Multi-Armed Bandits Based Task Selection of A Mobile Crowdsensing Worker

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26th July, 2022

ICCCN 2022

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Smart devices

Embedded sensors

Wireless networks

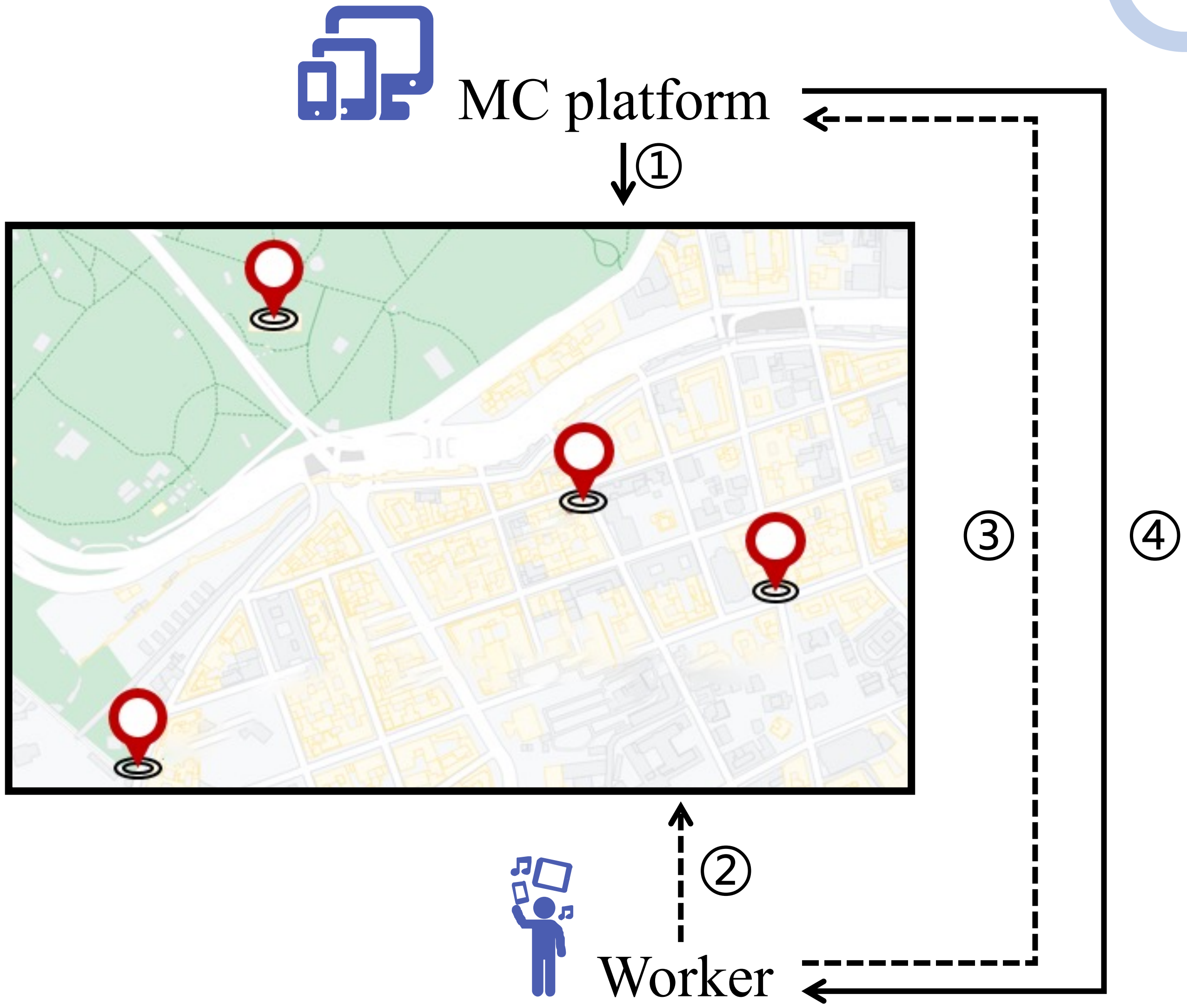
Mobile Crowdsensing (MC)

① The MC platform publishes sensing tasks.

② Workers decide on task selection and move to execute tasks.

③ Workers collect and submit data to the MC platform.

④ The MC platform pays workers corresponding reward.



Background

Mobile Crowdsensing

MC platform

Target

- maximize the number of tasks
- maximize the coverage of tasks
- ……

Ideal assumption

- workers always obey task assignment
- ignore the entitlement of workers

Worker

★ Target : Profit maximization

Task selection

Background

Scenario

- Unknown reward information
- Task execution $\Longrightarrow$ Resource consumption
- Position transfer $\Longrightarrow$ Extra cost / Traveling cost

Constraints

- Smart devices
- Worker preference
- Platform requirement

Target

- Profit maximization
  $\longrightarrow$ (Total reward - Total traveling cost)

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System model

Finite rounds

Time is slotted.

round 1	round 2	round 3	round 4	round 5	......	round $t(\mathcal{B})-2$	round $t(\mathcal{B})-1$	round $t(\mathcal{B})$

Before the system runs:

Tasks

- unknown
- heterogeneous
- location-based

Smart Devices

- limited resource ($\mathcal{B}$)

In each round:

Task Selection ← Specific standard

Position Transfer ← Traveling cost

Task execution ← Resource consumption

Problem Formulation

reward

traveling cost

$$Maximize: \mathbb{E}\Big[\sum_{t=1}^{t(\mathcal{B})}\Big(\sum_{s_i\in\mathcal{S}} r_i^t \cdot \mathbb{I}_i^t - \sum_{s_i,s_j\in\mathcal{S}} c_{ij}\cdot \mathbb{I}_i^{t-1}\cdot \mathbb{I}_j^t\Big)\Big]$$

$$Subject\ to: c_{ij} = 0 \ \text{ for } \ l_i^{t-1} \to l_j^t \text{ where } i = j$$

$$\sum_{t=1}^{t(\mathcal{B})}\sum_{s_i\in\mathcal{S}} \mathbb{I}_i^t \cdot b_i^t \le \mathcal{B}$$

$$\begin{cases} \sum_{s_i\in\mathcal{S}} \mathbb{I}_i^t = 1 \ \text{ for } \ \forall t \ge 1 \\ \mathbb{I}_i^t \in \{0,1\} \ \text{ for } \ \forall t \ge 1, s_i \in \mathcal{S} \end{cases}$$

Profit Maximization.

Traveling cost.

Limited resources.

1. At the same time, any task only has two states of being executed and not executed.
2. In each round, only one task is conducted by the worker.

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Basic Solution

Unknown task information

- Unaware of the reward information of the tasks.
- Solution : Reinforcement Learning Technique.

Profit maximization

- Maximize total profit ≈ maximize total reward while minimize total traveling cost.
- Solution : Epoch-style Algorithm.

✓ A Multi-Armed Bandit.

- exploration-exploitation dilemma;
- upper confidence bound strategy.

✓ UCB2 Strategy.

- epoch-style strategy;
- $$\widehat{r}_i(t) = \overline{r}_i(t) + \sqrt{\frac{(1+\alpha)\ln\left(\frac{et}{\lceil \tau(E_i(t)) \rceil}\right)}{2\lceil \tau(E_i(t)) \rceil}}$$

average reward

adjustment item

Constraint 1 : Smart Device

1. Task execution leads to continuous resource consumption (e.g., battery energy).
2. Resource consumption is negligible in position transfer.

Problems caused by constraint 1

1. Trade-off between reward and resource consumption.
2. Loss of total profit.

Adjustment to Basic Solution

- Learn the reward information and resource consumption of the task.
- Selection Standard.

$$i_{now} = \underset{s_i \in \mathcal{S}}{\operatorname{argmax}} \left(\left(\bar{r}_i(t) + \sqrt{\frac{(1+\alpha)\ln\left(\frac{et}{\lceil \tau(E_i(t)) \rceil}\right)}{2\lceil \tau(E_i(t)) \rceil}} \right) / \bar{b}_i(t) \right)$$

UCB-based reward

Average resource consumption

Constraint 2 : Worker Preference

1. The connotation of personal preferences is more complicated in actual situations.
2. Workers prefer closer locations and infrequent movements.

Problems caused by constraint 2

1. Trade-off between the previous selection standard and the traveling-cost-related preference.
2. Loss of total profit.

Adjustment to Previous Solution

- Take the traveling-cost-related preference as a penalty.
- Selection Standard :

$$i_{now} = \mathrm{argmax}_{s_i \in \mathcal{S}} \left(\hat{r}_i(t) / \bar{b}_i(t) - \varrho_1 p_{i_{old} i}(t) \right).$$

Previous selection standard

Traveling-cost-related preference

Constraint 3 : Platform Requirement

1. It is not advisable to view the MC process from only one perspective.
2. The platform has expectation for the number of rounds of task execution (called balance).

Problems caused by constraint 3

1. More complex trade-off due to the balance-related requirement.
2. A negative impact on the entitlement of workers in the long run.

Adjustment to Previous Solution

- Introduce the virtual queue.

$$Q_i(t) = \max\left\{0,\ Q_i(t-1) + e_i - \mathbb{I}\{i_{t-1}=i\}\right\}$$

- Selection Standard :

$$i_{now} = \underset{s_i \in S}{\operatorname{argmax}} \left(\underbrace{\widehat{r}_i(t)/\bar{b}_i(t) - \varrho_1 \cdot p_{i_{old}i}(t)}_{\text{Previous selection standard}} + \underbrace{\varrho_2 \cdot Q_i(t)}_{\text{The balance-related requirement.}} \right)$$

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Performance Evaluation

Metrics

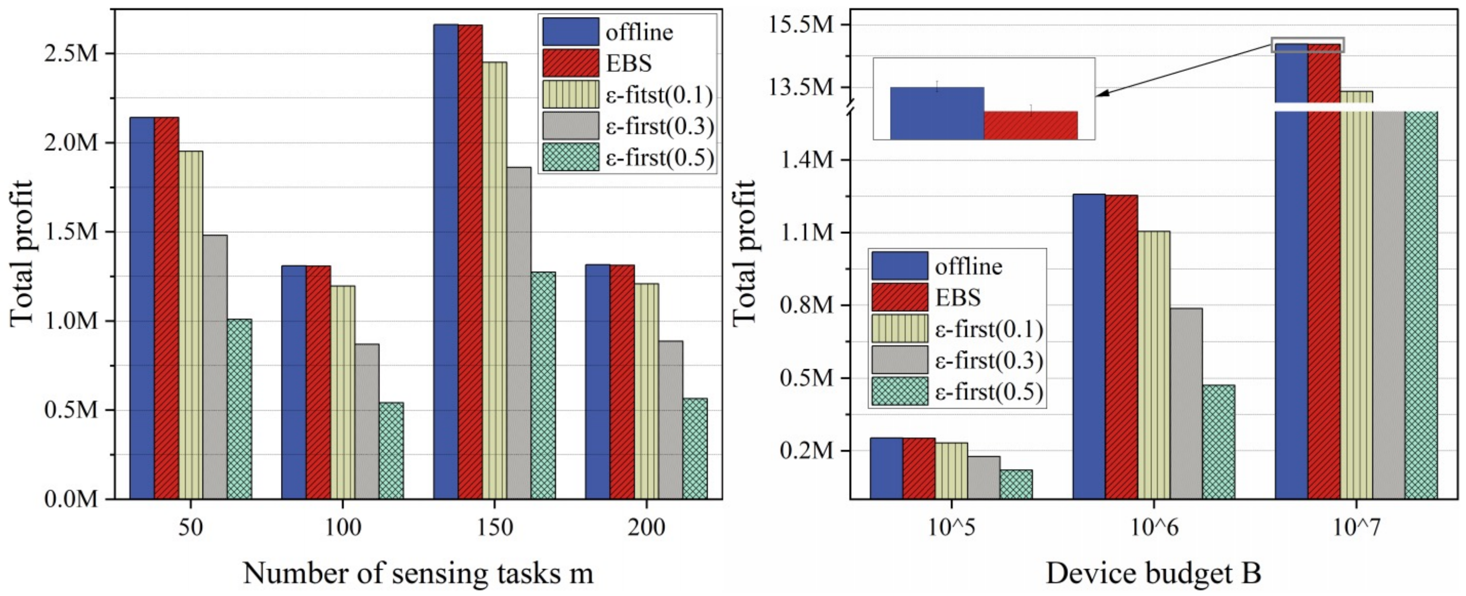
- total profit
- total traveling cost
- execution rounds of tasks

Algorithms

- EBS (constraint 1)
- PAS (constraint 2)
- BAS (constraint 3)

- offline algorithm
- ε-first algorithm ($\varepsilon \in \{0.1, 0.3, 0.5\}$)

Evaluation result of EBS

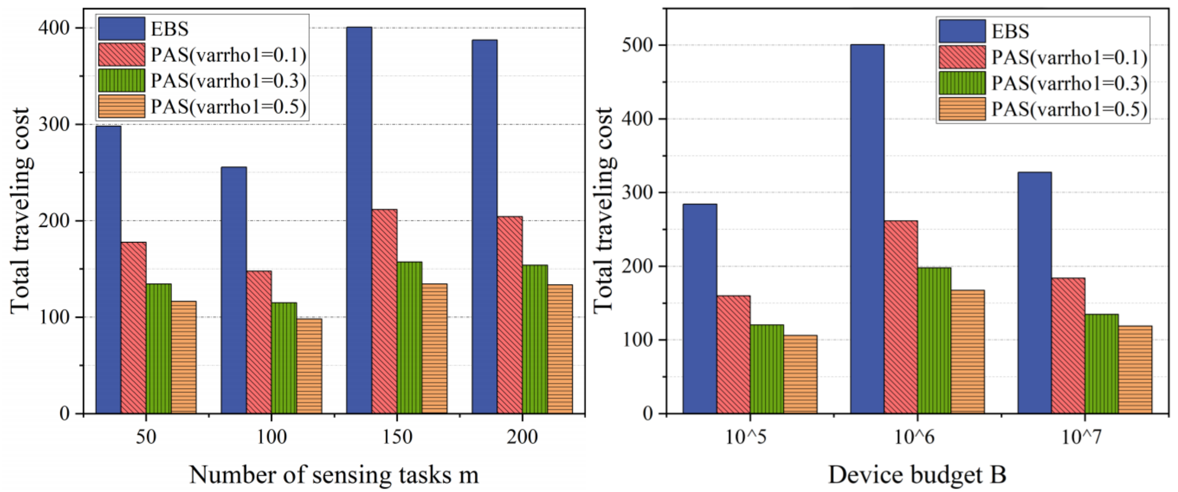


- The difference in the number of tasks and the device budget doesn't affect the performance of EBS.
- The total profit achieved by EBS has significantly better results than the ε-first algorithm.

Evaluation result of PAS

Total traveling cost

- PAS effectively reduces the total traveling cost.
- With the increase of ϱ_1, the reduction is more significant.



Total profit

- With the reduction in total traveling cost, the total profit slightly increases.
- PAS has higher usability in scenarios where the traveling cost between tasks is high.

TABLE III

COMPARISON OF PAS AND EBS UNDER DIFFERENT TASK NUMBERS

task number m	**metrics**	**PAS(0.1)**	**PAS(0.3)**	**PAS(0.5)**
50	traveling cost	-40.40%	-54.91%	-60.98%
	total profit	+0.10‰	+0.14‰	+0.16‰
100	traveling cost	-42.24%	-55.02%	-61.68%
	total profit	+0.05‰	+0.07‰	+0.08‰
150	traveling cost	-47.22%	-60.80%	-66.44%
	total profit	+0.08‰	+0.11‰	+0.12‰
200	traveling cost	-47.29%	-60.30%	-65.55%
	total profit	+0.08‰	+0.10‰	+0.13‰

The table shows the comparison results of PAS with different values of ϱ_1 and EBS under different task numbers in specific metrics.

TABLE IV

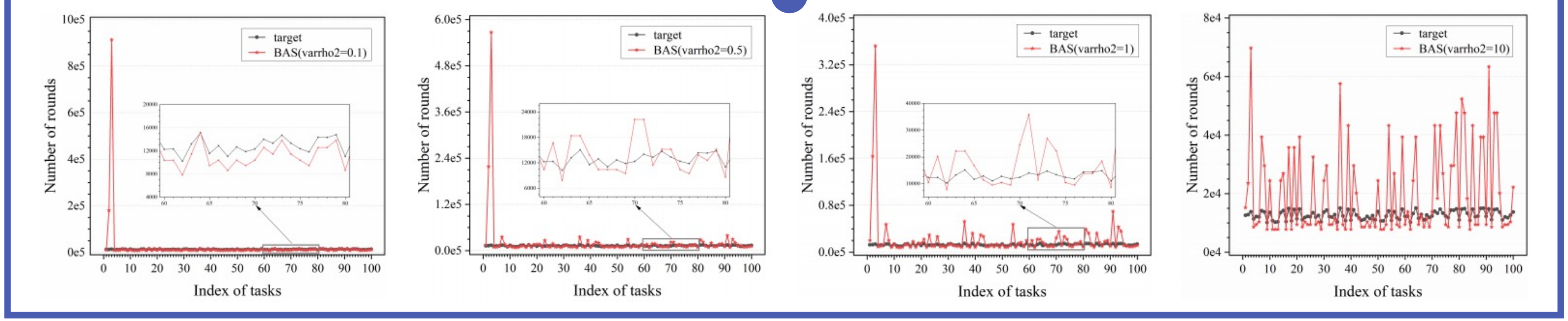
COMPARISON OF PAS AND EBS UNDER DIFFERENT DEVICE BUDGETS

device budget B	**metrics**	**PAS(0.1)**	**PAS(0.3)**	**PAS(0.5)**
10^5	traveling cost	-43.74%	-57.67%	-62.73%
	total profit	+0.78‰	+1.00‰	+1.10‰
10^6	traveling cost	-47.74%	-60.52%	-66.58%
	total profit	+0.21‰	+0.25‰	+0.30‰
10^7	traveling cost	-43.87%	-58.89%	-63.71%
	total profit	+0.006‰	+0.010‰	+0.011‰

The table shows the relative differences of PAS with different values of ϱ_1 compared with EBS in specific metrics under different device budgets.

Evaluation result of BAS

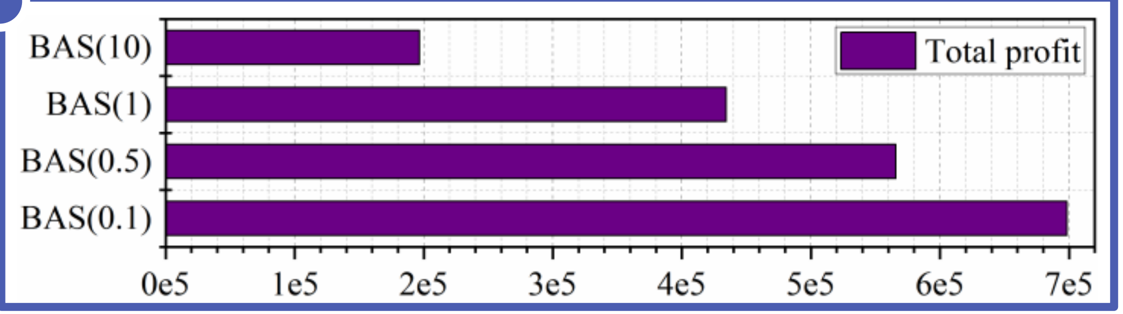
Execution rounds of tasks



- With the increase of ϱ_2, the execution rounds of tasks become more balanced.
- The proportion of tasks whose execution rounds meets the requirement of the platform shows an upward trend.

Total profit

- The achieved total profit by BAS decreases significantly since the worker compromises more with the platform.



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Conclusion

Summary

- View the Mobile Crowdsensing process from the perspective of an individual worker.
- Consider a scenario which is in line with our reality and further deal with possible constraints from different perspectives.
- Extensive simulations based on real-world verify the significant performance of our algorithms.

Future work

- More realistic scenarios.
- Multiple workers.

Thank you!

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