Distributed Game-Theoretical Route Navigation for Vehicular Crowdsensing

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I. Motivation and Problem

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**Motivation**

- **Mobile Crowdsensing (MCS)**
  - Vehicular crowdsensing
  - The existing task allocation strategies:
    - A heavy computation complexity
    - Fail to satisfy the preferences of users and the system.

**Mobile Crowdsensing (MCS)**

- Traffic monitoring
- Noise monitoring

**Platform**

**Distributed task allocation with the route navigation**
### Problem

**Question:** How to find an equilibrium state?

**Solution:**

<table>
<thead>
<tr>
<th>Approach</th>
<th>Solution</th>
<th>Profit</th>
<th>Equilibrium</th>
</tr>
</thead>
</table>
| Maximum profit              | $u_1: r_2$
                           | $u_2: r_3$
                           | $u_3: r_4$ | $u_1: 6/3=2$
                           | $u_2: 6/3=2$
                           | $u_3: 6/3=2$ | 6 | No |
| Distributed equilibrium      | $u_1: r_1$
                           | $u_2: r_3$
                           | $u_3: r_4$ | $u_1: 5$
                           | $u_2: 6/2=3$
                           | $u_3: 6/2=3$ | 11 | Yes |
| Centralized optimal          | $u_1: r_1$
                           | $u_2: r_3$
                           | $u_3: r_5$ | $u_1: 5$
                           | $u_2: 6$
                           | $u_3: 1$ | 12 | No |

*Note: $u_3$ can select $r_4$ to get more profit.*
Challenges

- How to construct a distributed model to achieve the equilibrium while guaranteeing the profit performance?

- How to design a unified distributed algorithm such that it could take the requirements of both the platform and users into consideration?

- How to guarantee a lower performance bound with respect to the centralized optimal solution?
System model

Profit of user $i$ under strategy profile $s$: $s = (s_i, s_{-i})$

$$P_i(s) = \alpha_i \cdot \sum_{k \in \mathcal{L}_{s_i}} \frac{w_k(n_k(s))}{n_k(s)} - \beta_i \cdot d(s_i) - \gamma_i \cdot b(s_i)$$

- the cost incurred by traveling the detour distance
- the cost incurred by the congestion

User parameters: $\alpha_i, \beta_i, \gamma_i$

System parameters: $\varphi, \theta$

An illustrative example of the influence of $\varphi$ and $\theta$

Profit function for $u_i$: $P_i(r_j) = \frac{w(r_j)}{n(r_i)} + \varphi \cdot h(r_j) + \theta \cdot c(r_j)$

<table>
<thead>
<tr>
<th>$r_1$</th>
<th>$r_2$</th>
<th>$h(r_i)$</th>
<th>$c(r_i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Achieve different purposes by adjusting the values of $\varphi$ and $\theta$.
Theoretical Analysis

- NP-hardness of The Centralized Problem

**Theorem 1.** The problem of finding the solution with the maximum total profit in a centralized manner is NP-hard.

- Nash equilibrium
  No user can improve the profit by altering the strategy unilaterally in a Nash equilibrium

- Potential game
  ✓ Nash equilibrium existence ✓ Finite improvement property

- Potential game proof

**Theorem 2.** The multi-user route navigation game is a weighted potential game and has a Nash equilibrium and finite improvement property.
Strategies

**Initialization Phase**

For user

**Algorithm 1** Distributed Game-Theoretical Route Navigation Algorithm for user $i \in U$.

1: Input $\alpha_i, \beta_i, \lambda_i$, the initial location and the destination.
2: Receive the recommended routes $R_i$.
3: Initialize $s_i(0) = r$ by randomly selecting a route $r \in R_i$.
4: Report $s_i(0)$ to the platform.
5: Receive $n_k$ for each task $k$ that is covered by $s_i(0)$.
6: Calculate the profit $P_i$.
7: Receive $d(r)$ and $b(r)$ for each route $r$ in $R_i$.
8: **repeat** for each decision slot $t$.
9: Obtain $n_k$ for each task $k$ that is covered by $R_i$.
10: Compute the best route set $\Delta_i(t)$.
11: **if** $\Delta_i(t) \neq \emptyset$ **then**
12: Send the request to contend the opportunity for updating decision.
   **if** Win the opportunity **then**
   Update the route selection decision $s_i(t)$ by selecting a route $r \in \Delta_i(t)$.
   Report $s_i(t)$ to the platform.
   **else**
   Choose the original decision $s_i(t) = s_i(t - 1)$.
13: **until** The termination message is received.

For platform

**Algorithm 2** Information Update Algorithm for the platform.

1: Send the recommended route set $R_i$ to the user $i \in U$.
2: Receive $s_i(0)$ from each user $i \in U$.
3: Calculate $n_k$ for each task $k \in L$.
4: Send $n_k, d(r)$ and $b(r)$ to the corresponding user.
5: **repeat** for each decision slot $t$.
6: Receive the request from the users and let $U'$ denote the set of users that send the request.
7: **if** $U' \neq \emptyset$ **then**
8: Select a set of users $\mu$ by SUU or PUU algorithm.
9: Inform the users in $\mu$ to update the decisions.
10: Receive $s_i(t)$ from user $i \in \mu$ and update $n_k$ for each task $k$.
11: **until** No request is received from the user.
12: Send the termination message to all users.

**Update strategy**

**Terminate the algorithm**

**Send the information to users**

**Select a set of users to update the strategy**
Performance Evaluation

- Convergence for Nash equilibrium

![Figure 3: User profit vs. decision slot.](image1)

![Figure 6: Potential function and total profit vs. decision slot.](image2)
Performance Evaluation

- Coverage and reward

**Figure 8:** Coverage vs. user number.

**Figure 9:** Average reward vs. task number.
Performance Evaluation

- The influence of user and system parameters

![Graphs showing average reward, detour distance, and congestion level](image)

Figure 12: The influence of system parameters.

Table 5: The influence of the user parameters.

<table>
<thead>
<tr>
<th>$\alpha_i$</th>
<th>reward</th>
<th>$\beta_i$</th>
<th>detour</th>
<th>$\gamma_i$</th>
<th>congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>7.74</td>
<td>0.1</td>
<td>12.24</td>
<td>0.1</td>
<td>12.03</td>
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<tr>
<td>0.2</td>
<td>7.85</td>
<td>0.2</td>
<td>10.97</td>
<td>0.2</td>
<td>10.48</td>
</tr>
<tr>
<td>0.3</td>
<td>7.94</td>
<td>0.3</td>
<td>9.88</td>
<td>0.3</td>
<td>9.52</td>
</tr>
<tr>
<td>0.4</td>
<td>7.96</td>
<td>0.4</td>
<td>9.38</td>
<td>0.4</td>
<td>8.75</td>
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<tr>
<td>0.5</td>
<td>7.98</td>
<td>0.5</td>
<td>8.84</td>
<td>0.5</td>
<td>8.48</td>
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<tr>
<td>0.6</td>
<td>8.08</td>
<td>0.6</td>
<td>8.38</td>
<td>0.6</td>
<td>8.20</td>
</tr>
<tr>
<td>0.7</td>
<td>8.10</td>
<td>0.7</td>
<td>8.07</td>
<td>0.7</td>
<td>8.05</td>
</tr>
<tr>
<td>0.8</td>
<td>8.16</td>
<td>0.8</td>
<td>7.99</td>
<td>0.8</td>
<td>7.97</td>
</tr>
</tbody>
</table>
Thanks for listening

Q&A