Facility Location Strategy for Minimizing Cost in Edge-Based Mobile Crowdsensing

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Outline

Background

❖ The limitation of centralized MCS

✓The significant computational burden on the central server.

✓The unpredictable network latency.

✓The risk of the user privacy leak.

Background

❖ The edge-based MCS

✓The mobile edge servers are deployed at network edge as the bridge between the central server and mobile users.

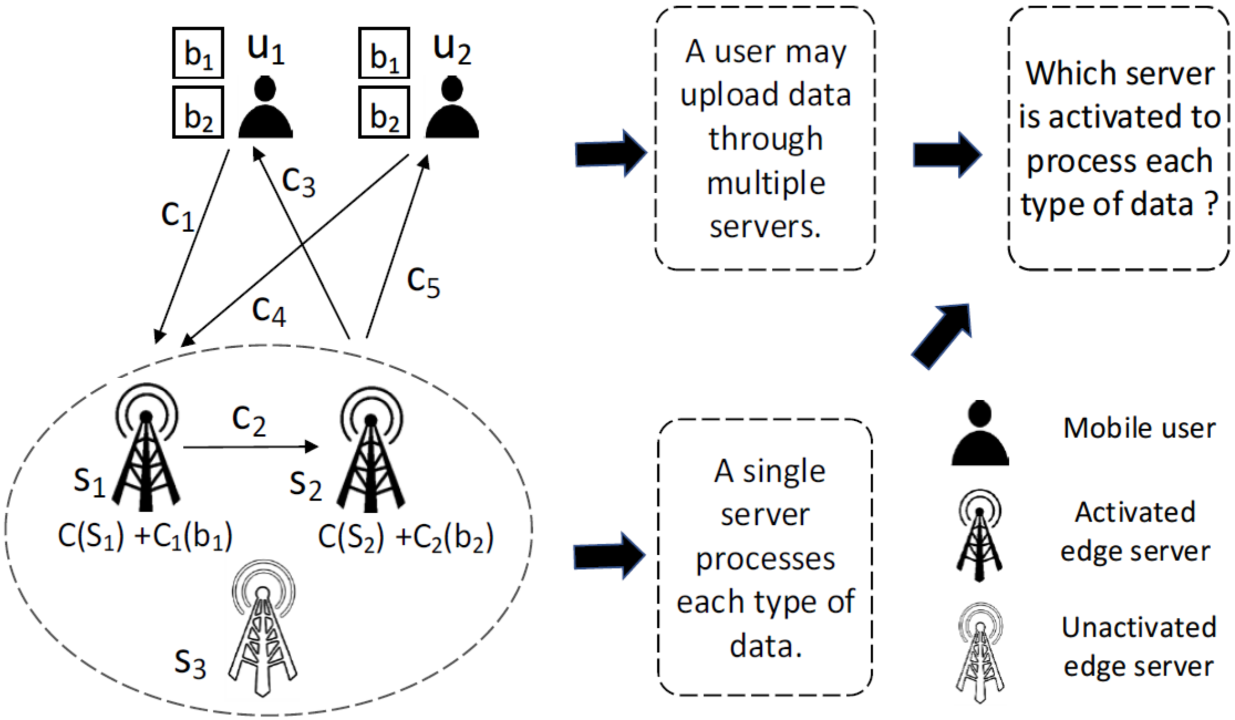
✓The mobile edge servers process and aggregate the uploaded data.

✓Each user may collect multiple types of data. To facilitate data aggregation, the same type of data should be uploaded to the same edge server.

Background

✓The total cost includes service cost and facility cost

✓Which server to activate for processing data and how to make a suitable match between users and mobile edge servers in order to minimize the total cost?



Challenges

- The problem is formulated as a variant of the facility location problem, which raises the following challenges:

✓The simplest facility location problem is NP-hard.

✓there are multiple data types and each user carries a subset of those types of data, so it is more difficult to find a facility location strategy with minimum cost .

✓It is difficult to find a solution with a bound of total cost to the optimal solution.

Problem Formulation

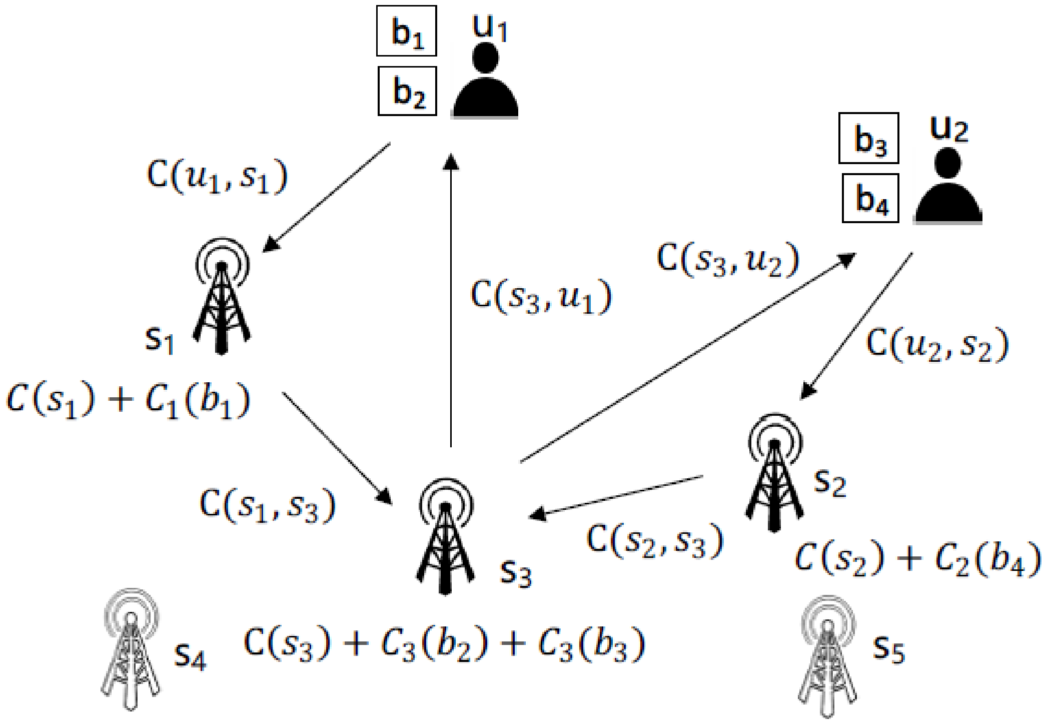
Service cost

- u-s service cost: the cost for travelling between the edge server and the initiation.
- s-s service cost: the cost for travelling between edge servers.

Facility cost

- Each edge server s_i has an activation cost $C(s_i)$ and for each data type b, there is a processing cost $C_i(b)$ for server s_i.
- Each edge server s_i can operate in any configuration $\beta(i) \in 2^B$ with the facility cost $C_i(\beta)$. $C_i(\beta) = C(s_i) + \sum_{b \in \beta} C_i(b)$.

Problem Formulation



For user u_1:

✓u-s service cost: $C(u_1, s_1) + C(s_3 + u_1)$

✓s-s service cost: $C(s_1, s_3)$

For server s_1:

✓the activation cost: $C(s_1)$

✓The cost for processing data: $C_1(b_1)$

Assumption: a mobile user carries at most two types of data.

Problem Formulation

❖ The formulated problem

✓When b=0, $C_i(b)$ denotes the cost for activating edge server i and b>0, $C_i(b)$ denotes the cost for processing data b.

$$
\begin{aligned}
Minimize\ \ & \sum_{i=1}^{m}\sum_{b=0}^{r} C_i(b) y_i^b + \sum_{j=1}^{n} C_j \\
s.t.\ \ & \sum_{i=1}^{m} x_{ij}^b = 1 \qquad && \forall b \in B_j, \forall j \in U \\
& \sum_{i=1}^{m} y_i^b = 1 && \forall b \in B \\
& x_{ij}^b \leq y_i^b && \forall b \in B, \forall i \in S, \forall j \in U \\
& y_i^b \leq y_i^0 && \forall b \in B, \forall i \in S \\
& x, y \in \{0, 1\}
\end{aligned}
$$

Strategy

❖ Overview of strategy

✓Transform each user into a set of virtual users where a virtual user has only one type of data.

✓Transform the objective function into a linear version and get the fractional solution by solving the linear relaxation.

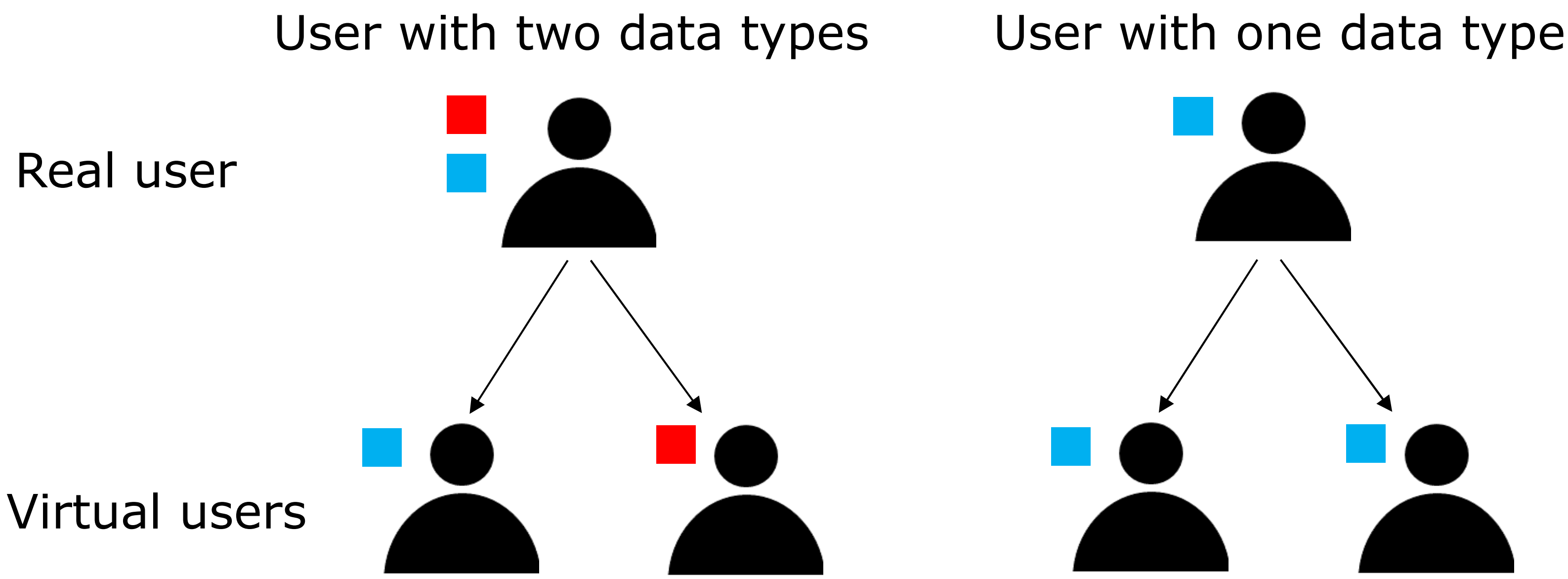
✓Filter the fractional solution.

✓Select a group of representatives from the virtual users.

✓Round the fractional solution into the integer solution to assign the representatives to the mobile edge servers and then assign the users to the servers that serve their representatives.

Strategy

❖ User virtualization



✓The u-s service cost of the real user is equal to the sum of the u-s service costs of its virtual users.

Strategy

❖ Linear relaxation

✓Relax the constraints as follows.

$$
\begin{aligned}
Minimize \quad & \sum_{i=1}^{m}\sum_{b=0}^{r} C_i(b)y_i^b + \sum_{j=1}^{n} C_j \\
s.t. \quad & \sum_{i=1}^{m} x_{ij}^b \geq 1 && \forall b \in B_j, \forall j \in U \\
& \sum_{i=1}^{m} y_i^b \geq 1 && \forall b \in B \\
& x_{ij}^b \leq y_i^b && \forall b \in B, \forall i \in S, \forall j \in U \\
& y_i^b \leq y_i^0 && \forall b \in B, \forall i \in S \\
& 0 \leq x, y \leq 1
\end{aligned}
$$

✓Find the fractional solution that minimizes the sum of facility cost and the virtual users' u-s service costs. We also prove that the s-s service cost also has a bound to the optimal solution.

Strategy

❖ Filtering technique

✓$\{u_j^b : \forall b \in B_j\}$:the virtual user set for user j.

✓Order the edge servers that serve u_j^b according to no-decreasing order to u_j^b. Let ∅ be a permutation of those servers that $c_{\phi(1)j} \leq c_{\phi(2)j} \leq \cdots \leq c_{\phi(k)j}$

✓Let $p_j^b(\alpha) = c_{\phi(i^*)j}$, where $i^* = \min\left\{i' : \sum_{i=1}^{i'} x_{\phi(i)j}^b \geq \alpha\right\}, (0 \leq \alpha \leq 1)$. $\alpha_j^b = \sum_{i:c_{ij} \leq p_j^b(\alpha)} x_{ij}^b$.

$$\overline{x}_{ij}^b = \begin{cases} x_{ij}^b / \alpha_j^b, & c_{ij} \leq p_j^b(\alpha); \\ 0 & otherwise. \end{cases}$$

$$\overline{y}_i^b = min\{1, y_i^b / \alpha\}$$

Strategy

❖ Representatives selection

✓Classify the virtual users who carry the same type of data into groups and select a representative from each group.

✓D_b: the set of virtual users that carry b type of data.

✓selection cost for u_j $\hat{c}_j = \sum_{j' \in D_b} c_{jj'}$

✓Select the user with the minimum selection cost to be the representative of D_b.

Strategy

❖ Rounding technique

✓Keep a feasible solution $(\hat{x}, \hat{y})$. Initially, $(\hat{x}, \hat{y}) = (\bar{x}, \bar{y})$.

✓The activated edge server set: $\hat{S} = \{i \in S: \exists b, \hat{y}_i^b > 0\}$

✓The edge server set that serves representative j_b: $S' = \{i \in \hat{S}: \hat{x}_{ij}^b > 0\}$

✓For each representative j_b, select the server i' that has the minimum activation cost from S'. Round the value:

$\hat{y}_{i'}^b = 1,\ \hat{x}_{i'j}^b = 1$ and $\hat{y}_i^b = 0, \hat{x}_{ij}^b = 0$ for each $i \in S - i'$

✓Assign the remaining users to the servers which serve their representatives.

Theoretical Analysis

The facility cost is bounded within $\log k/\alpha$ of the optimal solution.

The u-s service cost is no more than $\left(\frac{3}{1-\alpha}+4\right)\cdot C_{OPT}$

The s-s service cost is bounded within d_{max}/d_{min}

The approximation ratio of the proposed strategy is the maximum value of $\{\frac{\log k}{\alpha}, \frac{3}{1-\alpha}+4, \frac{d_{max}}{d_{min}}\}$

Performance Evaluation

❖ Data preparation

Roma/taxi set   epfl/mobility set   geolife trajectory set

❖ Methods in Comparison

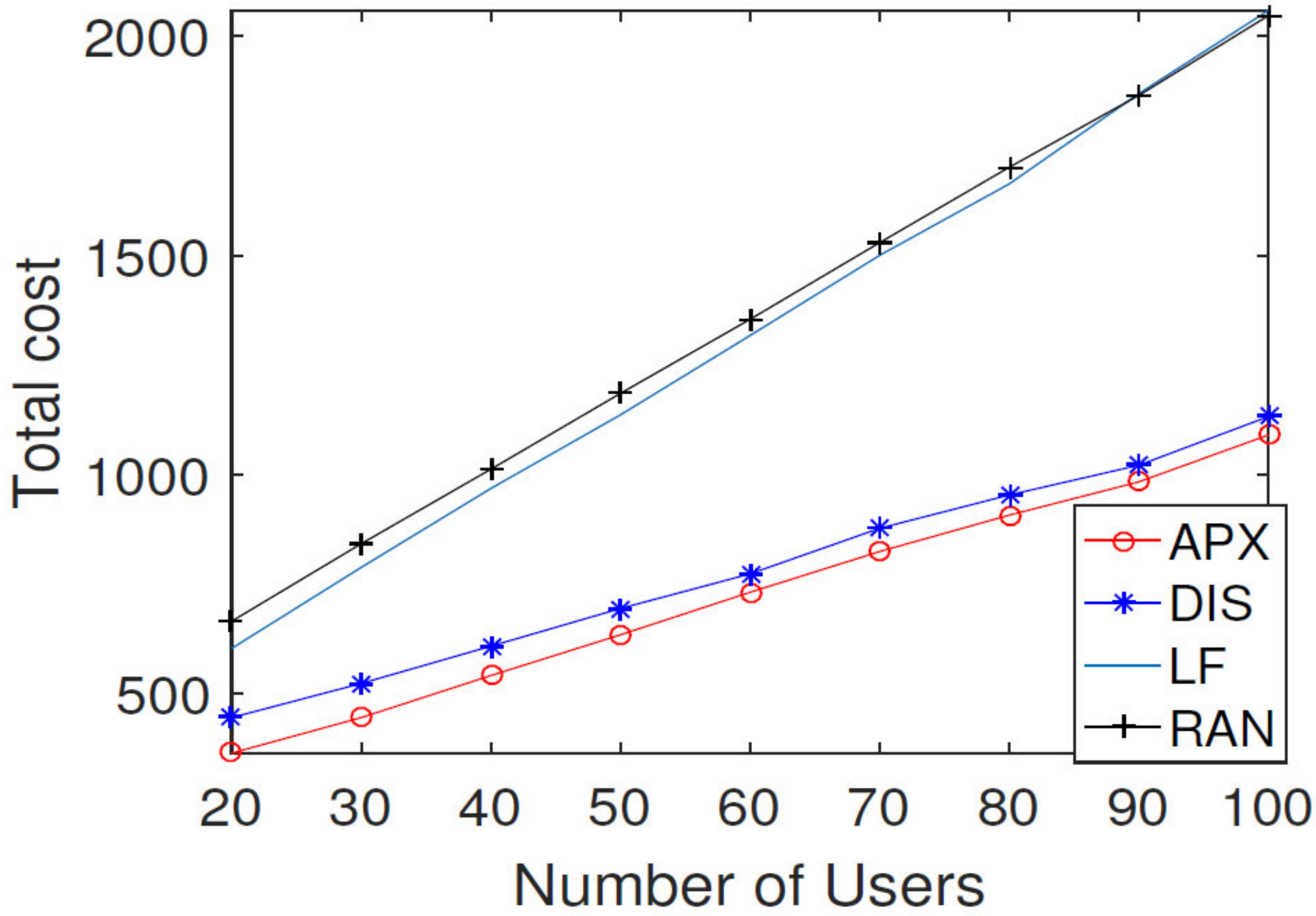
1. APX (the proposed approximation strategy in the paper)
2. DIS (for each data type, select the server that has the minimum average distance to the set of users with this data type)
3. LF (for each data type, select the server that has the minimum processing cost)
4. RAN (randomly select a server to each data type)

❖ Performance metric

total cost

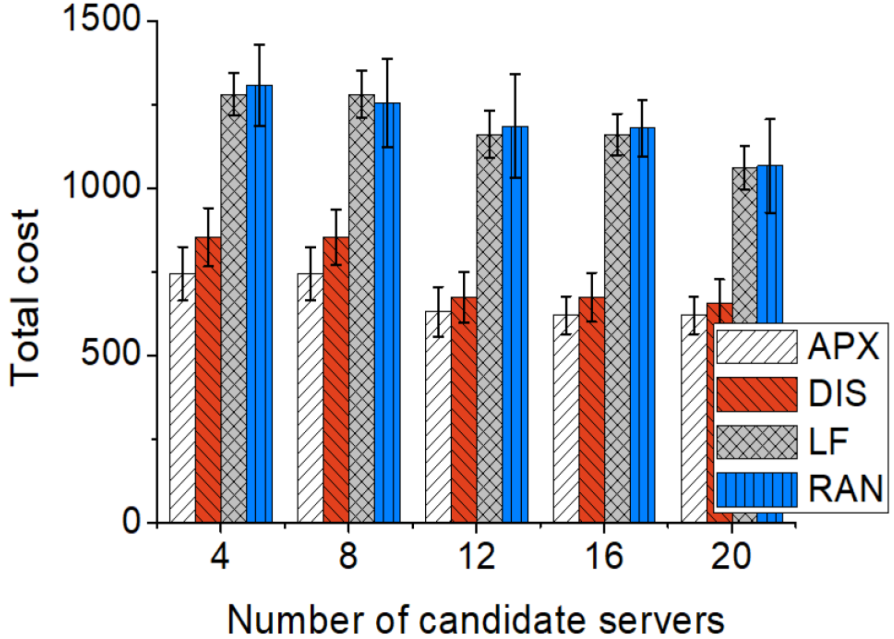
Performance Evaluation

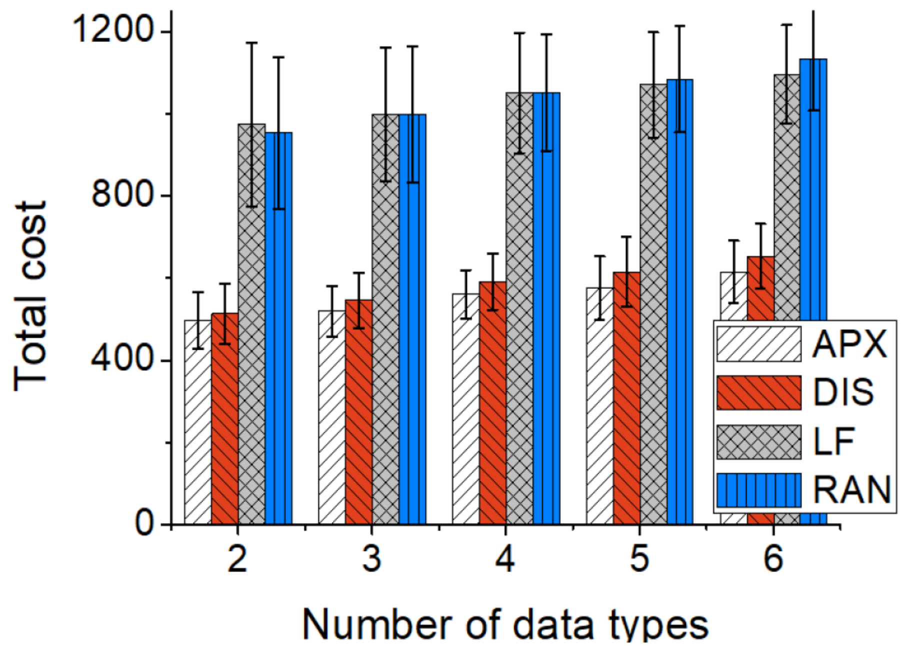
❖ The simulation result in terms of number of users



Performance Evaluation

- The simulation results in terms of number of candidate servers and data types





Performance Evaluation

- The comparison of facility cost between APX and the optimal solution

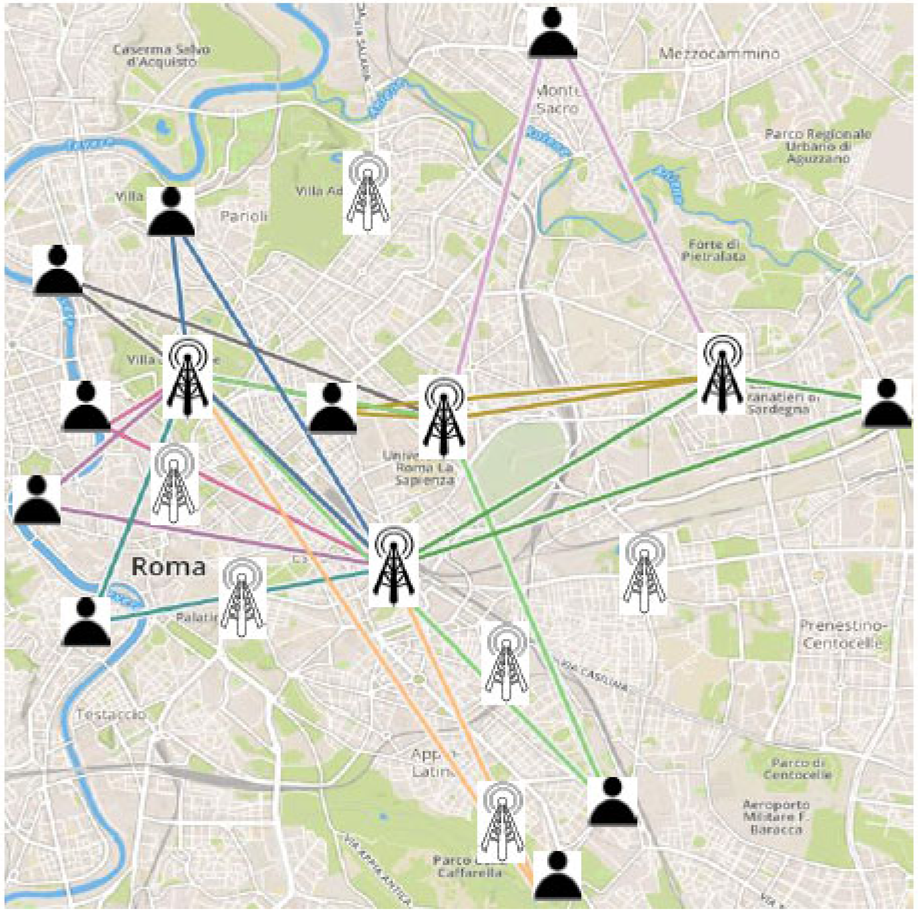
Data type number	APX	Optimal	Ratio	Bound
2	109	79	1.37	1.38
3	154	140	1.10	2.19
4	227	200	1.14	2.77
5	270	185	1.46	3.21
6	439	253	1.74	3.58

- The comparison of u-s service cost between APX and the optimal solution

α	APX	Optimal	Ratio	Bound
0.2	712	678	1.05	7.50
0.3	712	678	1.05	8.28
0.4	712	678	1.05	9.00
0.5	712	678	1.05	10.00
0.6	712	678	1.05	16.50

Performance Evaluation

❖ The presentation of the simulation results of APX in roma/taxi set



Thank you!

Q&A