i,k}M_i^d}{d_k}f(d_k)+\alpha_k$$

Payoff coef. — **contribution** — **Additional incentive**

  - **Cost**

$$\eta_{i,k}x_{i,k}M_i^d$$

Energy coef. — **Effort to train**

  - **Utility**

$$u_{i,k}=\gamma_{i,k}\frac{x_{i,k}M_i^d}{d_k}f(d_k)+\alpha_k-\eta_{i,k}x_{i,k}M_i^d \quad (1)$$

Evolutionary Game Formulation

■ Game Formulation

$$\mathcal{G} = (\mathcal{N}, \mathcal{A}, \mathcal{U})$$

where,

- SET of players ($\mathcal{N}$): The set of mobile devices $\mathcal{N}$ denotes the set of players of the game.
- SET of actions ($\mathcal{A}$): The set of action for each mobile device is denoted as $\mathcal{A} \triangleq \times_{k \in \mathcal{K}} [0, 1]$.
- Utility function matrix: Let $\mathcal{U} \triangleq [\mathbf{u_1}, \mathbf{u_2}, \ldots, \mathbf{u_N}]$ denote the utility matrix for the federation of mobile devices.

Evolutionary Game Formulation

■ **Replicator dynamics**

$$\dot{x}_{i,k}(t) = x_{i,k}(t)\left(u_{i,k}(t) - \bar{u}_i(t)\right) \quad (2)$$

Utility of mobile device i training for model owner k

Mobile device i's average utility

$$\bar{u}_i(t) = \sum_{i=1}^{K} x_{i,k}(t) u_{i,k}(t)$$

Evolutionary Game Formulation

- Equilibrium Analysis
  - *Definition*: The evolutionary equilibrium is the solution of the game defined in (2), i.e., replicator dynamics.
  - *Uniqueness of the equilibrium*

    Proved via *Cauchy- Lipschitz theorem*.
  - *Stability of the equilibrium*

    Proved via *Lyapunov's second method.*

Performance Evaluation

PARAMETERS SETTINGS

	Value		Value
N	3	K	3
M^d	$[100, 50000]$	η	cf. Table II
$f(\cdot)$	cf. (6)	α_k	[1 1 2]
$\mathbf{X}_0$	$\begin{bmatrix} 0.2 & 0.5 & 0.3 \\ 0.3 & 0.5 & 0.2 \\ 0.2 & 0.5 & 0.3 \end{bmatrix}$	$\gamma_{i,k}$	$\begin{bmatrix} 1 \\ 0.8 \\ 0.6 \end{bmatrix} \times \frac{[8,32,64]}{100}$

FITTED MODEL COEFFICIENTS FOR ACCURACY AND ENERGY CONSUMPTION AGAINST TRAINING SET SIZE

	Accuracy				Energy	
H	a	b	c	R^2	η	R^2
0	20.74	0.8090	0.9228	0.9979	1.2303	0.9991
64	10.18	0.7017	0.9608	0.9902	2.9587	0.9987
512	2.26	0.4686	0.9875	0.9909	21.4793	1.0000

Performance Evaluation

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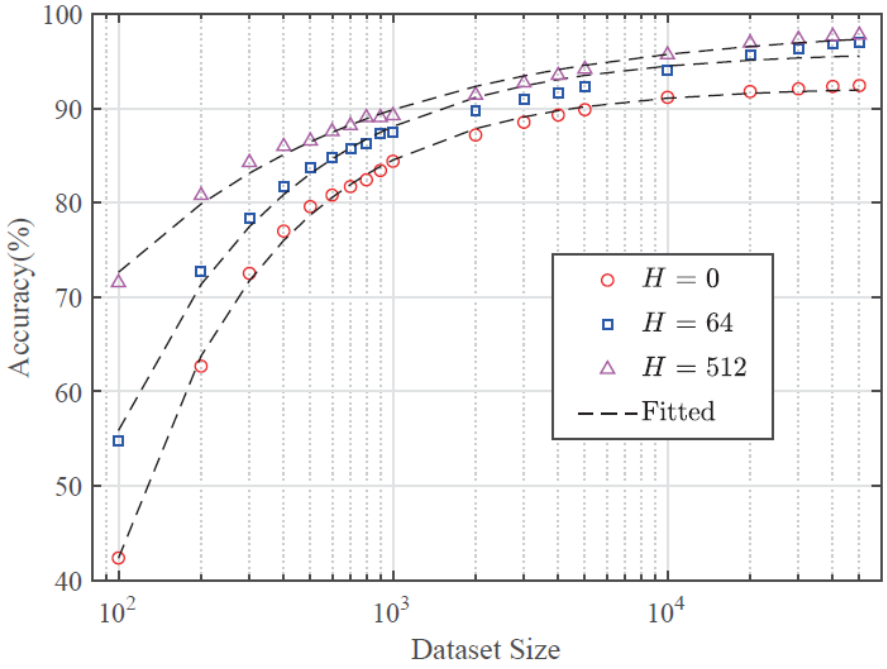
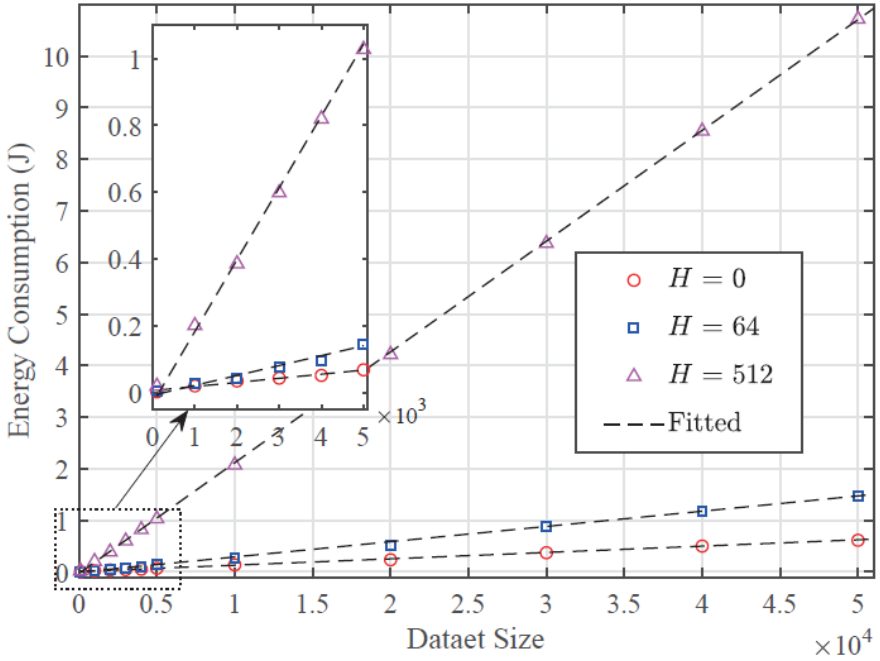


(a) Accuracy



(b) Energy Consumption

Accuracy and Energy Consumption Fitting for Different Learning Models

Performance Evaluation

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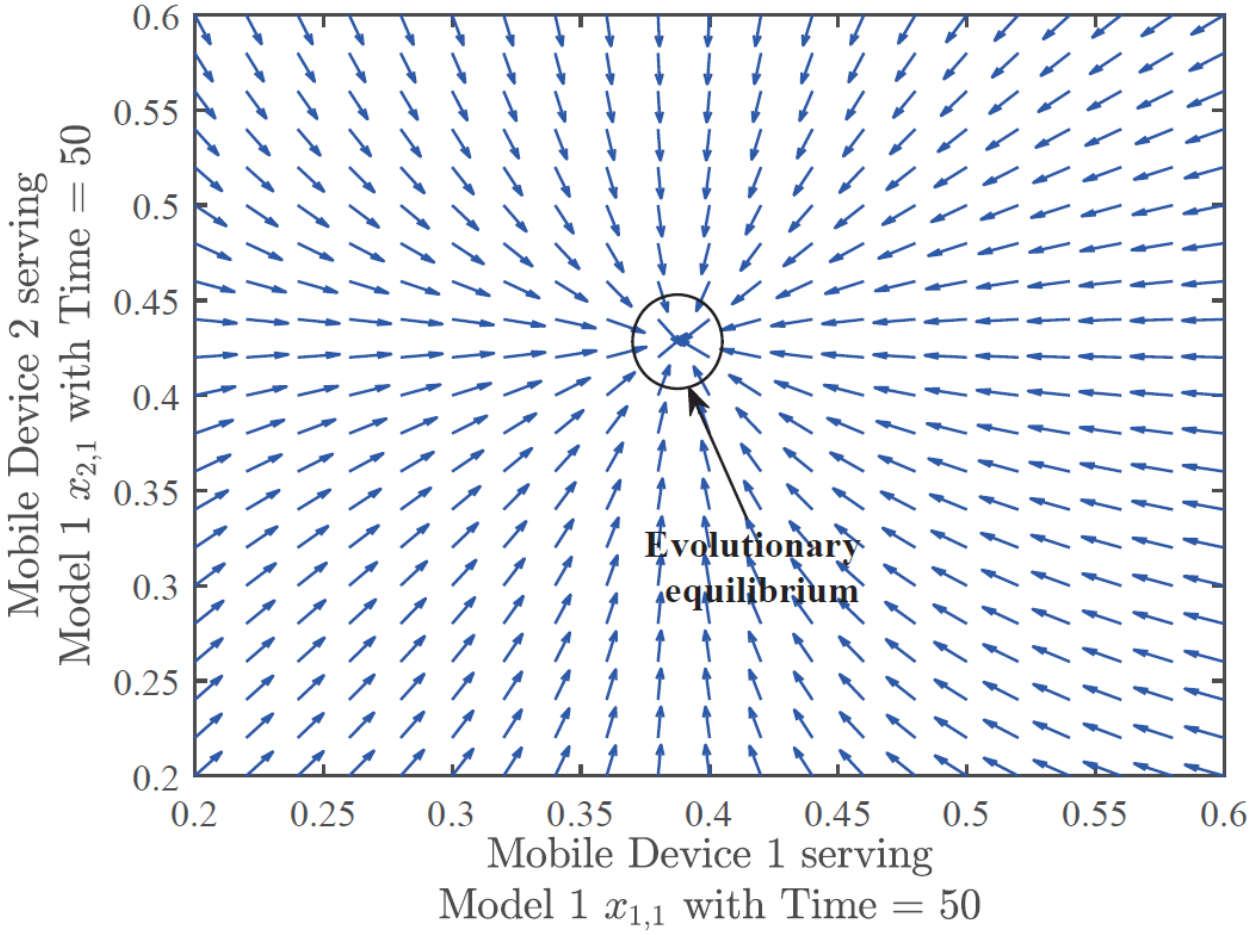
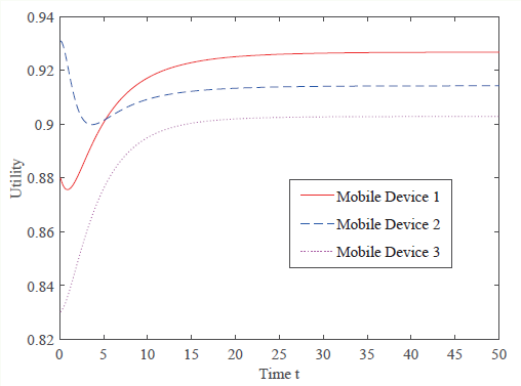
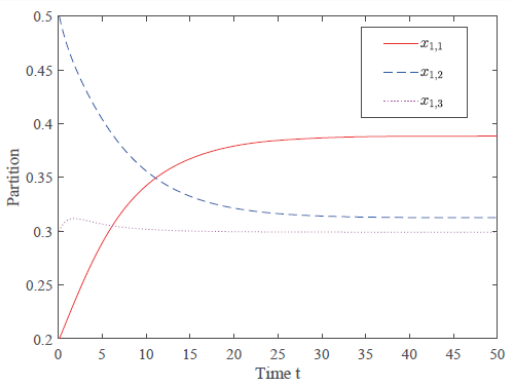


Direction Field of the replicator dynamics showing the stability of the evolutionary equilibrium

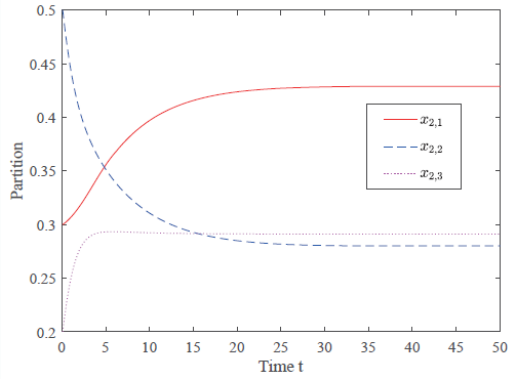
Performance Evaluation



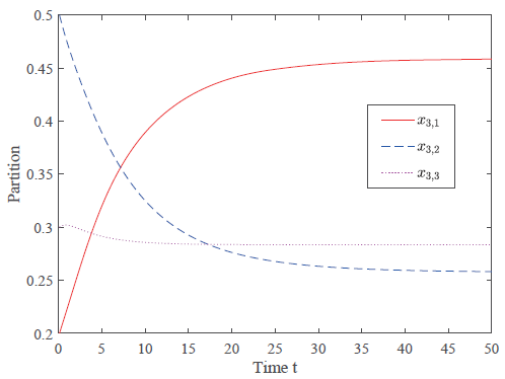
(a) Utility



(b) Mobile device 1



(c) Mobile device 2



(d) Mobile device 3

Evolutionary Game Dynamics: Utility and Training Strategy Variations of Mobile Devices

Conclusions

- **Contributions**
  - ✓ We proposed two metrics, i.e., the accuracy and energy consumption of federated learning performance, which correspond to the benefit and cost, respectively.
  - ✓ An evolutionary game model is formulated to investigate the mobile devices' training strategies under the scenario of multiple model owners. The uniqueness and stability of the evolutionary equilibrium are analyzed, and the stability is further validated numerically.

- **Future work:**
  - Take the non-iid property of federated learning into consideration

Questions & Answers

Thank you !