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Revenue-optimal task scheduling and resource management for IoT batch jobs in mobile edge computing

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Abstract

( ) , ( ) . , , . ( ) - , . ( ) . , - .

Keywords ( ) · . . . -

1 Introduction

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2 Related work

2.1 Peer-to-peer network

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2.2 Edge computing

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3 System model and problem formulation

3.1 Fundamental notations

System overview

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τ, t.

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τ.

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Γ.

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Γ ,

τ. A

Γ,

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t

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$R_j(t)$

A_j, $R_j(t) \leq A_j$.

. j

Table 1

t, τ	,
Γ	
i, N, N	, ,
j, M, M	, , /
B_i	i
L_j	/ j
M_i	/ i
N_j	/ j
μ_i^{lc}, μ_i^{rc}	i ,
$f_i, f_{\mathcal{M}}$	i,
τ_i^{lc}, τ_i^{rc}	, i
δ_i^{rc}	i
w_i, h_i, p_i	, , i
σ	
$d_{i,j}^{tr}, \tau_{i,j}^{tr}$	, i j
τ_i	i
$\mathsf{T}_{i,j}$	j i
$A_j, R_j(t)$	j , t
$k, \mathsf{R}_j(t)$	, j t
$\alpha_{i,j}(t)$	j i t
$\lambda_{i,j}^k(t)$	λ- 26

, t. , , $j \in \mathcal{M}$. B_i N . A 3.1, τ_i , . 4.

$$\sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \frac{B_i}{\tau_i^{rc}} \cdot \alpha_{i,j}(t) \tag{4}$$

t, $j \in \mathcal{M}$, (5) .

$$\sum_{i\in\mathcal{N}_j} \alpha_{i,j}(t) \leq R_j(t) \qquad \forall j \in \mathcal{M}, \quad \forall t \in \mathcal{T}_{i,j} \tag{5}$$

B , τ_i

1. . 6.

$$\sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \frac{\alpha_{i,j}(t)}{\tau_i^{rc}} \leq 1 \qquad \forall i \in \mathcal{N} \tag{6}$$

- , .

$$\max_{\alpha_{i,j}(t)} \sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \frac{B_i}{\tau_i^{rc}} \cdot \alpha_{i,j}(t) \tag{7}$$

,

$$\sum_{i\in\mathcal{N}_j} \alpha_{i,j}(t) \leq R_j(t) \qquad \forall j \in \mathcal{M}, \quad \forall t \in \mathcal{T}_{i,j} \tag{8}$$

$$\sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \alpha_{i,j}(t) \leq \tau_i^{rc} \qquad \forall i \in \mathcal{N} \tag{9}$$

$$\alpha_{i,j}(t) \in \mathcal{R}_j(t) \quad \forall i \in \mathcal{N}, \quad \forall j \in \mathcal{M}_i, \quad \forall t \in \mathcal{T}_{i,j} \tag{10}$$

$\mathcal{R}_j(t)$ $\{0, 1, \ldots, R_j(t)\}$, $\mathcal{T}_{i,j}$ $\{\tau_i^{lc} + \tau_{i,j}^{tr}, \tau_i^{lc} + \tau_{i,j}^{tr} + 1, ..., \tau_i\}$.

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4 Algorithm design

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4.1 Task scheduling framework overview

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B_i, τ_i , $etc.$) . A
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B_i
τ_i .
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τ_i .
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$\alpha_{i,j}(t)$,

$$\Gamma = \Gamma + 1.$$

4.2 Integral optimum guarantee

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(8) (9),
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- - $\mathbf{C}_{r\times c}$.
$\mathbf{C}_{r\times c}$,
: (1) A $a_{x,y}$
$\mathbf{C}_{r\times c}$ $\{-1, 0, 1\}$; (2)
R_1 R_2
{1,

: $\mathbf{C}_{r\times c}$ (8) (9),

r c, . 11 12.

, r_1 r_2 (8) (9).

$\boldsymbol{\alpha}$.

$$r = r_1 + r_2 = \sum_{j\in\mathcal{M}} \sum_{i\in\mathcal{N}_j} \left(\tau_i - \tau_i^{lc} - \tau_{i,j}^{tr} + 1 \right) + N \quad (11)$$

$$c = \sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{M}_i} \left(\tau_i - \tau_i^{lc} - \tau_{i,j}^{tr} + 1 \right) \quad (12)$$

, $\mathbf{C}_{r\times c}$ {0, 1}, 1 -1, 0, 1. , 2, {1, 2, ..., r_1} R_1. A , R_2, $R_1 \cap R_2 = \emptyset$. $\mathbf{C}_{r\times c}$ $a_{x,y}$, x y . (8), R_1 $1\times c$ 1, . 13. (9), , R_1 $1\times c$ 1, (14). (13) (14) , $\mathbf{C}_{r\times c}$ 2 . 15.

$$\sum_{x\in R_1} a_{x,y} = 1, \ \forall y \in \{1, 2, ..., c\} \quad (13)$$

$$\sum_{x\in R_2} a_{x,y} = 1, \ \forall y \in \{1, 2, ..., c\} \quad (14)$$

$$\left| \sum_{x\in R_1} a_{x,y} - \sum_{x\in R_2} a_{x,y} \right| = 0 \le 1, \ \forall y \in \{1, 2, ..., c\} \quad (15)$$

, $\mathbf{C}_{r\times c}$,

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1 (10). (7) . (10) . 16.

$$\alpha_{i,j}(t) \in \left[0, R_j(t)\right] \quad \forall i \in \mathcal{N}, \forall j \in \mathcal{M}_i, \forall t \in \mathcal{T}_{i,j} \quad (16)$$

4.3 Equivalent LP transformation

, λ- (7) ( ) 26 . , (7) . $\alpha_{i,j}(t) \in \mathcal{R}_j(t) = \{0, 1, ..., R_j(t)\}$, (4) λ- .

$$\sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \sum_{k=0}^{R_j(t)} \frac{B_i}{\tau_i^{rc}} \cdot k \cdot \lambda_{i,j}^k(t) \quad (17)$$

, $\alpha_{i,j}(t)$ (7) $k \in \mathcal{R}_j(t)$, $\lambda_{i,j}^k(t) \in \mathbb{R}^+$, .

$$\alpha_{i,j}(t) = \sum_{k=0}^{R_j(t)} k \cdot \lambda_{i,j}^k(t), \quad \sum_{k=0}^{R_j(t)} \lambda_{i,j}^k(t) = 1 \quad (18)$$

$$\lambda_{i,j}^k(t) \in \mathbb{R}^+, \ \forall k \in \mathcal{R}_j(t) \quad (19)$$

(10), .

$$\max_{\alpha_{i,j}(t),\ \lambda_{i,j}^k(t)} \sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \sum_{k=0}^{R_j(t)} \frac{B_i}{p_i} \cdot k \cdot \lambda_{i,j}^k(t) \quad (20)$$

,

$$\sum_{i\in\mathcal{N}_j} \sum_{k=0}^{R_j(t)} k \cdot \lambda_{i,j}^k(t) \le R_j(t) \quad \forall j \in \mathcal{M}, \quad \forall t \in \mathcal{T}_{i,j} \quad (21)$$

$$\sum_{j\in\mathcal{M}_i} \sum_{t=\tau_i^{lc}+\tau_{i,j}^{tr}}^{\tau_i} \sum_{k=0}^{R_j(t)} k \cdot \lambda_{i,j}^k(t) \le \tau_i^{rc} \quad \forall i \in \mathcal{N} \quad (22)$$

$$\sum_{k=0}^{R_j(t)} \lambda_{i,j}^k(t) = 1 \quad \forall i \in \mathcal{N}, \quad \forall j \in \mathcal{M}_i, \quad \forall t \in \mathcal{T}_{i,j} \quad (23)$$

$$\alpha_{i,j}(t),\ \lambda_{i,j}^k(t) \in \mathbb{R}^+ \quad \forall i \in \mathcal{N}, \quad \forall j \in \mathcal{M}_i, \quad \forall k \in \mathcal{R}_j(t), \quad \forall t \in \mathcal{T}_{i,j} \quad (24)$$

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(20) $O(NMT^*R^*)$, T^* R^*

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. 21 23 $O(NMT^*)$.

$$T^* = \lceil \max_{i\in\mathcal{N}, j\in\mathcal{M}_i} \mathcal{T}_{i,j} \rceil, \quad R^* = \lceil \max_{j\in\mathcal{M}} A_j \rceil \quad (25)$$

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$O(NMT^*R^*)$.

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5 Evaluation

5.1 Experimental setup

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, L_i, B_i, τ_i

Table 2

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τ	2 ⋆	Γ	50
w_i	1.5	p_i	1 ⋆
σ	10^{-13} ⋆	δ_i^{rc}	2,000
L_i	550 - 750	B_i	10 - 15
A_j	5	τ_i	140 - 155

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5.2 Experimental results

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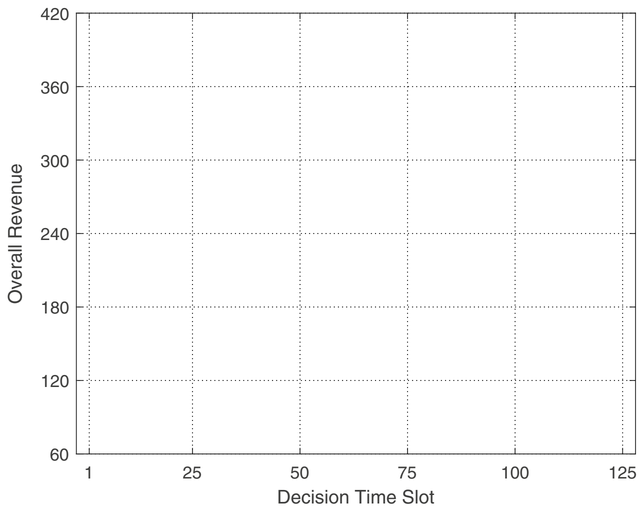
420
360
300
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Overall Revenue
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Decision Time Slot

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6 Conclusion and future work

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34(12):3590 3605
26. (1977) A
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15(6):935 946
27. ' , A, , 5 (2019)
. 12
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28. A, (2010) - -
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21(4):466 479
29. A AA, , , , B (2017)
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. : ., A . ( )
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30. , , A, 5 , , (2019) A
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94:351 367
31. , , , , , (2019)
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57(5):64 69
32. , 5, , (2017) -
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807
33. 5 , , , 5 (2016) - -
- . /A
24(5):2795 2808
34. 5 , , (2019)
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3(2):483 493
35. , , , , 5 5 (2019)
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. 6(1):545 556
37. , , , A , ,
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:// . /10.1109/ .2019.2901474
38. , , , , , (2019) A
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. :
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39. , (2014)
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Publisher's note

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