# Optimal Selection of Crowdsourcing Workers Balancing their Utilities and Platform Profit

MS Thesis Defense


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Exam Roll: 1314 (2015 - 2016)

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# Presentation Outline

- Introduction
- Research Challenges and Motivation
- Related Work
- Contribution
- Proposed System
- Performance evaluation
- Summery of the thesis

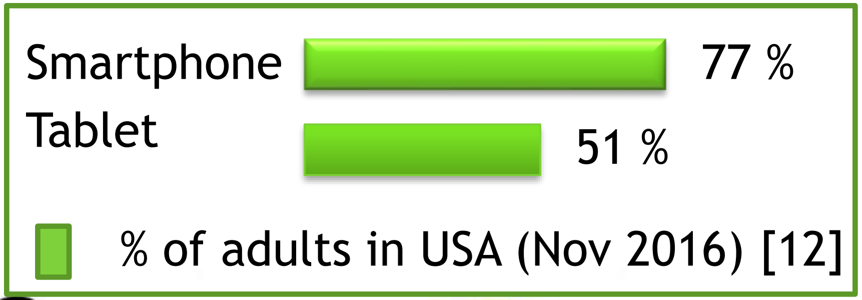
# Crowdsourcing

- Distributed problem solving model
- Outsources tasks to the crowd
  - Online community
  - Easy for human, difficult for computer
- Innovation
- Problem solving
- Efficiency


# Mobile Crowdsourcing

Smartphone

- ubiquitous
- seamless Internet connectivity (e.g.,Wi-Fi, cellular, etc.)
- multi sensing capabilities

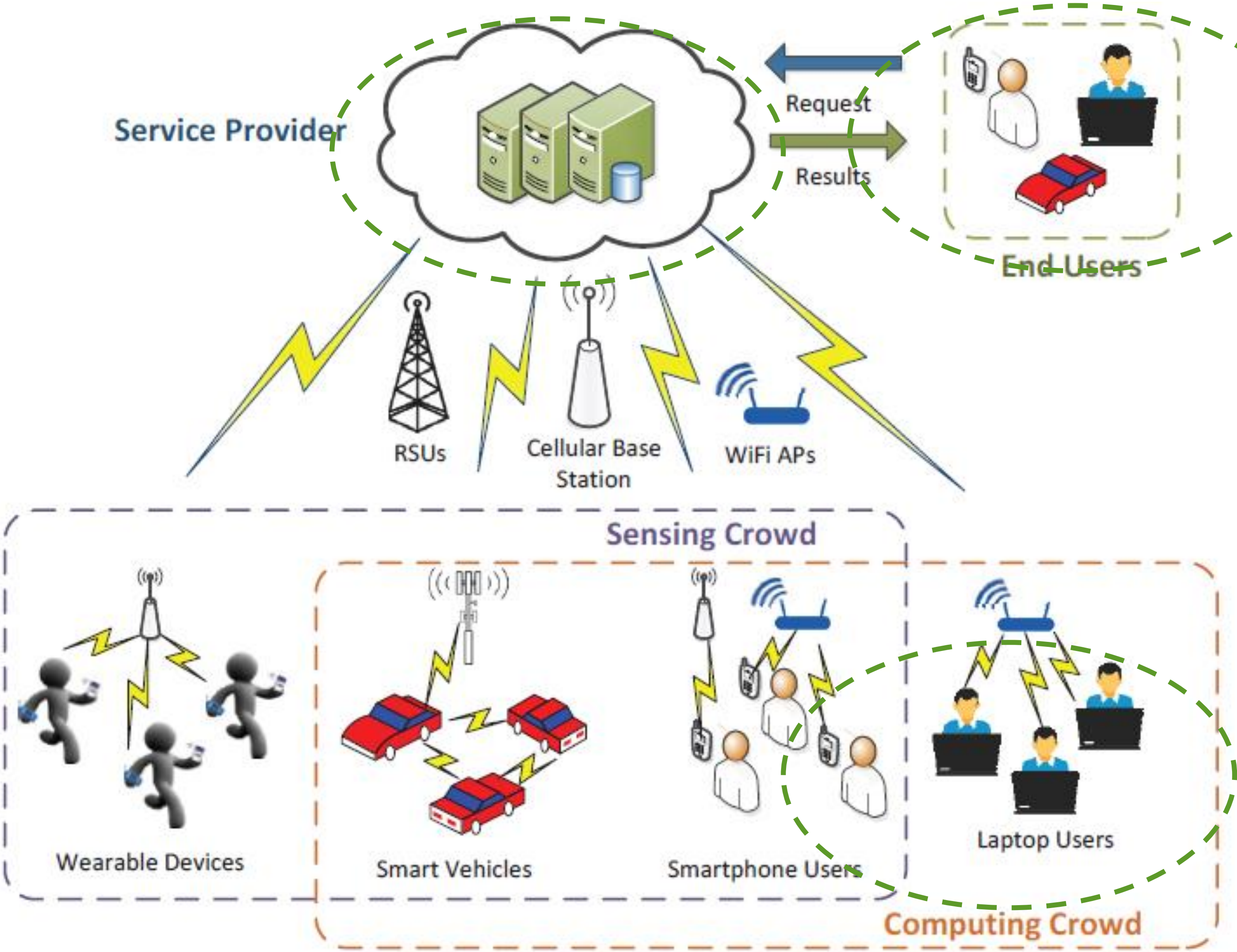




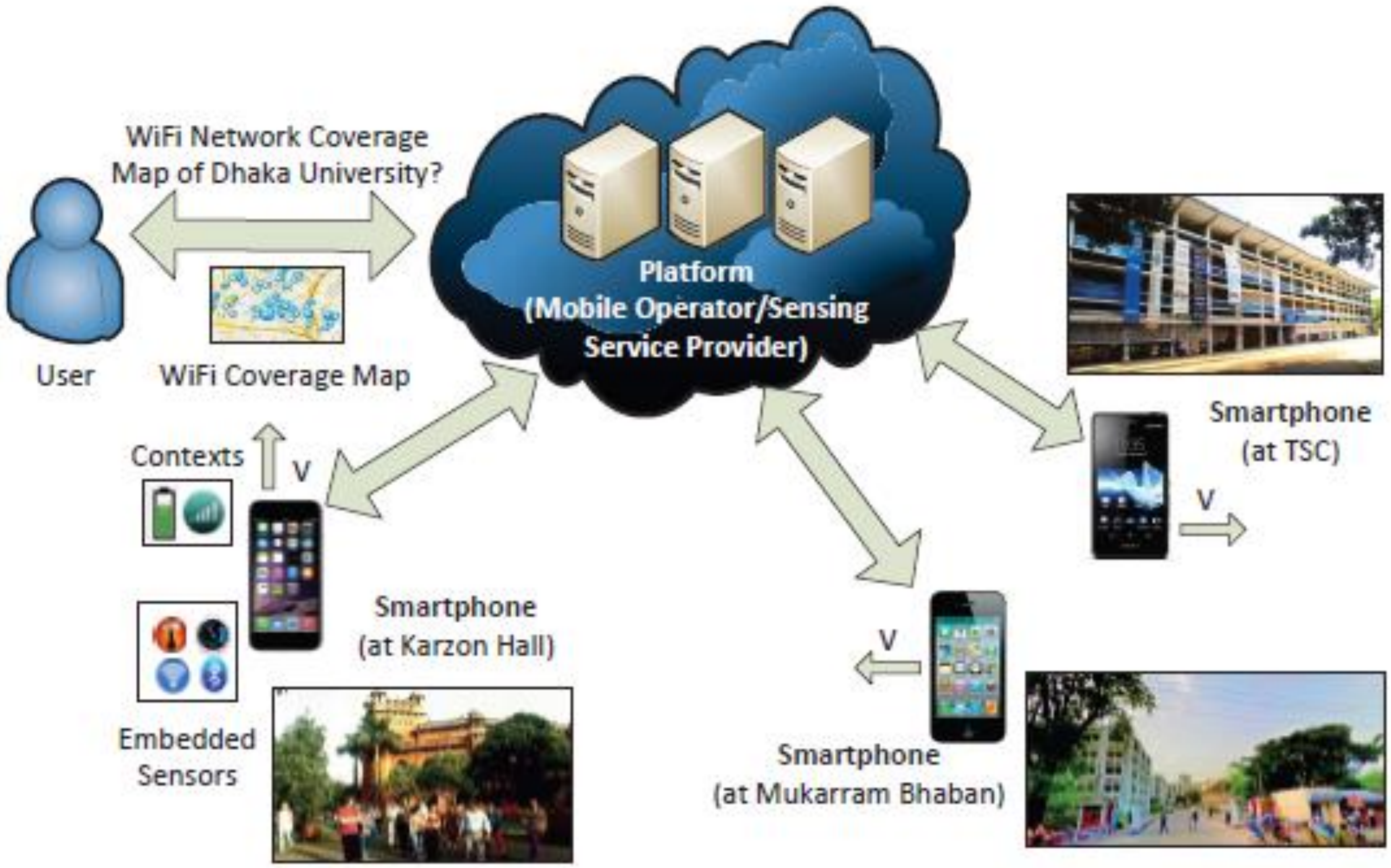
Mixing smartphone based mobile technologies and crowdsourcing offers a new paradigm called **Mobile Crowdsourcing (MCS)**

[12] “Mobile technology fact sheet,” Available online: http://www.pewinternet.org/fact-sheets/mobile technology-fact-sheet, accessed on 17 November 2017.

# Players in MCS



# An Example of MCS System



# Some MCS Applications

- Traffic monitoring and smart navigation
  - Nericel[3], Vtrack[4]
- Environmental monitoring
  - PIER[2], EarPhone[5]
- Social networking
  - crowdSMILE[28]
- Disaster Reporting
  - Project Jagriti[25]

# Challenges in MCS

- Decomposing service request into subtasks
- Considering workers spatial and temporal availability
- Controlling sensing quality
- Making sufficient profit from the MCS system
- Trade-off issues (e.g., profit quality trade-off)
- Data quality assessment
- Lucrative payment policy for the workers
- Managing past sensing reputation

# Research Questions

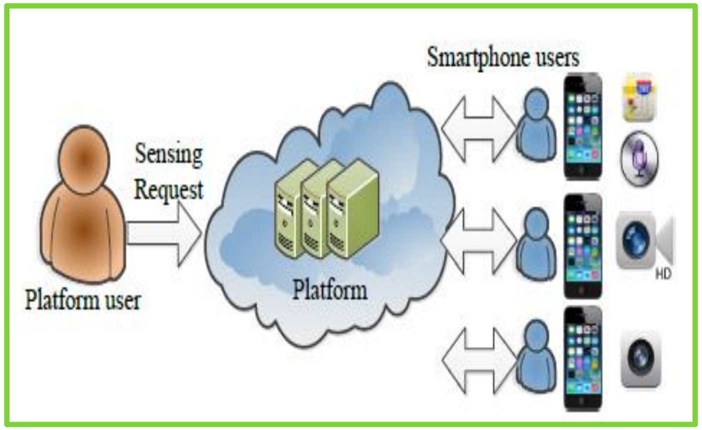
- How to maximize quality of sensed data while fixing a profit margin of the platform?
- How to maximize profit of a platform while keeping the required quality of sensed data for MCS applications?
- How to make a reasonable trade-off in between the above two performance metrics?

# State-of-the-Art-Works

# PROMOT Mechanism [39]

Greedily selects worker with a aim to maximize platform profit

Provide satisfactory reward to the winners




Do not consider worker's location or mobility

Tasks are considered atomic

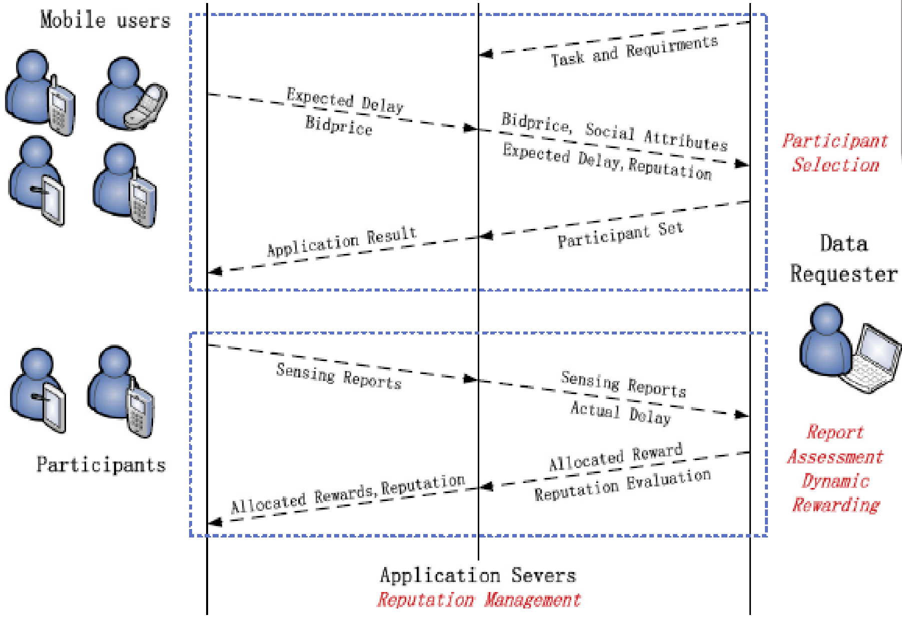
Do not consider worker past sensing reputation

[ 39] H. Shah-Mansouri and V. W. S. Wong, **"Profit maximization in mobile crowdsourcing: A truthful auction mechanism,"** in 2015 IEEE International Conference on Communications (ICC), June 2015, pp. 3216–3221.

# SACRM System [36]

Consider worker's social attribute, task completion delay and reputation

Report assessment and rewarding scheme




Profit of the platform is not considered

Do not consider worker mobility or location

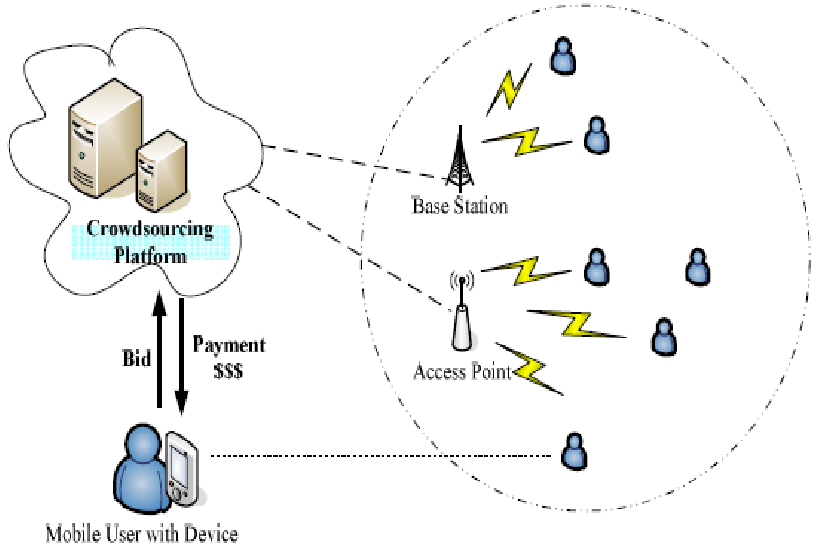
Can't handle heterogeneous task request

[ 36] J. Ren, Y. Zhang, K. Zhang, and X. S. Shen, **"Sacrm: Social aware crowdsourcing with reputation management in mobile sensing,"** Computer Communications, vol. 65, pp. 55 – 65, 2015, mobile Ubiquitous Sensing from Social Network Viewpoint.

# MSC System [46]

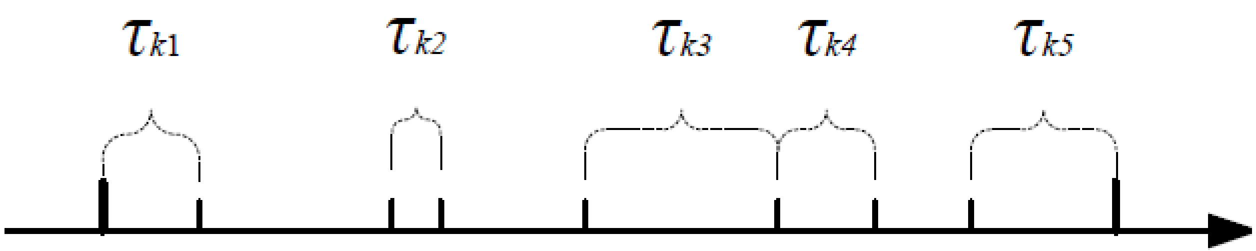
Consider Two patterns : continuous and Discontinuous

Selects workers with a aim to minimize social cost




Worker location, mobility or past sensing reputation are not considered

Can't handle heterogeneous task request

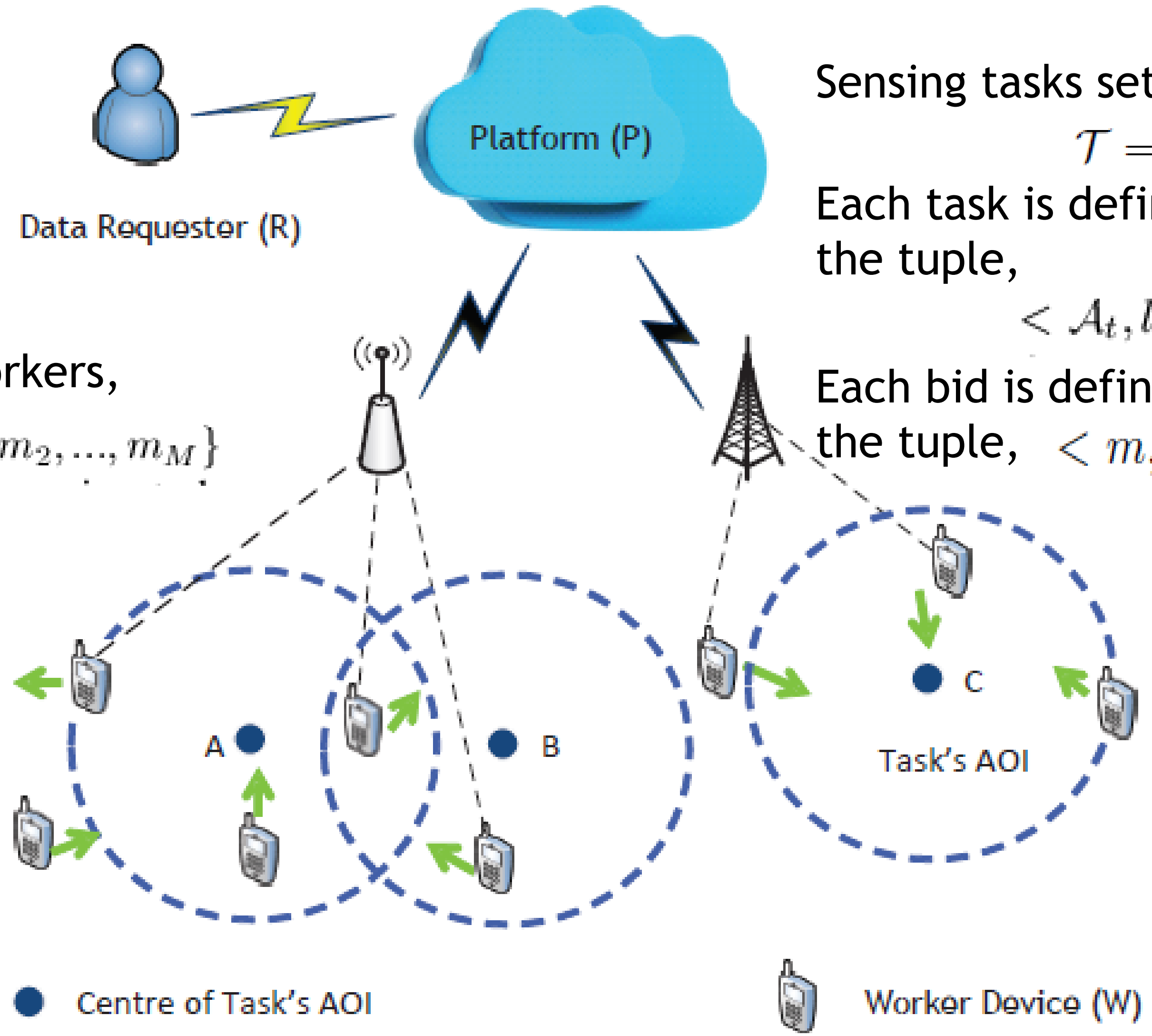



[46 ] Z. Duan, M. Yan, Z. Cai, X. Wang, M. Han, and Y. Li, **"Truthful incentive mechanisms for social cost minimization in mobile crowdsourcing systems,"** Sensors, vol. 16, no. 4, 2016.

# Thesis Contributions

- Designed a workload allocation framework for MCS platform named PQ-Trade system.
- Defined worker utility based on its mobility, current location and past sensing reputations.
- Allocation problem is formulated as MONLP problem
  - Proven to be NP-Hard
- Developed two greedy solutions
  - First fit utility maximization
  - First fit profit maximization
- A payment policy for the selected worker
- Performance evaluation of the algorithms and comparison with existing techniques

# System Model




Set of workers,

$$\mathcal{M} = \{m_1, m_2, ..., m_M\}$$

Sensing tasks set,

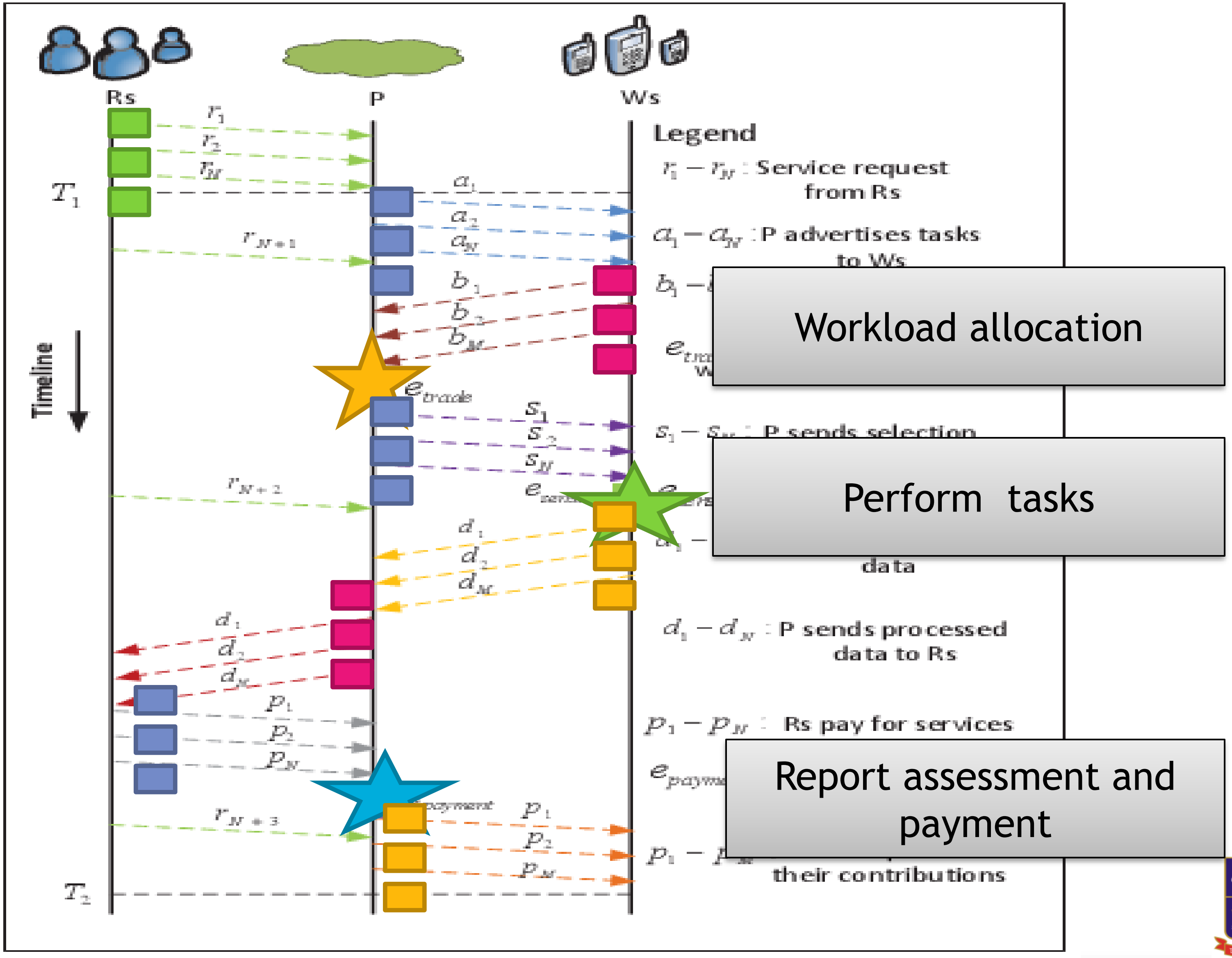
$$\mathcal{T} = \{t_1, t_2, ..., t_N\}$$

Each task is define by the tuple,

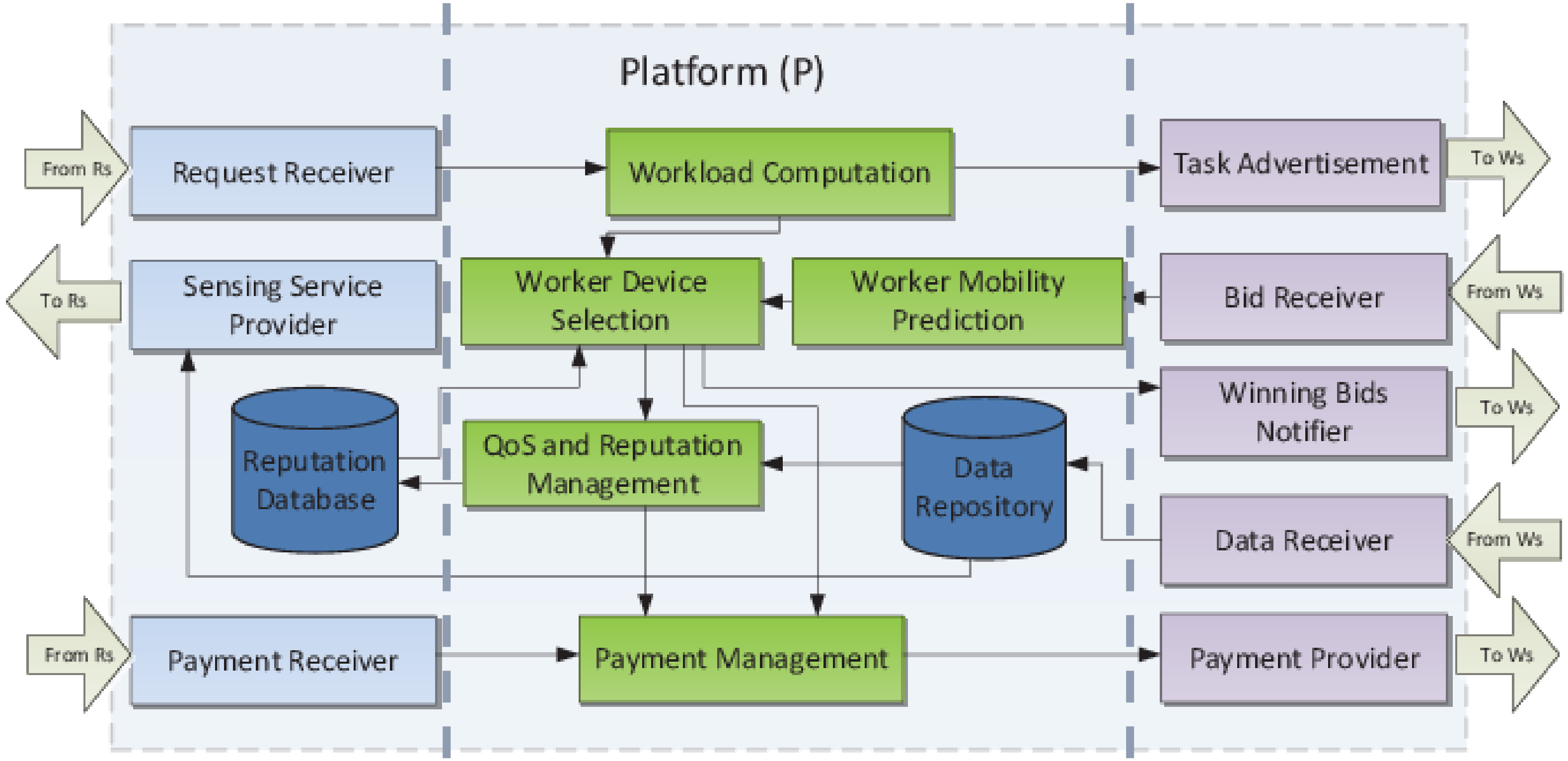
$$< A_t, l_t, r_t, D_t, \mathscr{W}_t, V_t >$$

Each bid is defined by the tuple, $< m, t, w_m^t, c_m^t, d_m^t >$

# Interaction among Entities



# Computational Model of PQ - Trade Platform




Interact with Data Requesters

Core Computational Modules

Interact with Worker Devices

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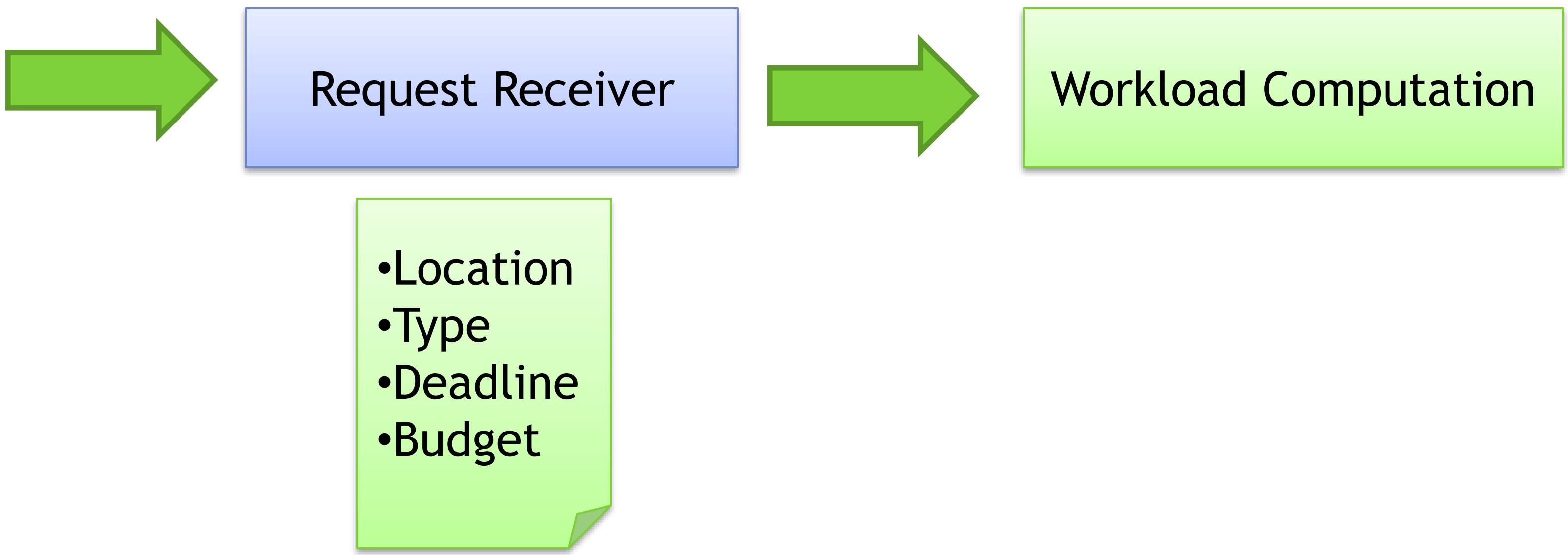
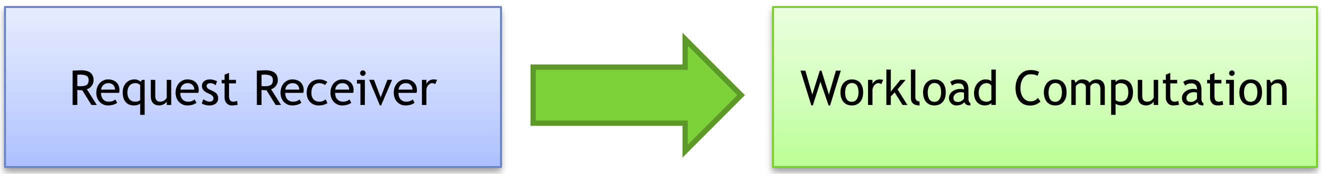
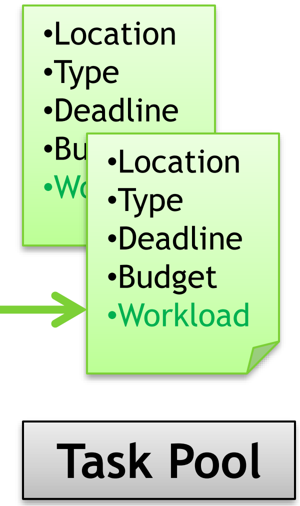
# Receiving Sensing Task Request



# Workload Computation




- Each task is divided into subtasks of **uniform size**.
- Total number of subtasks is defined as **workload** of that task

$$\mathscr{W}_t = \frac{\mathscr{V}_t}{\mathscr{S}_t}$$

Task volume

Size of uniform subtask

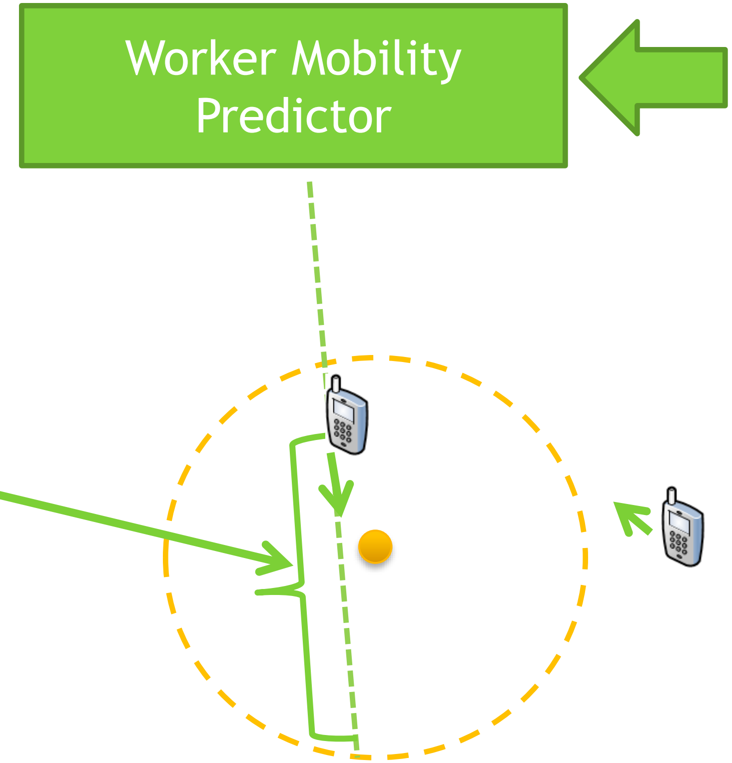
- For heterogeneous service request subtask definition can be more complex
  - Introduces another research problem [62]

[62] S. Chen, M. Liu, and X. Chen, “A truthful double auction for two-sided heterogeneous mobile crowdsensing markets,” *Computer Communications, vol. 81, no.* Complete, pp. 31–42, 2016.

# Calculation of Worker Sojourn Time in a Task's AOI

- Worker move at random direction with random velocity
- Smooth Random mobility mode to predict expected velocity, $\hat{E}(v)$ and sojourn time, $\mathscr{L}_t^m$ [65]

$$\mathscr{L}_t^m = \frac{||A - l_m||_2}{\hat{E}_m(v)},$$




[65] M. H. G. F. Asma Enayet, Md. Abdur Razzaque, "A mobility-aware optimal resource allocation architecture for big data task execution on mobile cloud in smart cities,"IEEE Communications Magazine, 2017.

# Utility of a Worker

Distance Based Utility

Mobility Based Utility

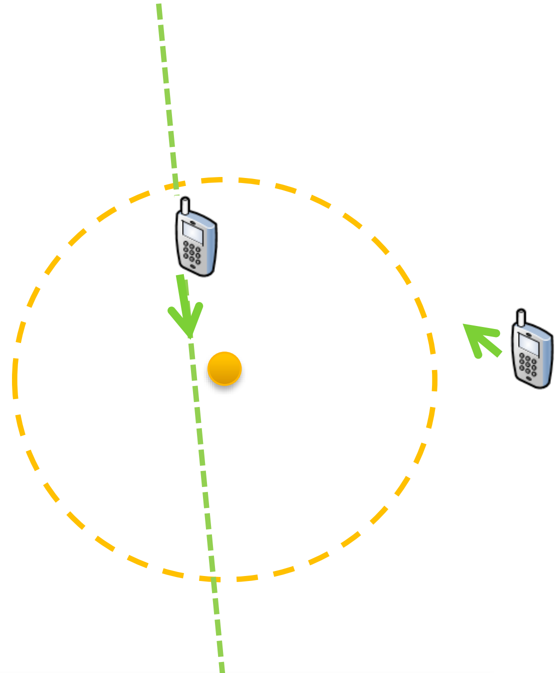
Past Sensing Quality Based Utility

# Mobility Based Utility Calculation

Worker Device Selection ← Worker Mobility Prediction

$$\mathcal{U}_{\mathcal{M}} = \begin{cases} 1 - e^{(d_m^t - min(\mathscr{L}_m^t, \mathcal{D}_t))} & d_m^t < min(\mathscr{L}_m^t, \mathcal{D}_t) \\ 0 & otherwise, \end{cases}$$

- $d_m^t$ is the completion delay of task t by worker m
- $\mathcal{D}_t$ is the delay deadline of task t
- $\mathscr{L}_t^m$ is the sojourn time of worker m in the AOI of task t

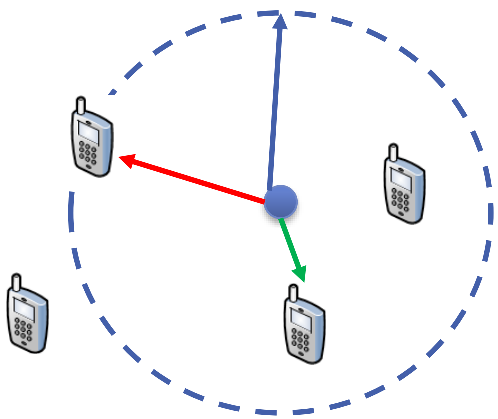


[36] J. Ren, Y. Zhang, K. Zhang, and X. S. Shen, "Sacrm: Social aware crowdsourcing with reputation management in mobile sensing," *Computer Communications, vol. 65, pp. 55 – 65, 2015.*

# Distance Based Utility Calculation

Worker Device Selection ← Worker Mobility Prediction

- Further away the user is, less sensing quality it can provide.
  - Temperature, Wi-Fi signal Strength, etc.
- Can be modeled as:



**Distance factor**

$$\mathcal{U}_{\mathcal{D}} = \begin{cases} \left(1 - \frac{||l_m - l_t||_2}{r_t}\right)^{\delta} & ||l_m - l_t||_2 \leq r_t, \\ 0 & otherwise, \end{cases}$$

# Location Based Utility Calculation

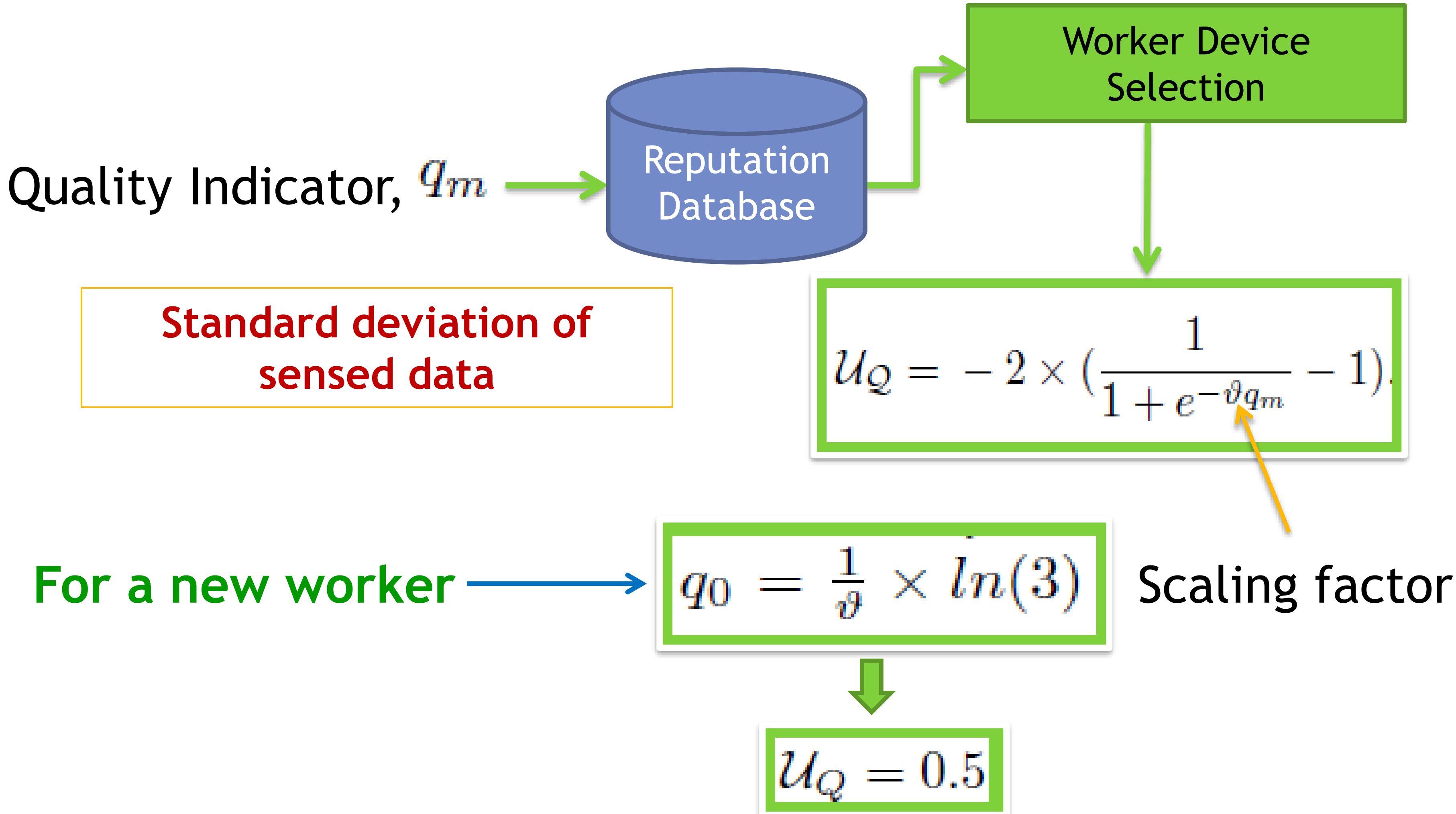
Worker Device Selection ← Worker Mobility Prediction

Combines $u_M$ and $u_D$ to define location based utility

$$u_{MD} = u_M \times u_D$$

**Worker with longer remaining lifetime and closer to the task center gives higher utility**

# Past Quality Based Utility Calculation




[37] B. Song, H. Shah-Mansouri, and V. W. S. Wong, "Quality of sensing aware budget feasible mechanism for mobile crowdsensing," *IEEE Transactions on Wireless Communications, vol. 16, no. 6, pp. 3619-3631, June 2017.*

# Combined Utility Calculation

- Now we calculate the combined utility of a worker m for performing task t as,

$$\mathcal{U}_m^t = \alpha \times \mathcal{U}_{\mathcal{MD}} + (1 - \alpha) \times \mathcal{U}_{\mathcal{R}}$$

weighting factor $(0 \leq \alpha \leq 1)$

# Profit of the Platform

- Profit of the Cloud Platform can be calculated as:

$$\mathcal{P}_m^t = \mathcal{V}_m^t - c_m^t;$$

Worker claimed cost

Monetary value of the task, $\mathcal{V}_m^t > 0$

- Now we calculate normalized profit as:

$$\rho_m^t = \frac{\mathcal{P}_m^t}{V^{max}},$$

where, $0 \leq \rho_m^t \leq 1$ and $V^{max} = \max_{t \in \mathcal{T}} V_t$.

# MONLP Problem Formulation

$$\mathscr{B}' = \underset{b \in \mathcal{P}(\mathscr{B})}{\operatorname{argmax}} \sum_{\forall \Gamma_m^t \in b} \{\omega \times \mathcal{U}_m^t + (1-\omega) \times \rho_m^t\}$$

where, $\omega$ $(0 \leq \omega \leq 1)$

$\omega = 1$ → **Utility maximization problem**

$\omega = 0$ → **Profit maximization problem**

$0 < \omega < 1$ → **Makes desired trade-off**

# Constraints

$$\sum_{\forall \Gamma_m^t \in b} w_m^t \leq \mathscr{W}_t, \quad \forall t \in \mathcal{T}$$ → **Workload constraint**

$$|\mathscr{B}' \bigcap \mathscr{B}_m| \leq n_m^{max}, \quad \forall \Gamma_m^t \in b$$ → **Maximum bid constraint**

$$\mathcal{U}_{MD} > 0, \quad \forall \Gamma_m^t \in b, \forall t \in \mathcal{T}$$ → **Worker availability constraint**

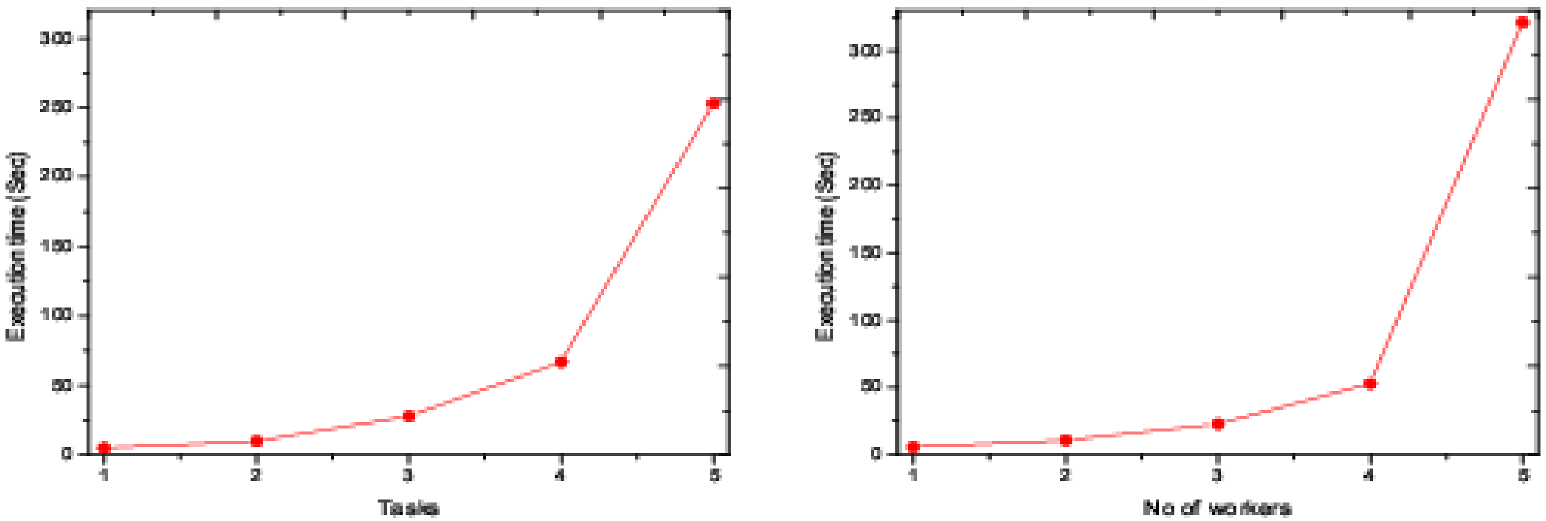
$$\mathcal{U}_m^t \geq \mathcal{U}_{th}^t, \quad \forall \Gamma_m^t \in b, \forall t \in \mathcal{T}$$ → **Marginal utility constraint**

$$\rho_m^t \geq \rho_{th}^t, \quad \forall \Gamma_m^t \in b, \forall t \in \mathcal{T}$$ → **Marginal profit constraint**

# Workload Allocation Problem is NP - Hard

- MONLP selects a subset b from P(B), i.e., $b \in P(B)$ that maximizes the objective function satisfying given constraints.
  - Same as **maximum weight subset selection** problem
    - **NP-hard**

# Execution Time




(a) Number of tasks (b) Number of workers

NEOS Optimization server (2x Intel Xeon E5-2698 @ 2.3GHz CPU and 92GB RAM

# First-Fit Greedy Solutions

- First-Fit Utility Maximization (FFU): aims at maximizing utility while keeps profit in a marginal level.

- First-Fit Profit Maximization (FFP): profit is maximized while utility is kept in a marginal level.

# FFP Maximization Algorithm

**Algorithm 1** First-Fit Utility Maximization Algorithm

**INPUT:** Set of bids of all workers, $\mathscr{B} \leftarrow \bigcup_{\forall m \in \mathcal{M}} \mathscr{B}_m$

**OUTPUT:** Set of winning bids, $\mathscr{B}'$

$\mathscr{B}' \leftarrow \phi$
**for all** $m \in \mathcal{M}$ **do**
  $n_m \leftarrow 0$
**end for**
**for all** $t \in \mathcal{T}$ **do**
  $w_t \leftarrow 0,\ c_t \leftarrow 0$
**end for**
**for all** $q \in \mathscr{B}$ **do**
  Calculate $\mathcal{U}_m^t$, $\mathcal{V}_m^t$ and $\mathcal{P}_m^t$ using Eq. (8), (9) and (10), respectively
**end for**
Sort $\mathscr{B}$ in descending order of $\mathcal{U}_m^t$
**while** $(\mathscr{B} \neq \phi)$ **do**
  $q \leftarrow$ First element of $\mathscr{B}$
  **if** $(\mathcal{P}_m^t \geq \mathcal{P}_{min}^t\ \&\&\ (\mathscr{W}_t - w_t) \geq w_m^t\ \&\&\ n_m < n_m^{max}\ \&\&\ (V_t - c_t) \geq c_m^t)$ **then**
    $\mathscr{B}' \leftarrow \mathscr{B}' \bigcup q$
    $w_t \leftarrow w_t + w_m^t,\ c_t \leftarrow c_t + c_m^t$
    $n_m \leftarrow n_m + 1$
  **end if**
  $\mathscr{B} \leftarrow \mathscr{B} \setminus q$
**end while**
**return** $\mathscr{B}'$

$$O(|\mathcal{M}|^2 \times |\mathcal{T}|^2).$$

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# FFU Maximization Algorithm

**Algorithm 2** First-Fit Profit Maximization Algorithm

**INPUT:** Set of bids of all worker, $\mathscr{B} \leftarrow \bigcup_{\forall m \in \mathcal{M}} \mathscr{B}_m$

**OUTPUT:** Set of winning bids, $\mathscr{B}'$

$\mathscr{B}' \leftarrow \phi$
**for all** $m \in \mathcal{M}$ **do**
    $n_m \leftarrow 0$
**end for**
**for all** $t \in \mathcal{T}$ **do**
    $w_t \leftarrow 0,\ c_t \leftarrow 0$
**end for**
**for all** $q \in \mathscr{B}$ **do**
    Calculate $\mathcal{U}_m^t$, $\mathcal{V}_m^t$ and $\mathcal{P}_m^t$ using Eq. (8), (9) and (10), respectively
**end for**
Sort $\mathscr{B}$ in descending order of $\mathcal{P}_m^t$
**while** $(\mathscr{B} \neq \phi)$ **do**
    $q \leftarrow$ First element of $\mathscr{B}$
    **if** $(\mathcal{U}_m^t \geq \mathcal{U}_{min}^t$ && $(\mathscr{W}_t - w_t) \geq w_m^t$ && $n_m < n_m^{max}$ && $(V_t - c_t) \geq c_m^t)$ **then**
        $\mathscr{B}' \leftarrow \mathscr{B}' \bigcup q$
        $w_t \leftarrow w_t + w_m^t,\ c_t \leftarrow c_t + c_m^t$
        $n_m \leftarrow n_m + 1$
    **end if**
    $\mathscr{B} \leftarrow \mathscr{B} \setminus q$
**end while**
**return** $\mathscr{B}'$

$O(|\mathcal{M}|^2 \times |\mathcal{T}|^2)$.

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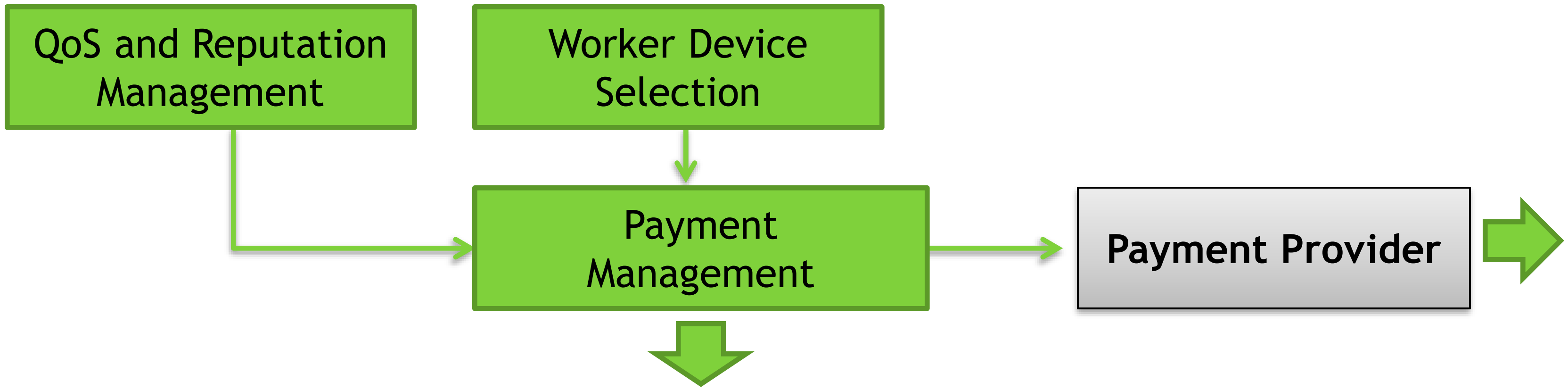
# Worker Payment Policy




$$\mathcal{P}^t = \begin{cases} c_m^t + \varphi & q_m^t \leq q_{max}^t \ \&\& \ \mathcal{P}_m^t \geq \mathcal{P}_{min}^t \\ \varepsilon \times c_m^t & q_m^t > q_{max}^t, \\ c_m^t & Otherwise, \end{cases}$$

**Penalty factor**

**Reward point**

$$\varepsilon = e^{(q_{min}^t - q_m^t) \times \theta_2}$$

$$\varphi = (\mathcal{P}_m^t - \mathcal{P}_{min}^t) \times \{1 - e^{(q_m^t - q_{max}^t) \times \theta_1}\}$$

**Weight factors**

# Worker Payment Determination Algorithm

**Algorithm 3** Determination of Payment Vector

**INPUT:** Set of winning bids, $\mathscr{B}'$

**OUTPUT:** Payment vector, $\mathscr{P}$

$\mathcal{M}' \leftarrow \{m : q_m^t \in \mathscr{B}'\}$
**for all** $m \in \mathcal{M}'$ **do**
    $\mathscr{P}_m \leftarrow 0$
**end for**
**for all** $q \in \mathscr{B}'$ **do**
    Calculate $p_m^t$ using Eq. (19)
    $\mathscr{P}_m \leftarrow \mathscr{P}_m + p_m^t$
**end for**
**return** $\mathscr{P}$

$O(|\mathcal{M}| \times (|\mathcal{T}| + 1))$

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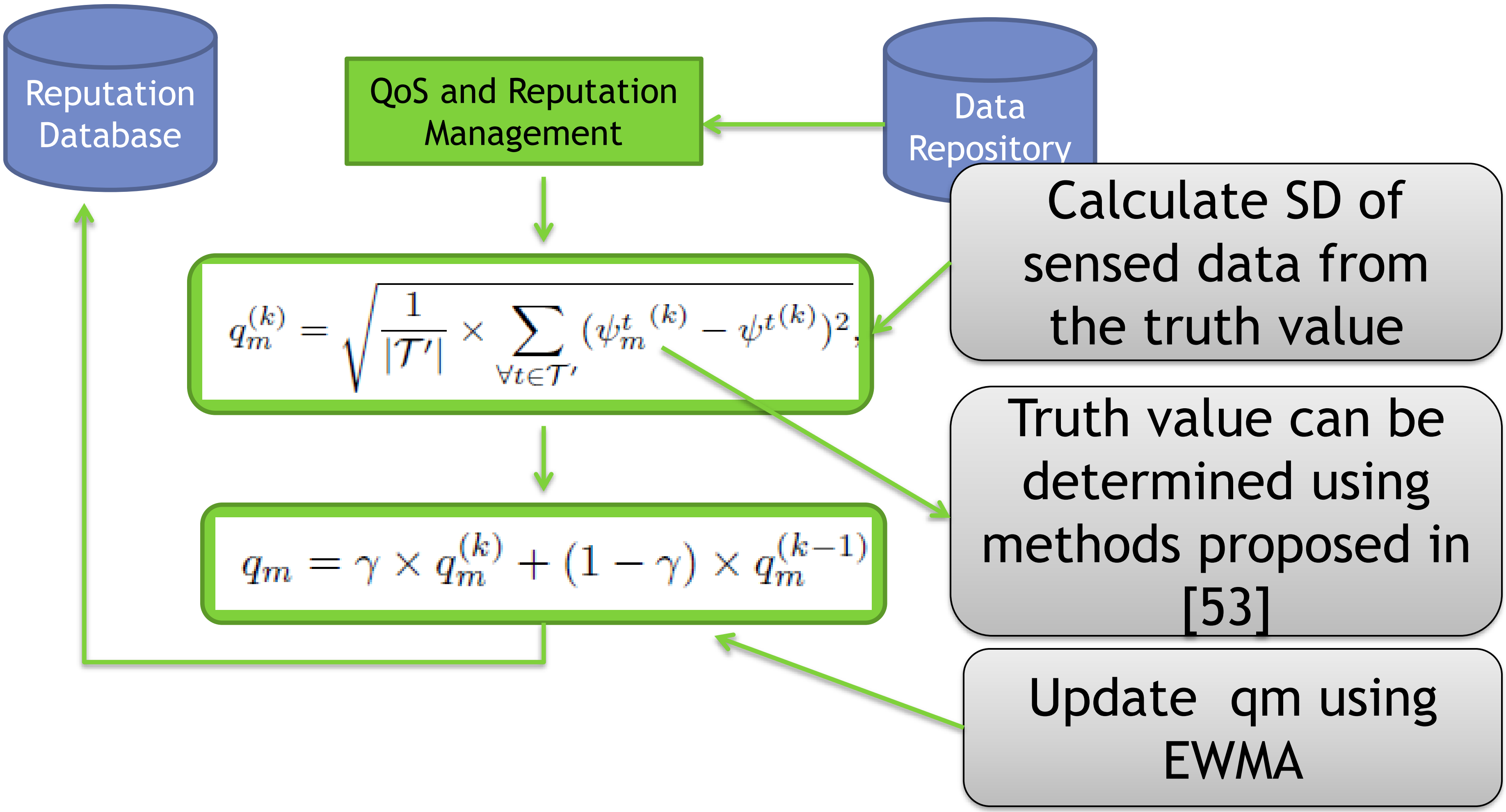
# Updating Quality Records




[53] Y. Li, Q. Li, J. Gao, L. Su, B. Zhao, W. Fan, and J. Han, “Conflicts to harmony: A framework for resolving conflicts in heterogeneous data by truth discovery,” *IEEE Transactions on Knowledge and Data Engineering, vol. 28, no. 8, pp. 1986-1999*,Aug 2016.

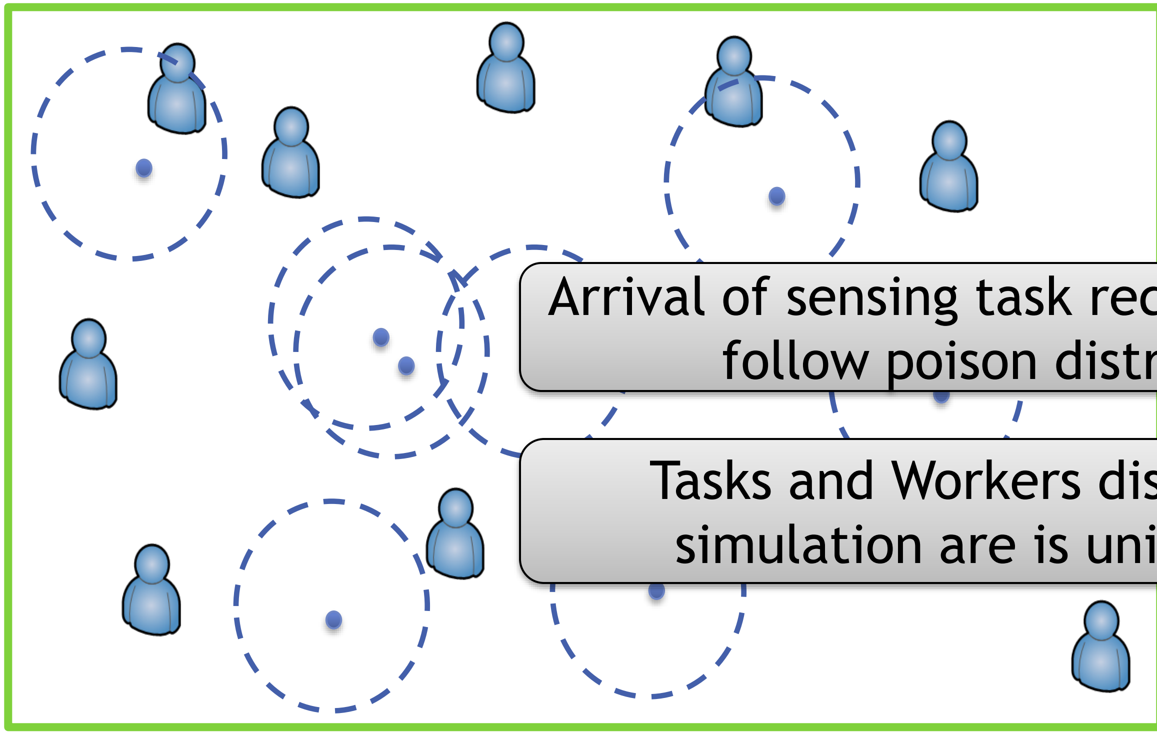
# Performance Evaluation

- We carry out performance analysis of the proposed algorithms – **PQ-Trade (ω = 0.6), FFP** and **FFU** using **MATLAB** [67]
- Present comparative results with state-of-the-art works **SACRM** [36] and **MSC** [46]

**We hardly found any simulation tool for MCS system simulation**

[36] J. Ren, Y. Zhang, K. Zhang, and X. S. Shen, "Sacrm: Social aware crowdsourcing with reputation management in mobile sensing," *Computer Communications, vol. 65, pp. 55 - 65, 2015.*
[46] Z. Duan, M. Yan, Z. Cai, X. Wang, M. Han, and Y. Li, "Truthful incentive mechanisms for social cost minimization in mobile crowdsourcing systems," *Sensors*, vol. 16, no. 4, 2016.

# Simulation Environment



Worker device

Sensing task

Arrival of sensing task requests and workers follow poison distribution [69]

Tasks and Workers distribution over simulation are is uniform random

$1000 \times 1000\ m^2$

[69] Y. Zhu, Q. Zhang, H. Zhu, J. Yu, J. Cao and L. M. Ni, "Towards Truthful Mechanisms for Mobile Crowdsourcing with Dynamic Smartphones," *2014 IEEE 34th International Conference on Distributed Computing Systems*, Madrid, 2014, pp. 11-20.

# Simulation Parameters

| Parameter | Value |
|---|---|
| Simulation area | $1000 \times 1000\ m^2$ |
| Arrival rate of sensing tasks | $2 \sim 8$ tasks/sec |
| Arrival rate of worker devices | $2 \sim 8$ workers/sec |
| Workloads of task | $1 \sim 7$ |
| Radius of task's AOI | $20 \sim 150$m |
| Task budget | $5 \sim 15$ units |
| Worker claimed cost | $1 \sim 20$ units |
| Task delay deadline | $5 \sim 15$s |
| Task completion time | $1 \sim 20$s |
| Worker mobility speed | $4.5 \sim 7$km/h |
| $\mathcal{U}_{min}$ | 0.3 |
| $\mathcal{P}_{min}$ | 10% |
| $\alpha$ | 0.6 |
| $\omega$ | 0.6 |
| Simulation time | 1000 Seconds |

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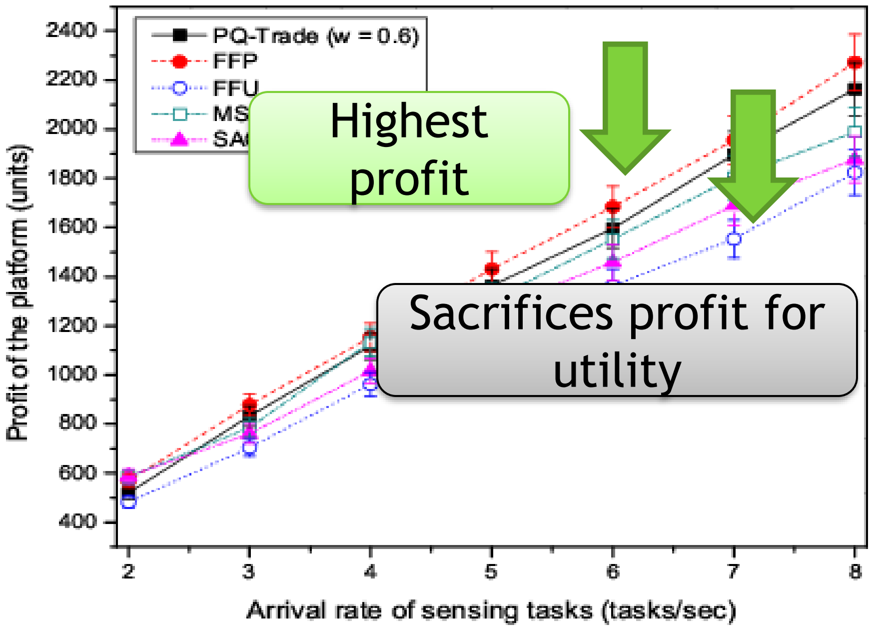
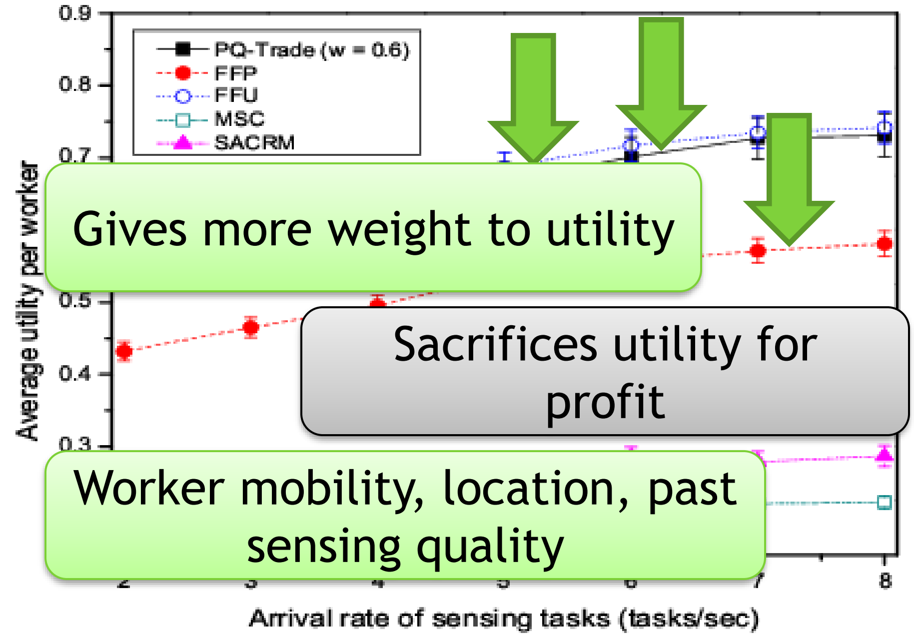
# Simulation Metrics

- **Profit of the platform**
  - Total amount of revenue received by the platform
- **Average utility per worker**
  - Ratio of total utility received from selected workers to total number of workers
- **Request service satisfaction**
  - Ratio of total number of completed workloads to total number of requested workloads
- **Standard deviation of sensing quality**
  - Average SD of quality of sensed data received from the selected workers
- **Average payment per worker**
  - Ratio of total payment of selected workers to total number of workers
- **Execution time**
  - Total time required to run worker selection and task allocation algorithms

# Impact of Varying Task Arrival Rates (1/3)




(a) Profit of the platform




(b) Average Utility per worker

Arrival rate of workers
5 workers/sec

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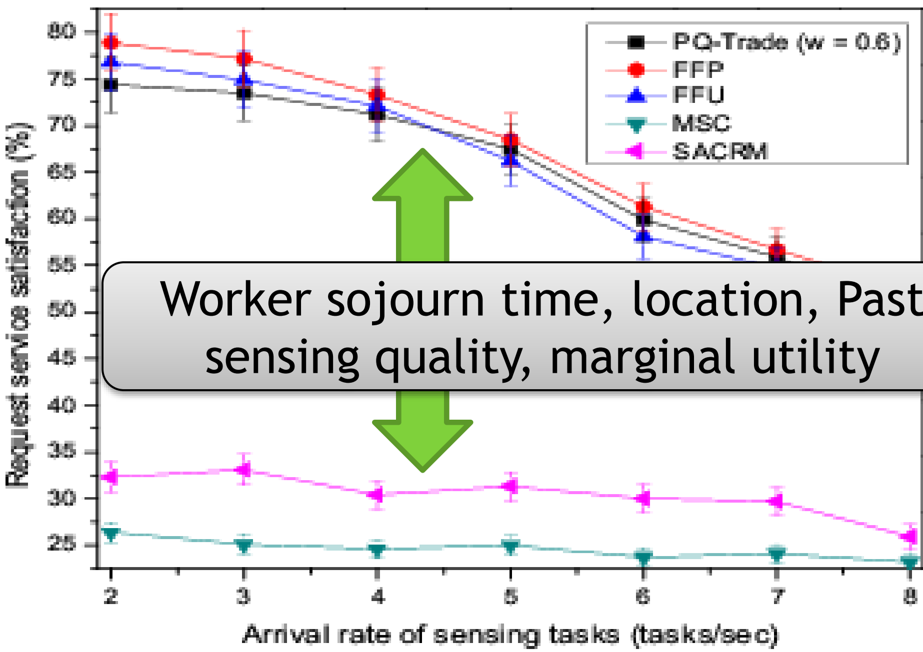
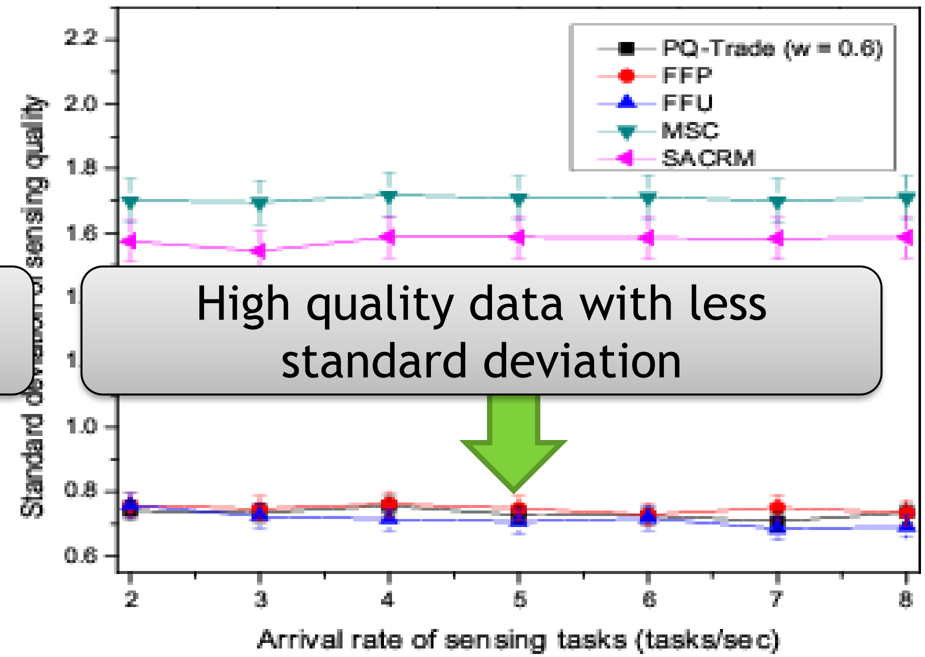
# Impact of Varying Task Arrival Rates (2/3)




Worker sojourn time, location, Past sensing quality, marginal utility

(c) Request service satisfaction

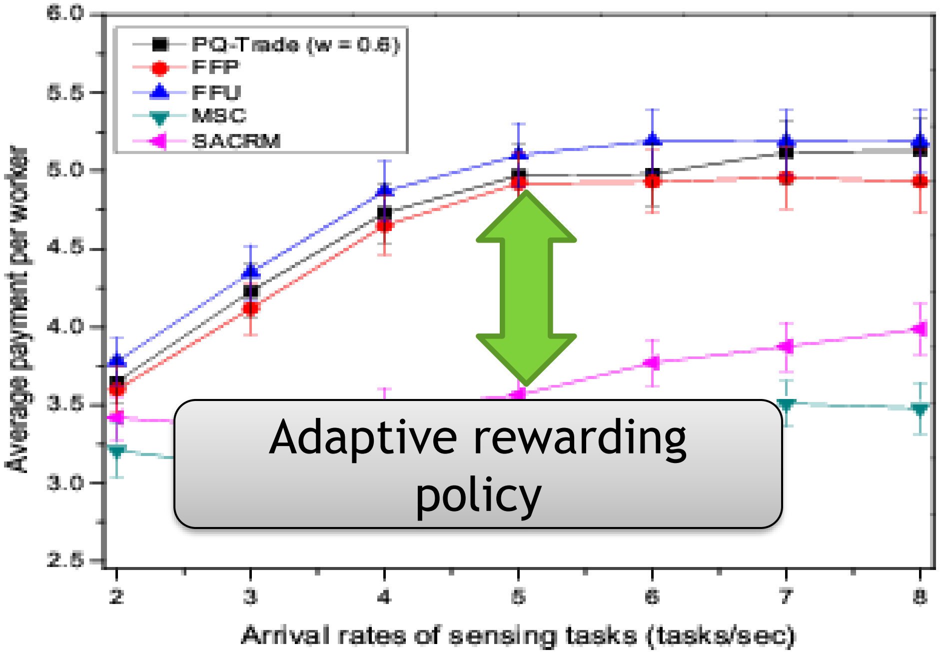



High quality data with less standard deviation

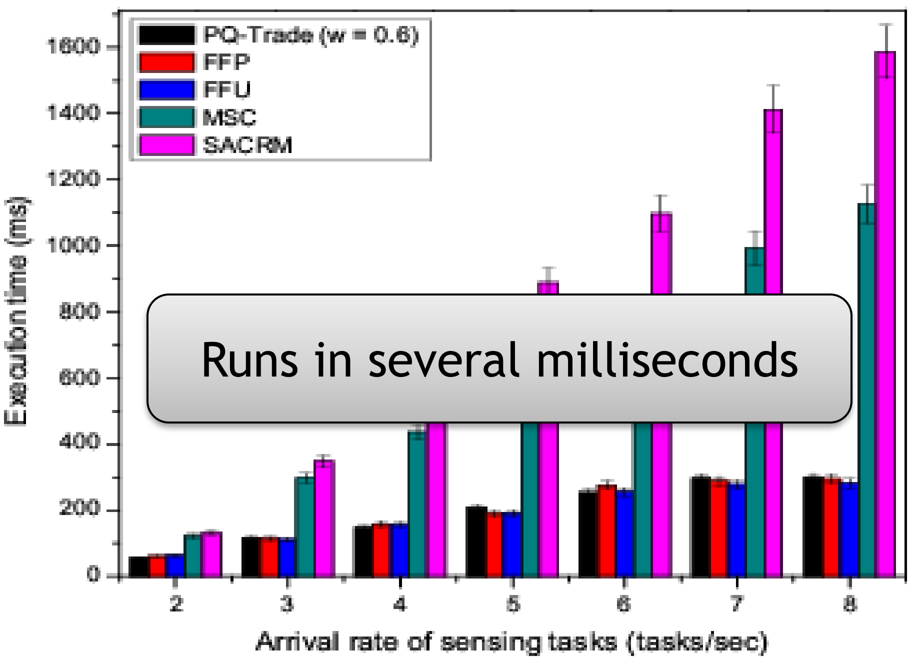
(d) Standard deviation of sensing quality

Arrival rate of workers
5 workers/sec

# Impact of Varying Task Arrival Rates (3/3)




(e) Average payment per worker




(f) Execution time

Arrival rate of workers
5 workers/sec

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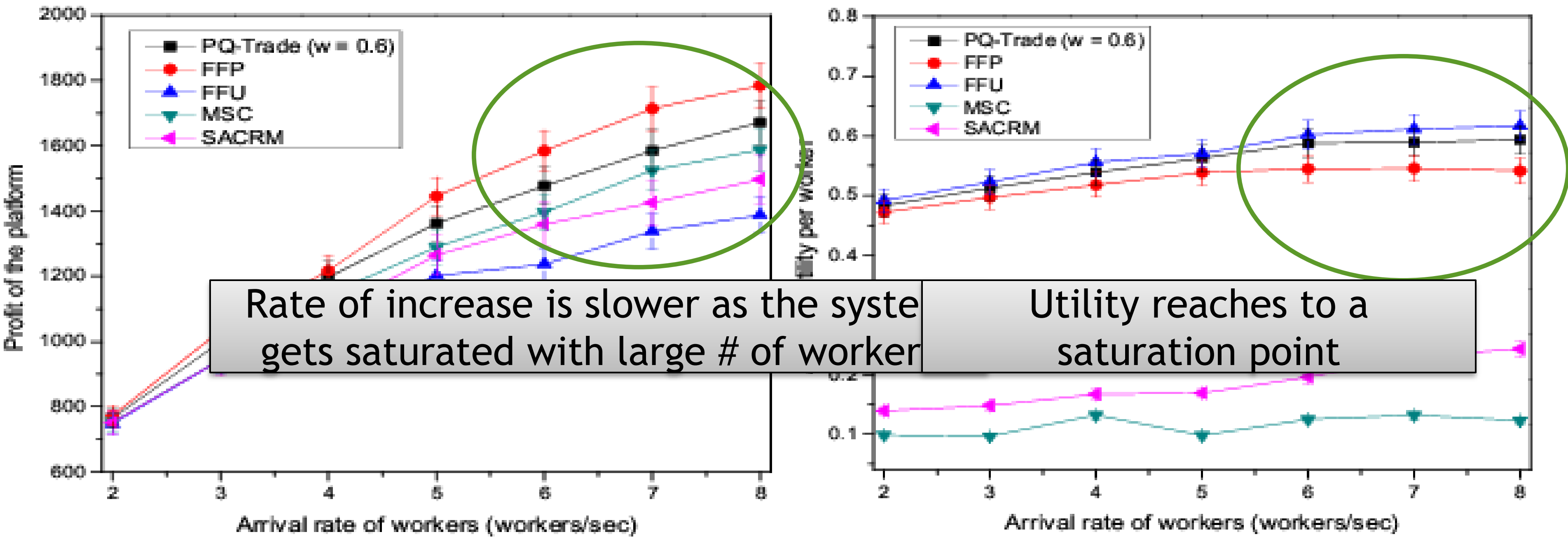
# Impact of Varying Worker Arrival Rates (1/3)

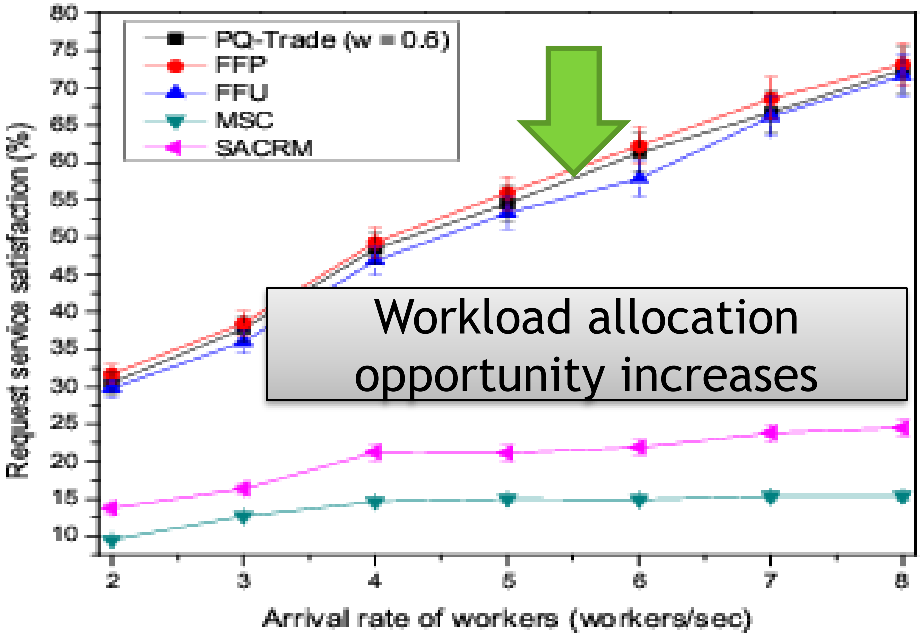



(a) Profit of the platform

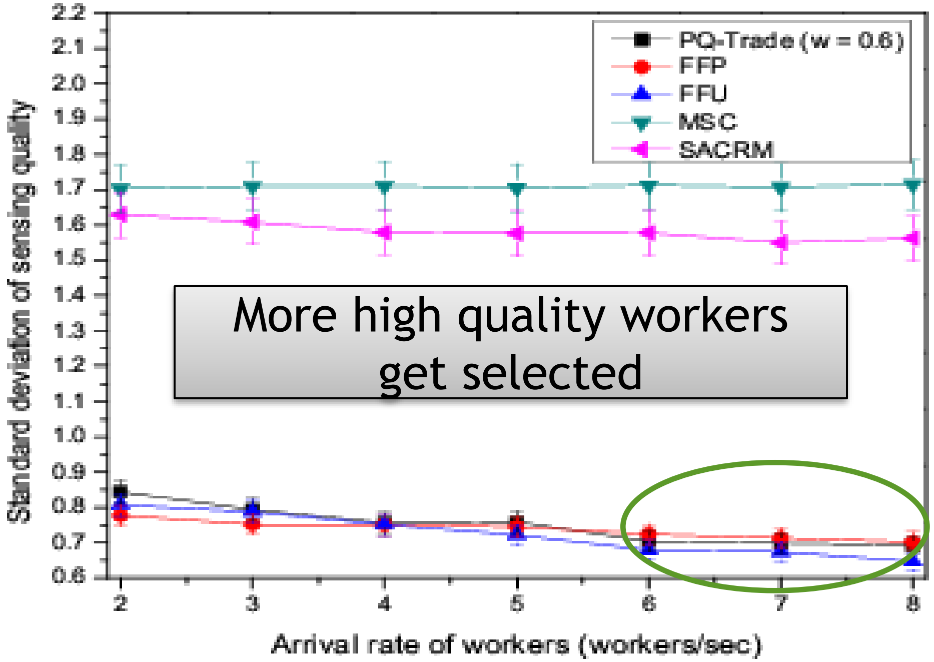
(b) Average Utility per worker

Arrival rate of tasks
5 tasks/sec

# Impact of Varying Worker Arrival Rates (2/3)



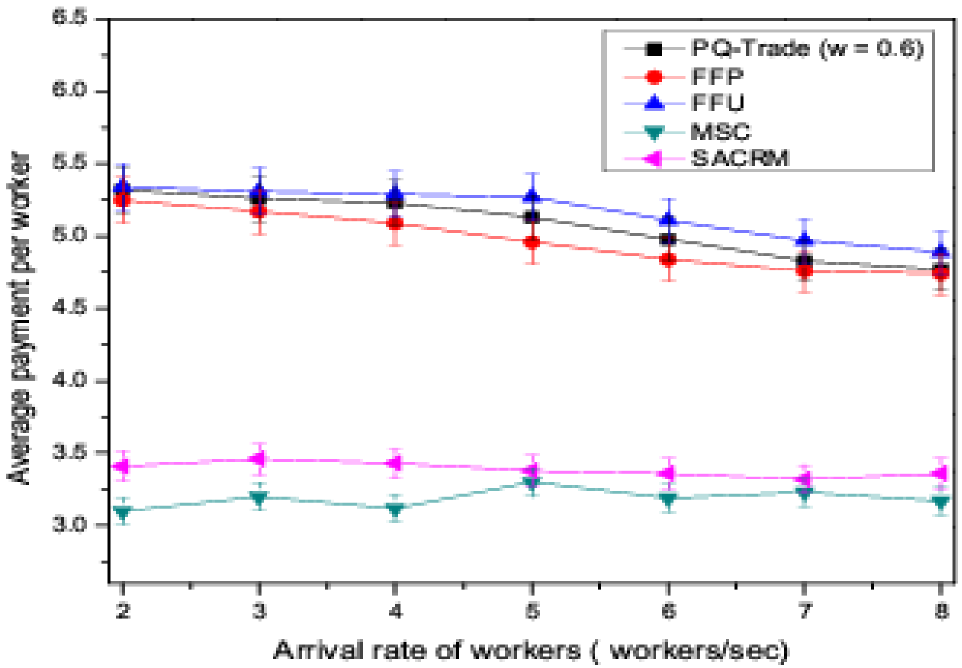

(c) Request service satisfaction



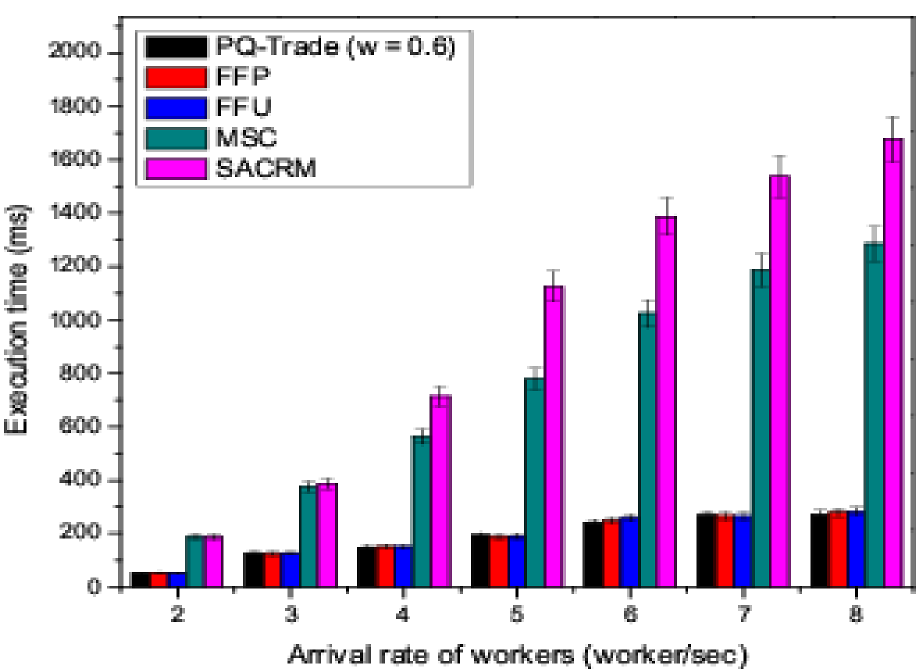

(d) Standard deviation of sensing quality

Arrival rate of workers
5 workers/sec

# Impact of Varying Worker Arrival Rates (3/3)




(e) Average payment per worker




(f) Execution time

Arrival rate of workers
5 workers/sec

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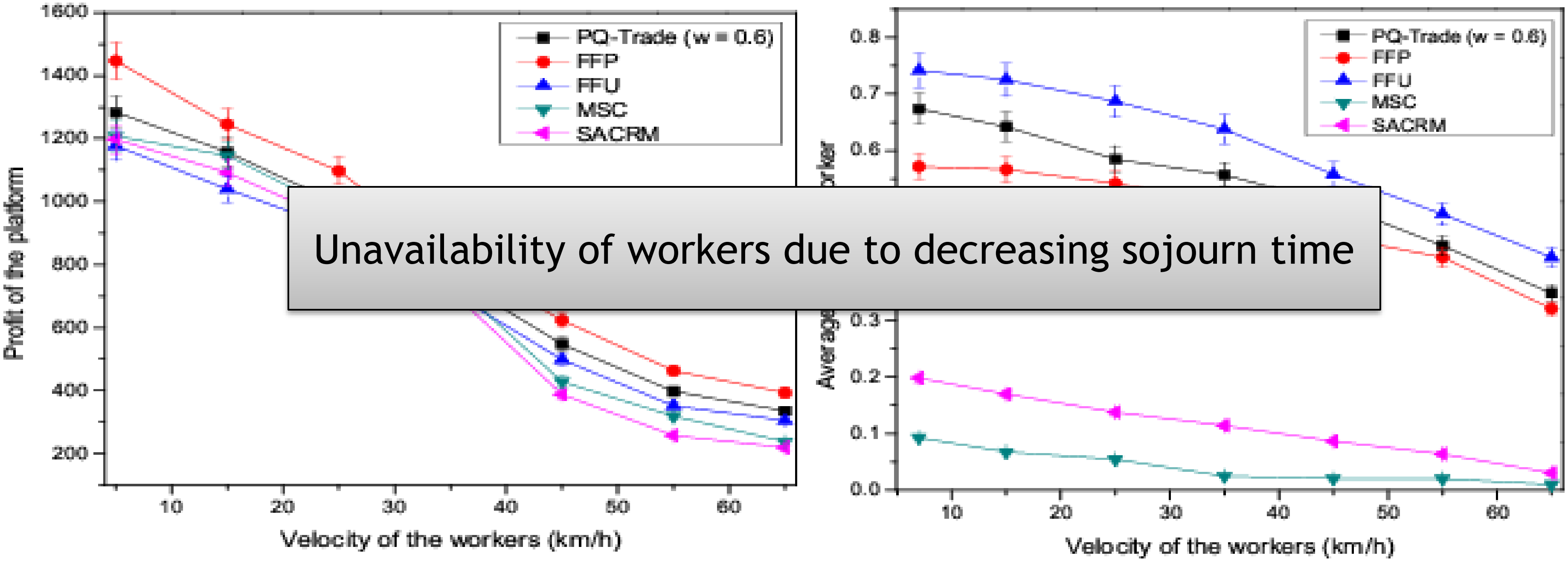
# Impact of Varying Worker Velocities (1/2)



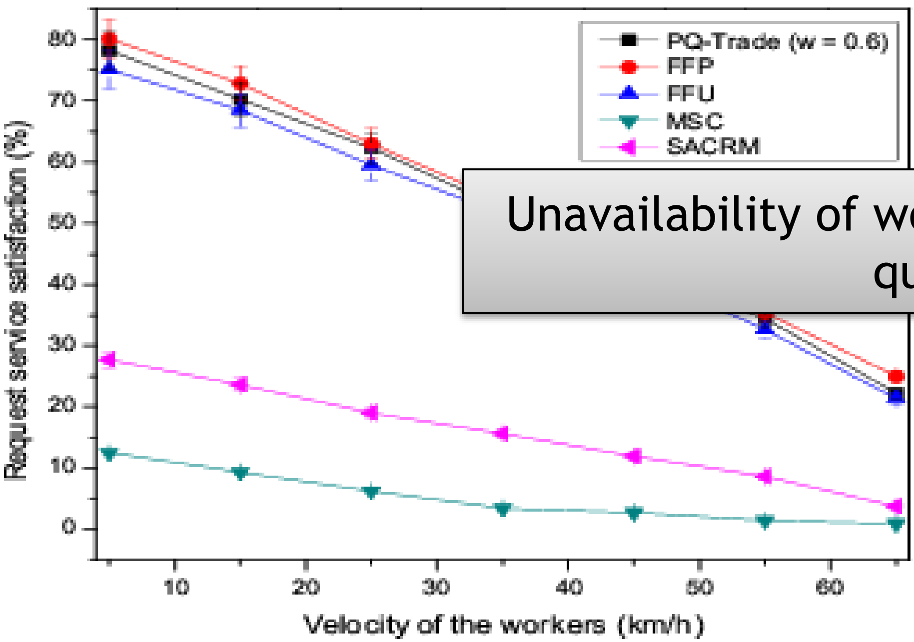

(a) Profit of the platform

(b) Average Utility per worker

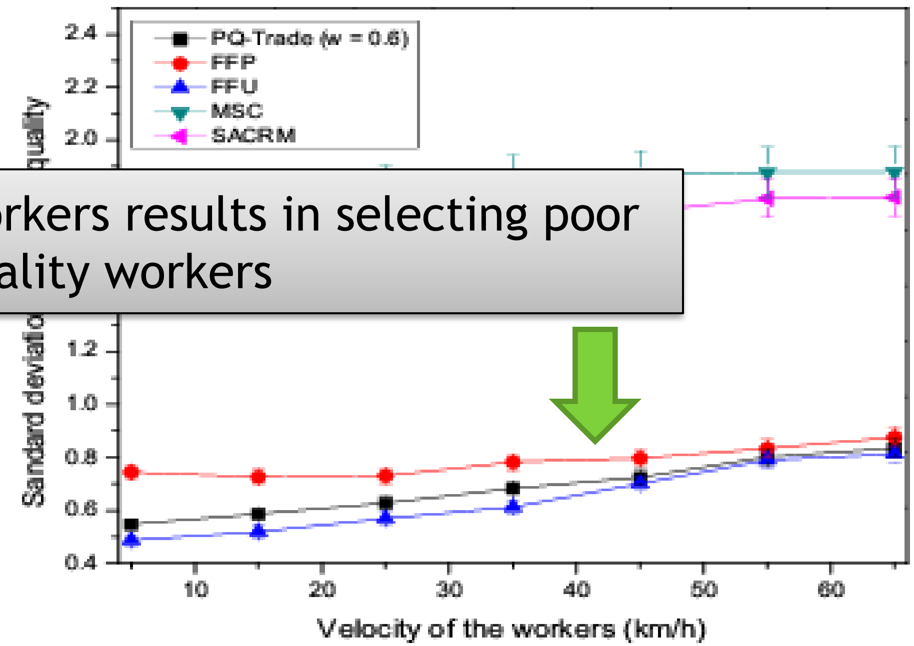
Unavailability of workers due to decreasing sojourn time

Arrival rate of tasks 5 tasks/sec
Arrival rate of workers 5 workers/sec

# Impact of Varying Worker Velocities (2/2)




(c) Request service satisfaction

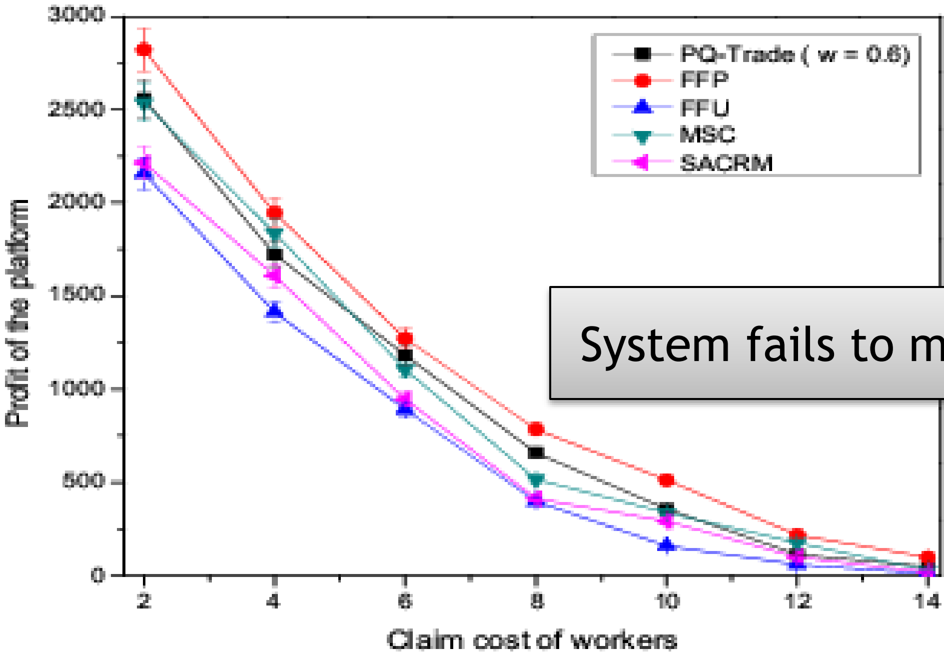



(d) Standard deviation of sensing quality

Unavailability of workers results in selecting poor quality workers

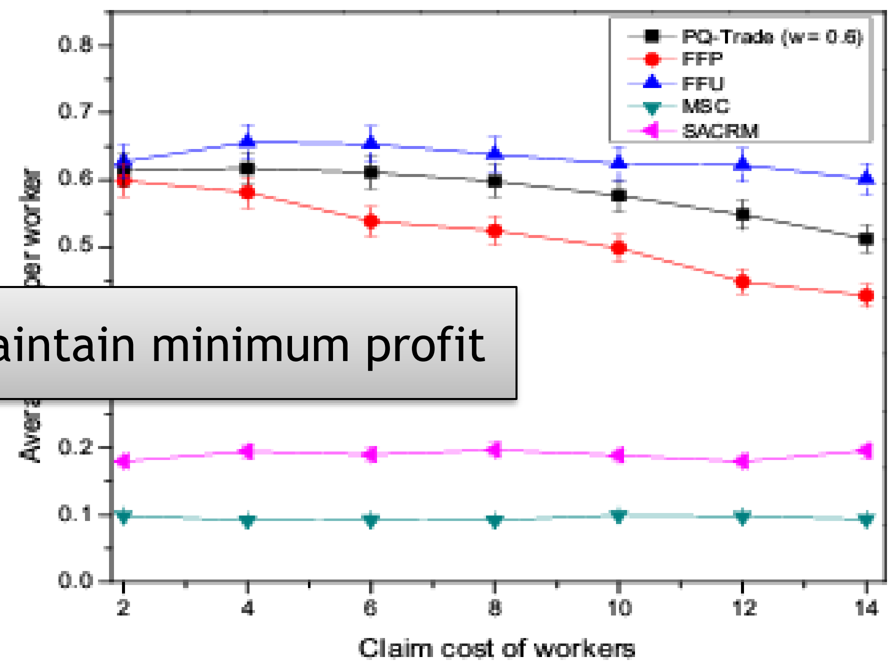
Arrival rate of tasks 5 tasks/sec
Arrival rate of workers 5 workers/sec

# Impact of Varying Claimed Costs (1/2)




(a) Profit of the platform

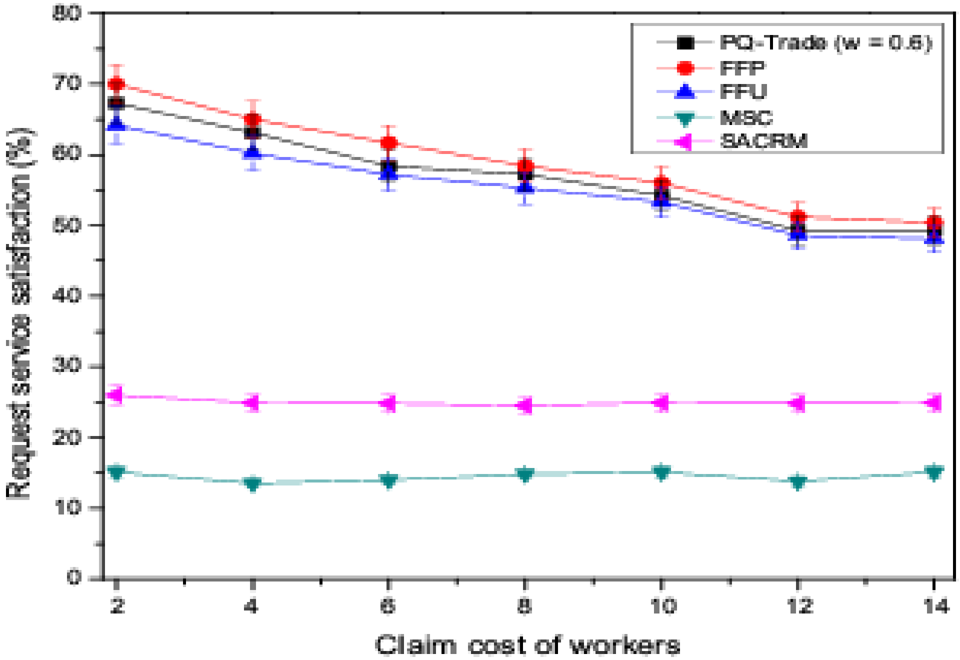
System fails to maintain minimum profit



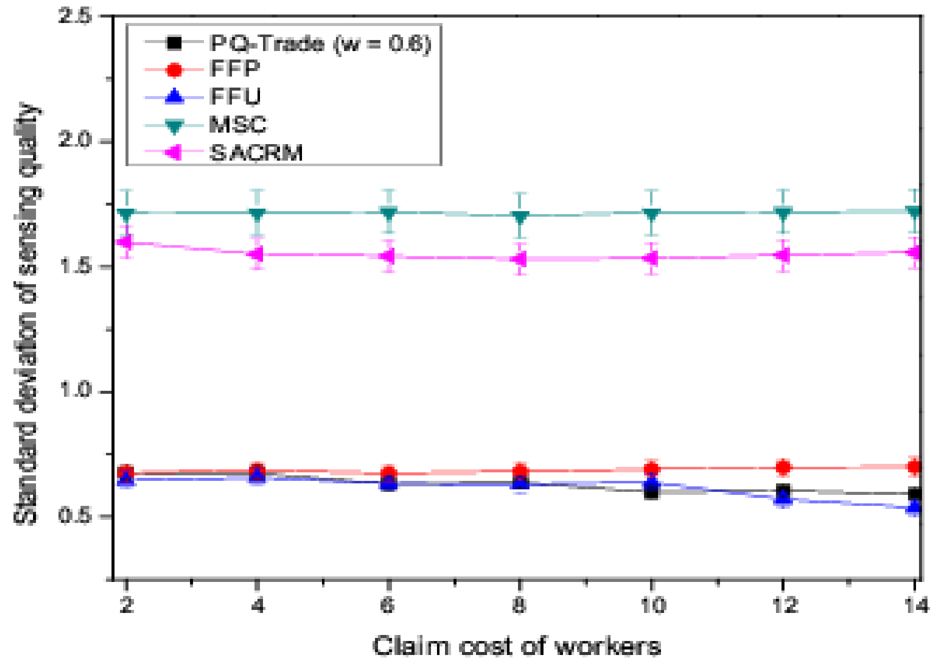

(b) Average Utility per worker

Arrival rate of tasks 5 tasks/sec
Arrival rate of workers 5 workers/sec

# Impact of Varying Claimed Costs (2/2)




(c) Request service satisfaction




(d) Average payment per worker

Arrival rate of tasks 5 tasks/sec
Arrival rate of workers 5 workers/sec

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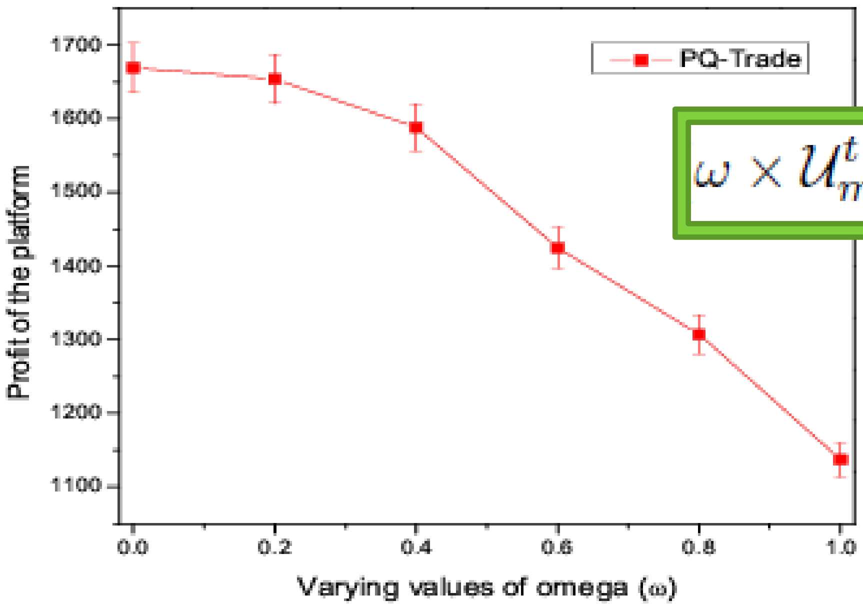
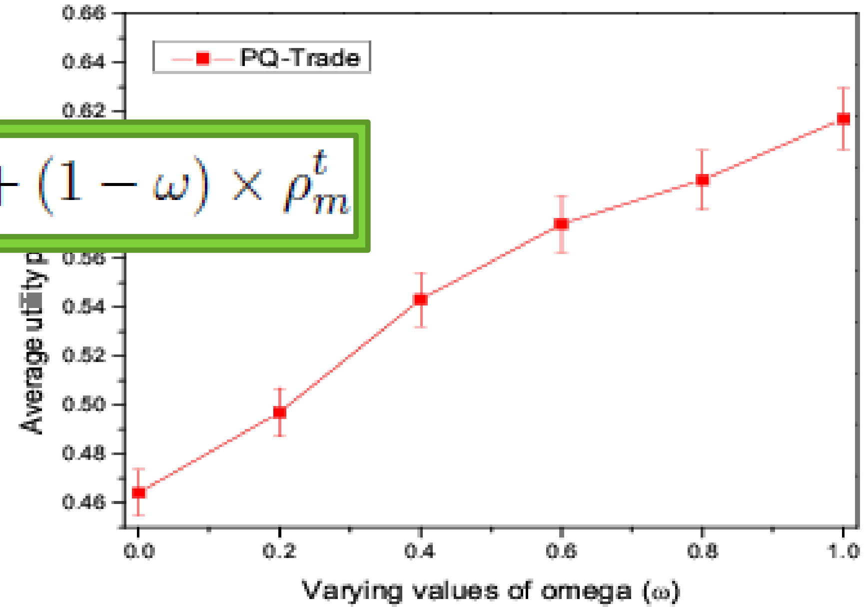
# Impact of Varying ω




(a) Profit of the platform

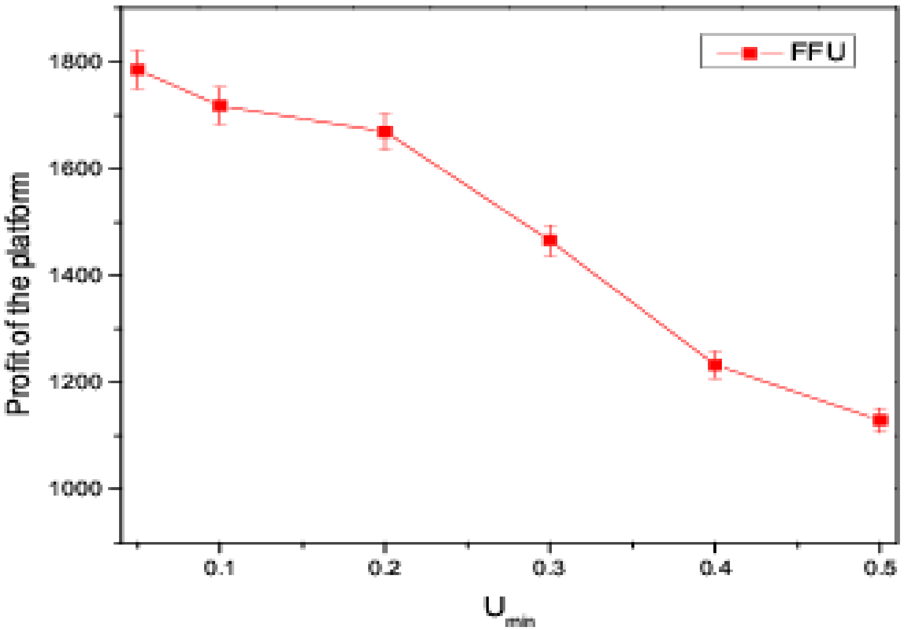



$$\omega \times \mathcal{U}_m^t + (1-\omega) \times \rho_m^t$$

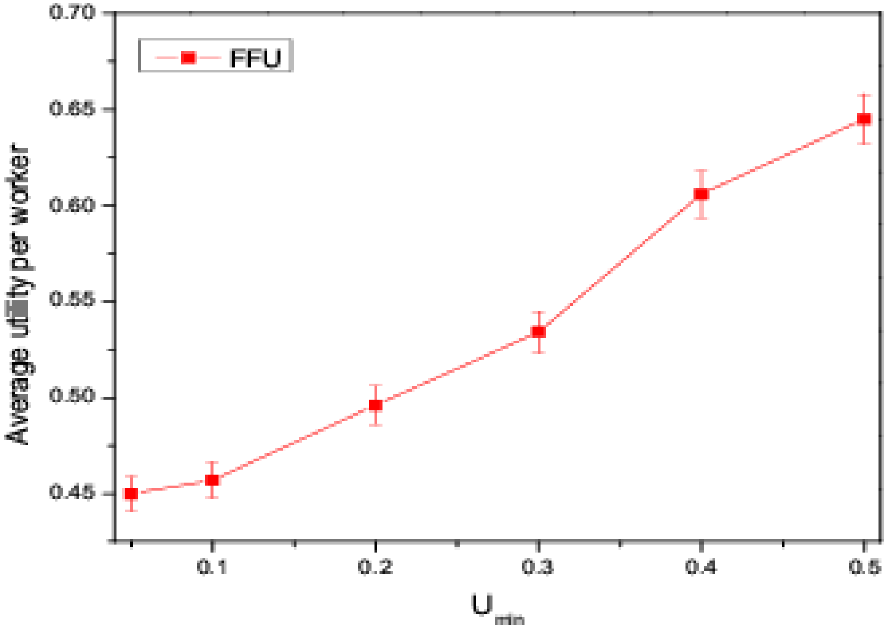
(b) Average utility per worker

Platform gives more weight to worker utility than its profit

# Impact of Varying $U_{min}$



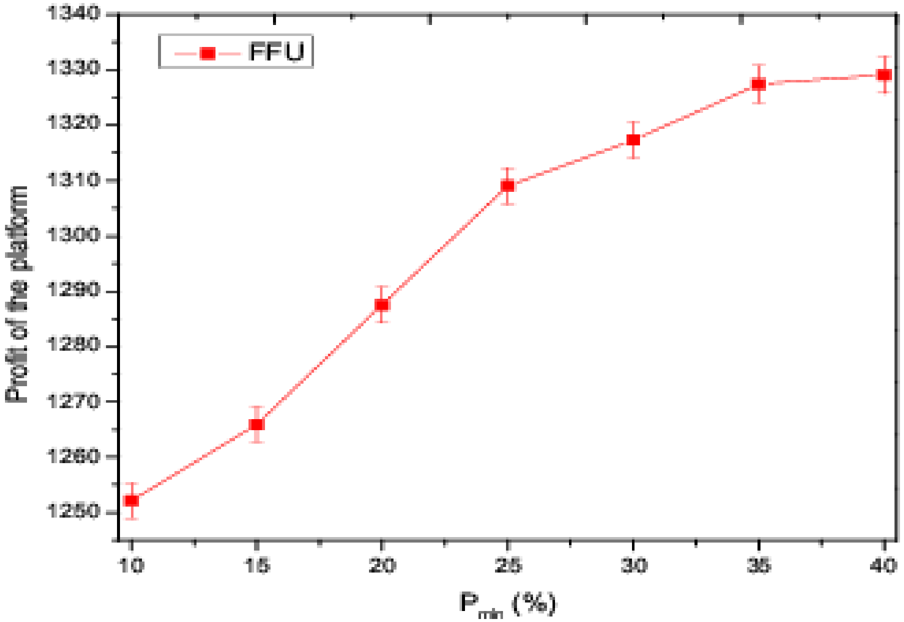

(a) Profit of the platform



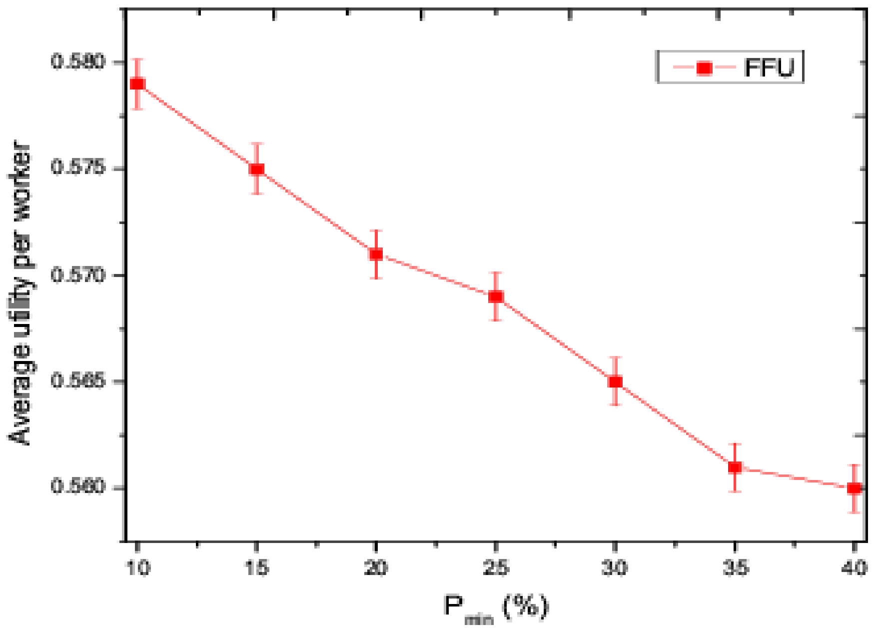

(b) Average utility per worker

Instead of profit, platform maximizes worker utility violating design principle

# Impact of Varying $P_{min}$




(a) Profit of the platform




(b) Average utility per worker

Instead of utility, platform maximizes its profit violating design principle

# Summery of the Thesis (1/2)

- Designed **workload allocation framework** for location aware MCS system.
- Worker **spacial and temporal availability** aware utility model
- **A MONLP optimization formulation** for allocating workload to maintain a reasonable **trade-off between quality and profit**, proven to **NP-hard**.

# Summery of the Thesis (2/2)

- Greedy solutions to avoid the complexity – **FFP**, **FFU** and **PQ-Trade (ω)**
- FFP achieves **profit** as higher as **23.8%**
- FFU achieves **average utility** gain **2.29x**
- System's **service satisfaction** is **1.6x**
- PQ-Trade (**ω = 0.6**) achieves profit as high as **17.21%** and utility gain **2.22x**
- Success of the system **highly depends on the system parameter setup**

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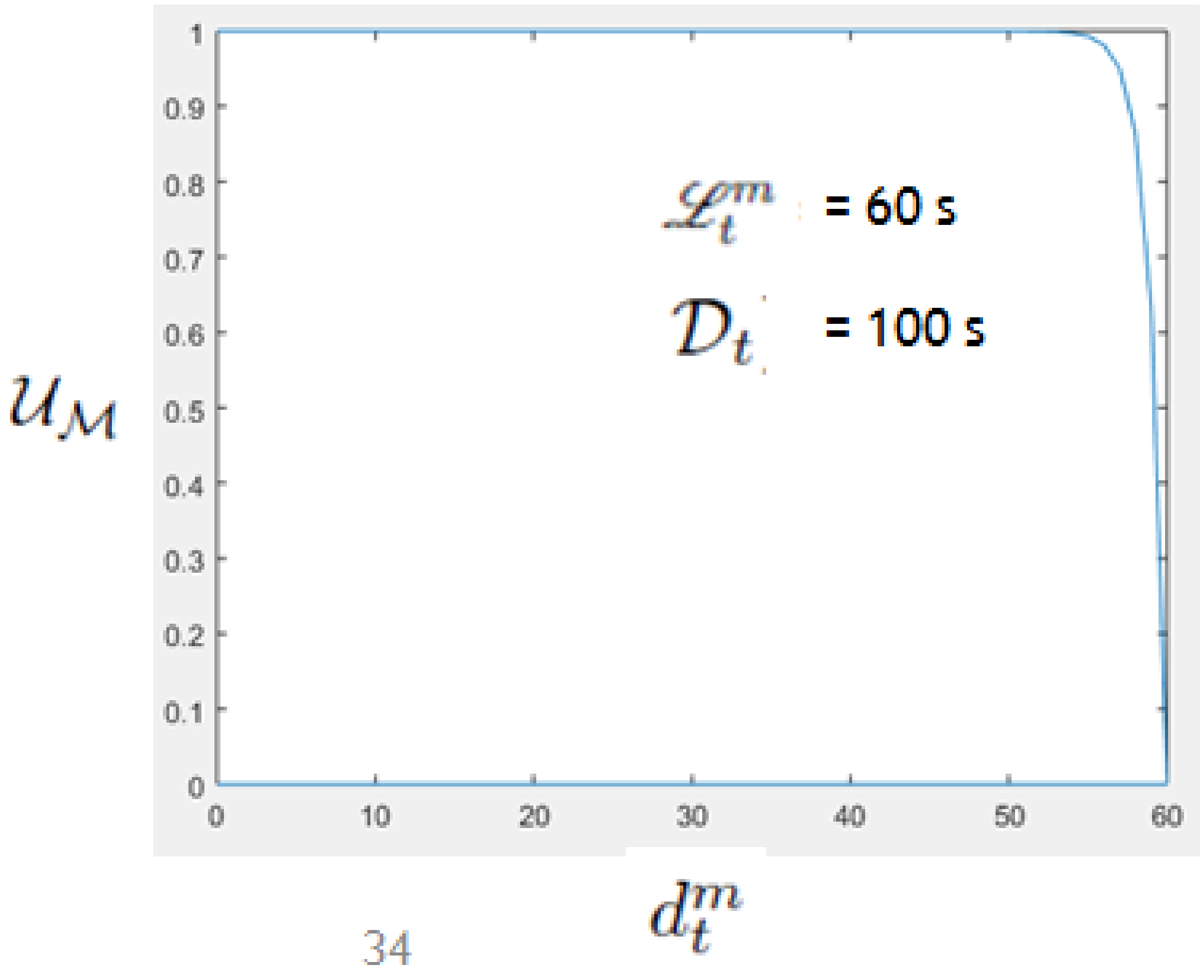
# Thank you for your patience



$\mathcal{L}_t^m$ = 60 s
$\mathcal{D}_t$ = 100 s
$\mathcal{U}_\mathcal{M}$
$d_t^m$
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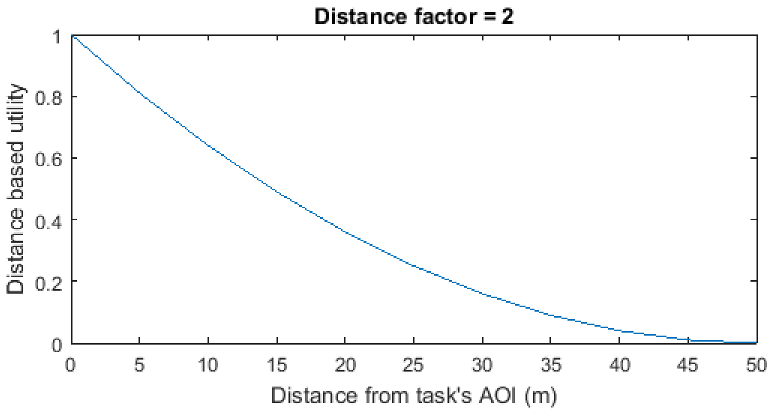
50
60


34


Distance factor = 2
Distance based utility
Distance from task's AOI (m)
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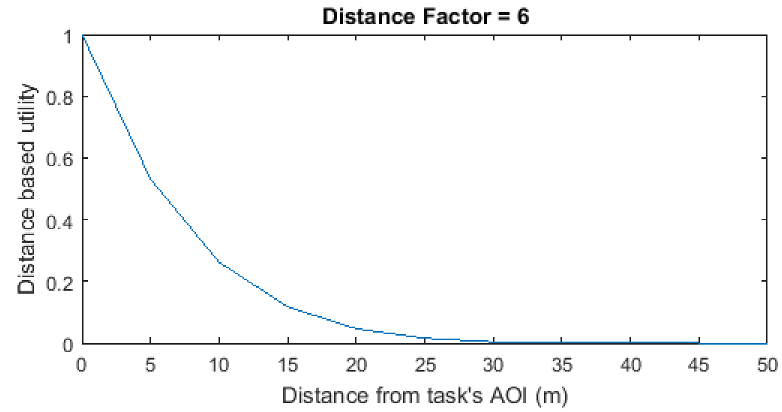
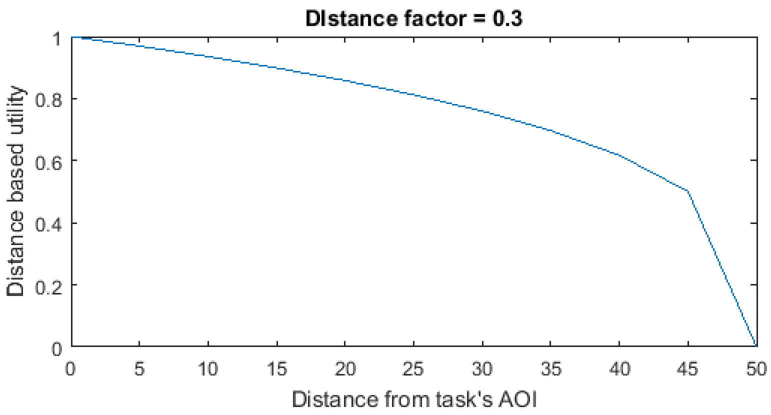
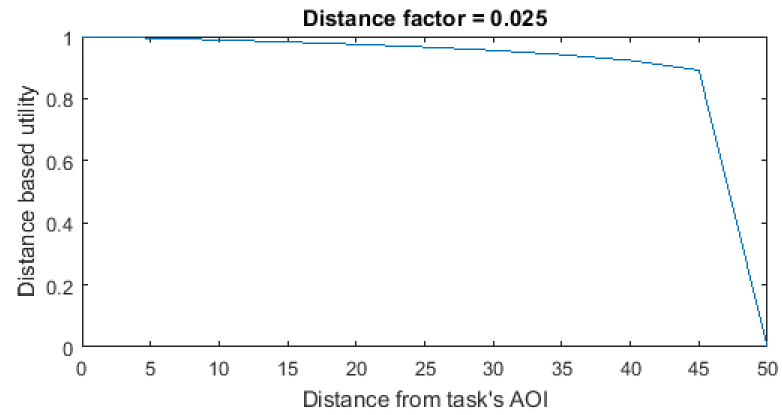
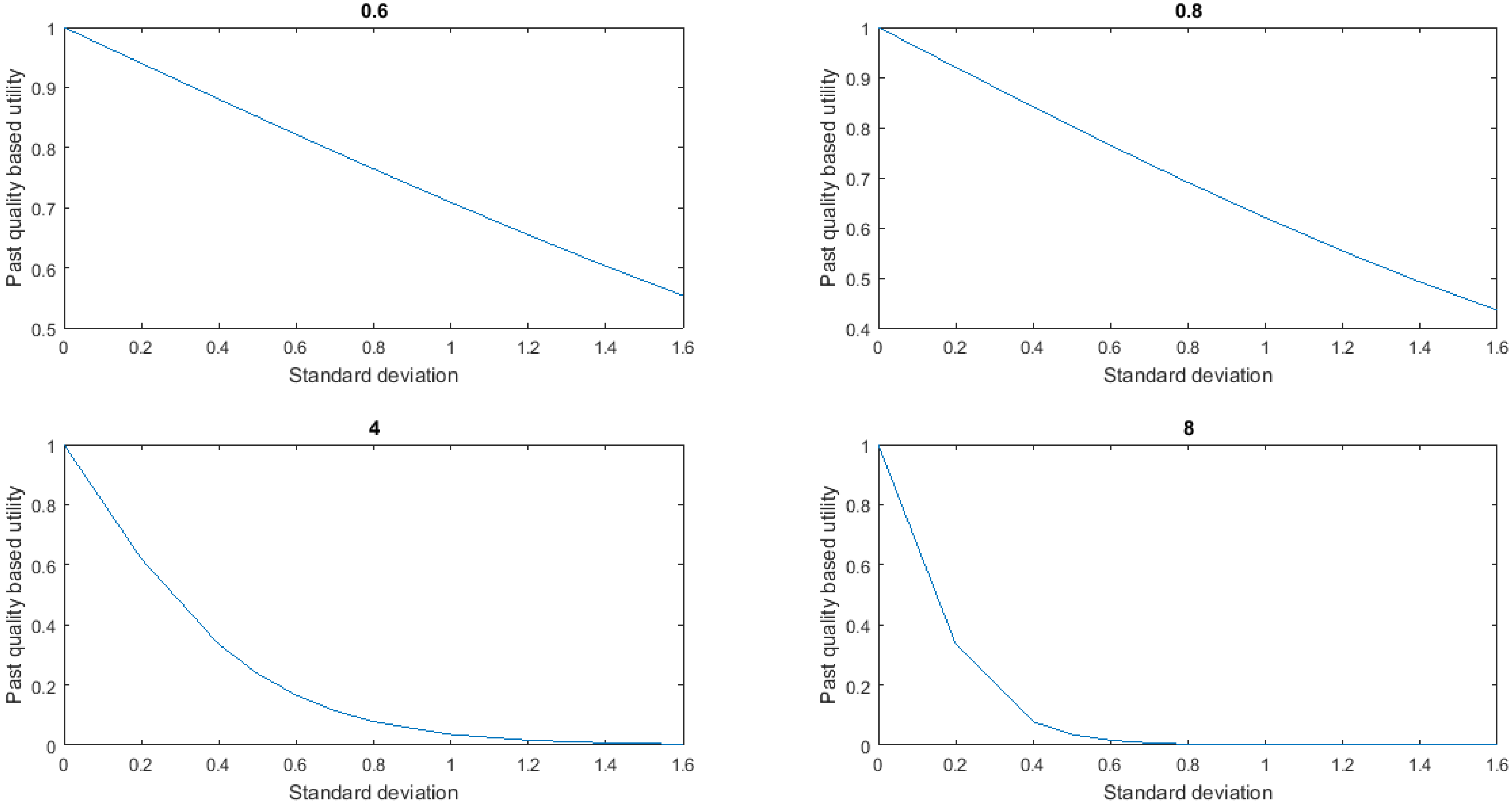
0.2
0.4
0.6
0.8
1
0 5 10 15 20 25 30 35 40 45 50


Distance Factor = 6
Distance based utility
Distance from task's AOI (m)
0
0.2
0.4
0.6
0.8
1
0 5 10 15 20 25 30 35 40 45 50


DIstance factor = 0.3
Distance based utility
Distance from task's AOI
0
0.2
0.4
0.6
0.8
1
0 5 10 15 20 25 30 35 40 45 50


Distance factor = 0.025
Distance based utility
Distance from task's AOI
0
0.2
0.4
0.6
0.8
1
0 5 10 15 20 25 30 35 40 45 50


0.6
0.8
4
8
Past quality based utility
Standard deviation
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6