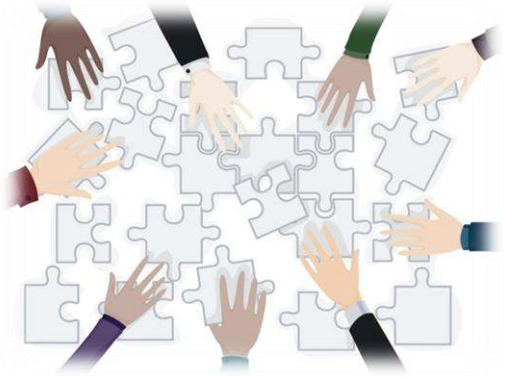


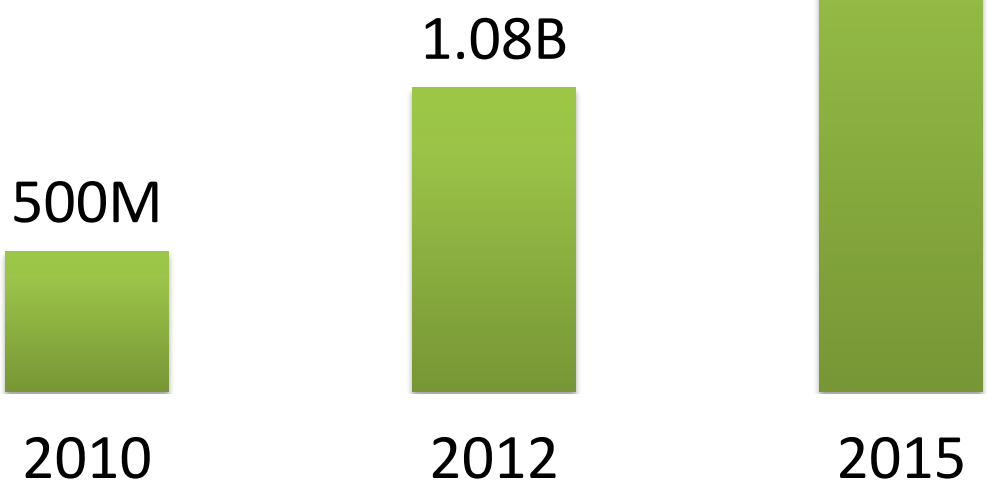
Crowdsourcing to Smartphones: Incentive Mechanism Design for Mobile Phone Sensing

Dejun Yang, Guoliang (Larry) Xue, Xi Fang and Jian Tang

Arizona State University

Syracuse University

Global Smartphone Users



Date Source: IDC http://www.idc.com/getdoc.jsp?containerId=233553, Go-Gulf http://www.go-gulf.com/blog/smartphone
Image source: http://www.foxshop.seeon.com/images/smartphone_shadow-group.jpg

Mobile Phone Sensing Apps

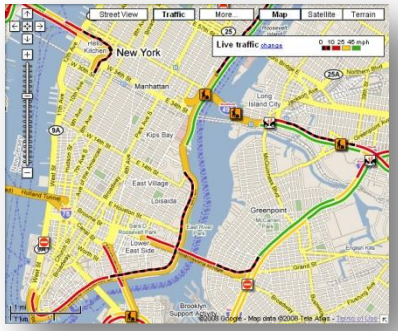
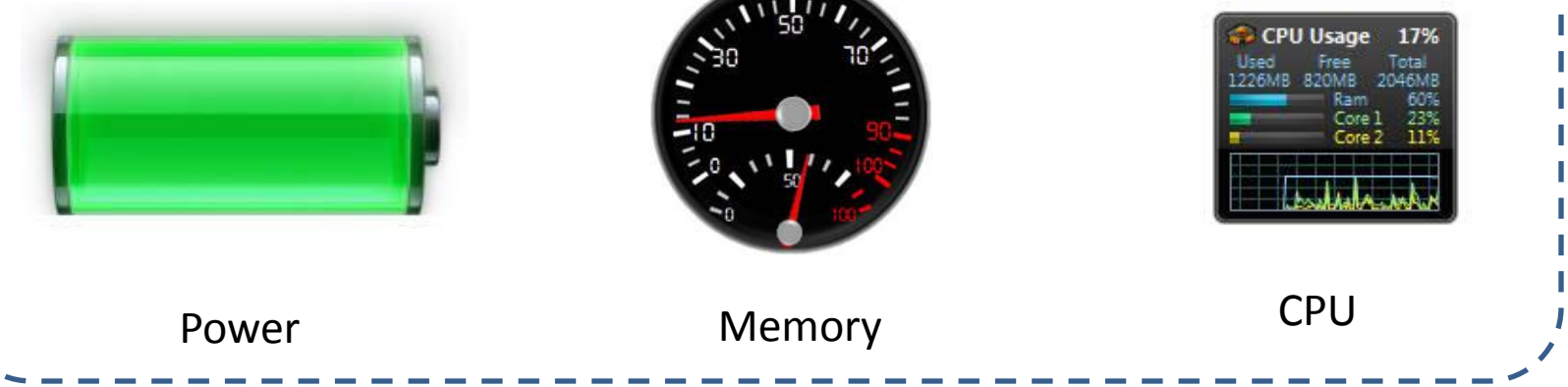


Image source: http://www.mynewplace.com/blog/files/2011/05/smart-phone-user.jpg, http://serc.carleton.edu/images/sp/library/google_earth/google_maps_new_york.v2.jpg, http://media.treehugger.com/assets/images/2011/10/nextfest-peir-001.jpg

What is Missing?

Smartphone users consume their own resource



Related Works



S. Reddy D. Estrin M.B. Srivastava

- Developed recruitment frameworks
- Focused on user selection, not incentive design

- Developed a sealed-bid second-price auction
- The platform utility was not considered



G. Danezis S. Lewis R. Anderson


J-S. Lee B. Hoh

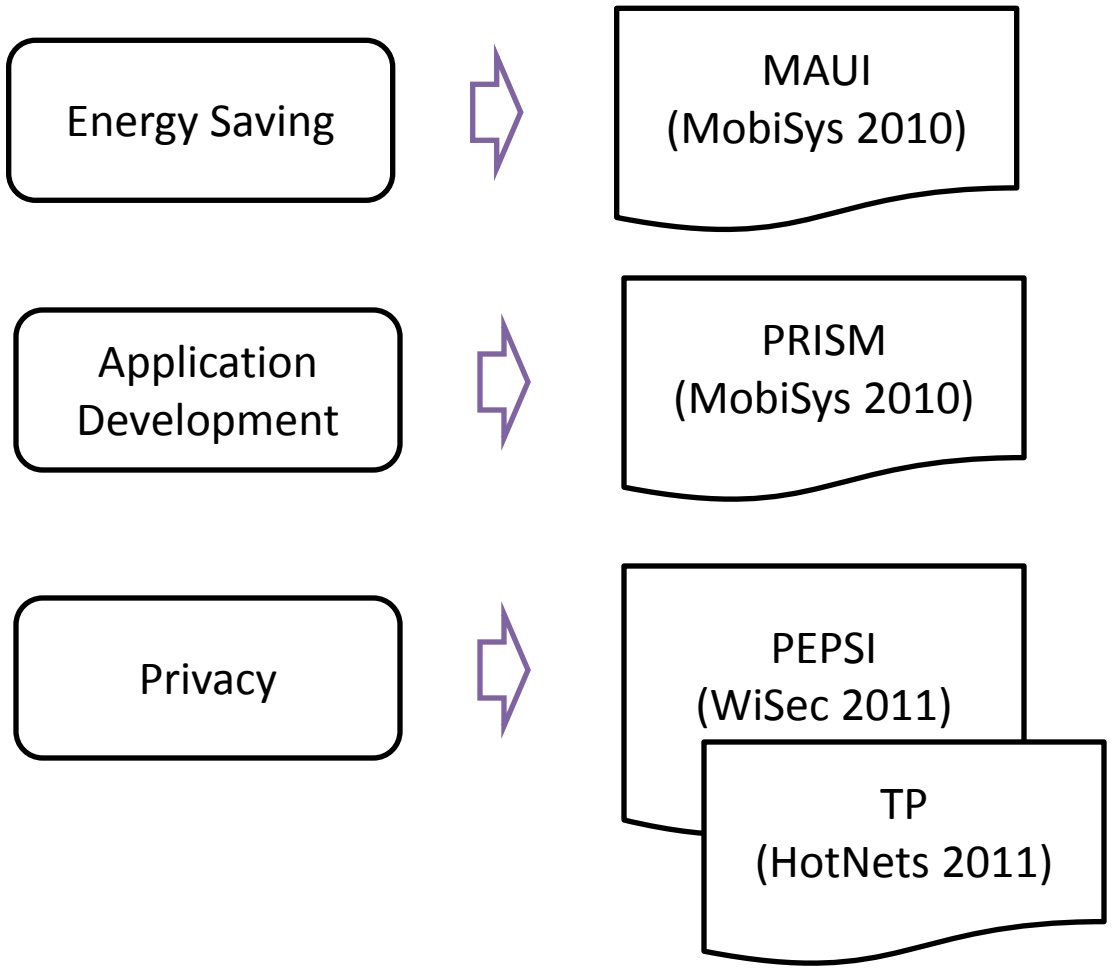
- Designed an auction based dynamic price incentive mechanism
- Truthfulness was not considered

S. Reddy, D. Estrin, and M.B. Srivastava; "Recruitment framework for participatory sensing data collections" in PERVASIVE 2010

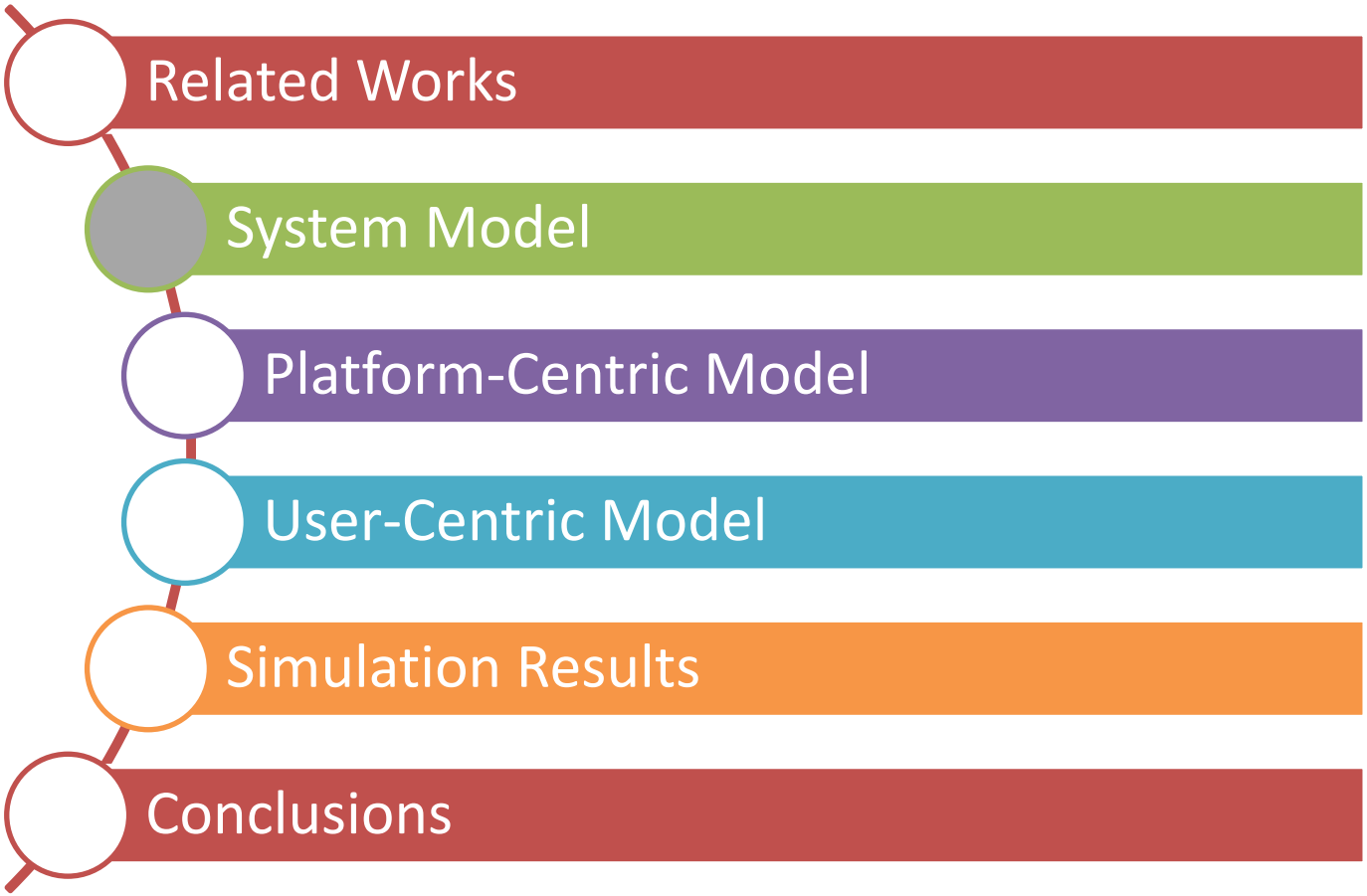
G. Danezis, S. Lewis, and R. Anderson; "How Much is Location Privacy Worth?" In WEIS 2005.

J-S. Lee and B. Hoh; "Sell Your Experiences: Market Mechanism based Participation Incentive for Participatory Sensing" in PERCOM 2010

Other Related Works



Outline/Progress



System Model

$U = \{1, 2, \ldots, n\}, n \geq 2$

Platform-Centric Model

User-Centric Model

Platform-Centric Model

- Platform announces a total reward R
- Each user i has the sensing time $t_i \geq 0$ and sensing cost $\kappa_i \times t_i$, where κ_i is its unit cost
- The utility of user i is

$$\bar{u}_i = \frac{t_i}{\sum_{j \in U} t_j} R - t_i \kappa_i$$

- The utility of the platform is

$$\bar{u}_0 = \lambda \log\left(1 + \sum_{i \in U} \log(1 + t_i)\right) - R$$

where $\lambda > 1$ is a system parameter.

User-Centric Model

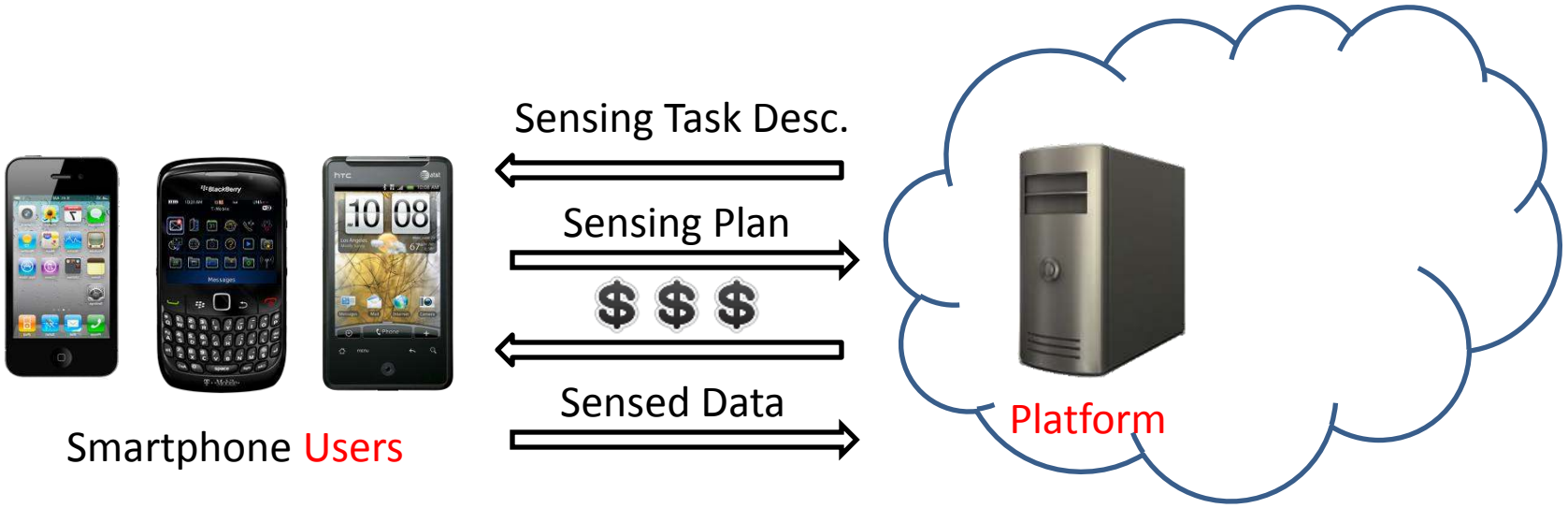
- Platform announces a set $\Gamma = \{\tau_1, \tau_2, \ldots, \tau_m\}$ of tasks, where each τ_j has a (private) value $v_j > 0$.
- Each user $i \in U$ selects a subset $\Gamma_i \subseteq \Gamma$, based on which user i has a (private) cost c_i

$(\Gamma_1, b_1), \ldots, (\Gamma_n, b_n)$ ⇨ **Auction** ⇨ S

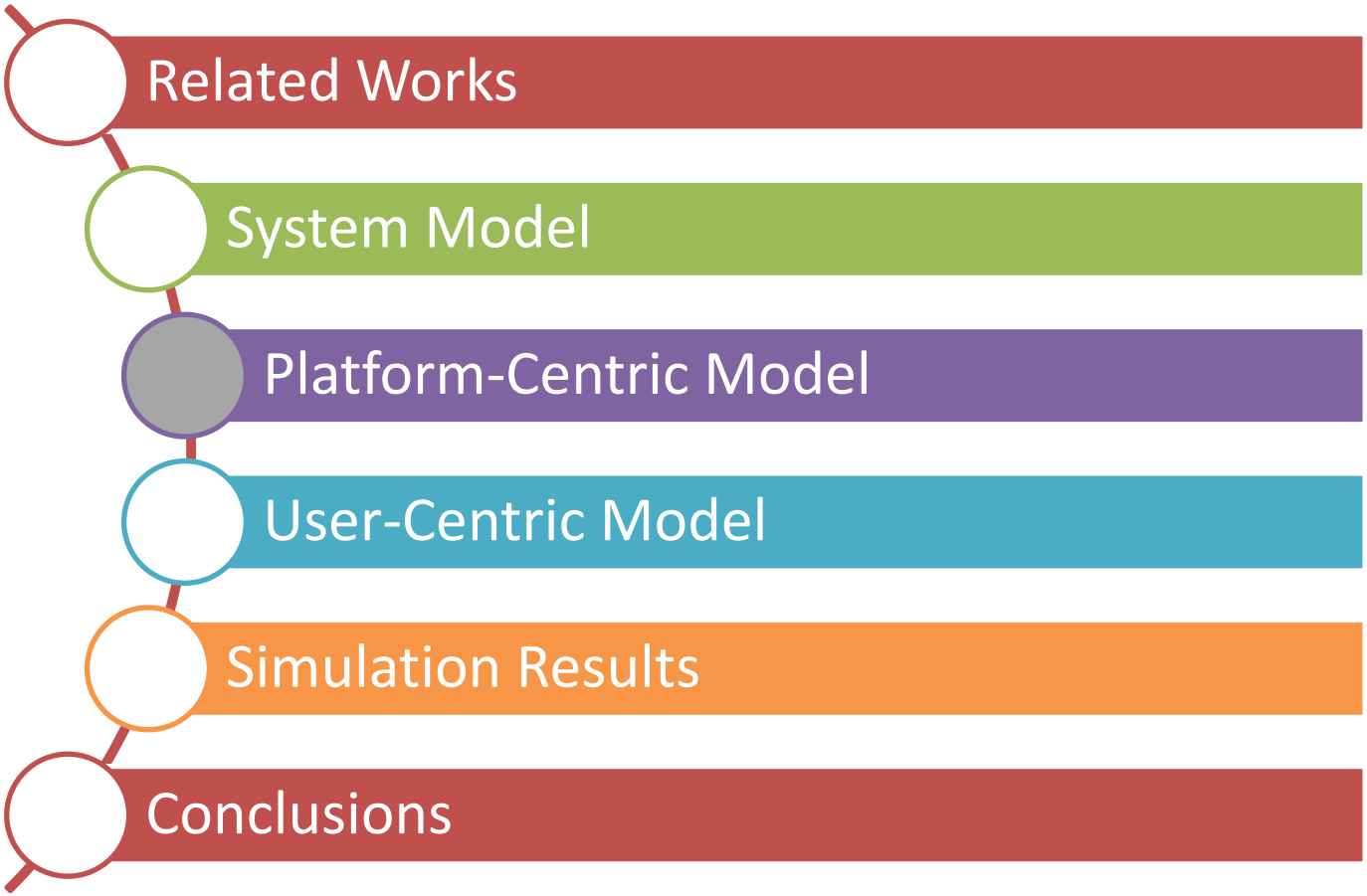
⇨ $p_1, p_2, \ldots, p_n$

- Utility of user i is $\tilde{u}_i = \begin{cases} p_i - c_i, & if\ i \in S, \\ 0, & otherwise. \end{cases}$
- Utility of the platform is $\tilde{u}_0 = v(S) - \sum_{i \in S} p_i$,where $v(S) = \sum_{\tau_j \in \cup_{i \in S} \Gamma_i} v_j$.

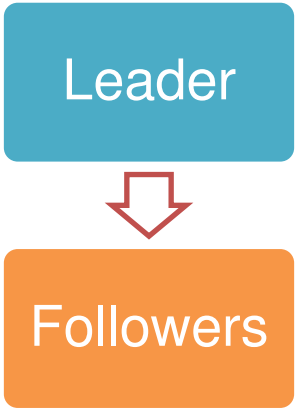
Mobile Phone Sensing System



Outline/Progress



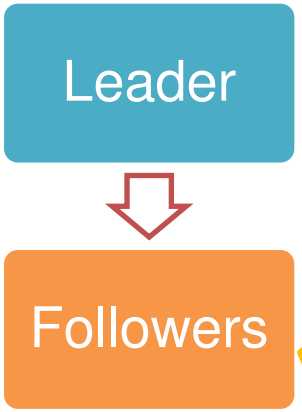
Stackelberg Game (Platform-Centric)



Stackelberg Equilibrium:

- Each follower tries to maximize its utility, given the leader's strategy
- The leader tries to maximize its utility, given the knowledge of the followers' behavior

User Sensing Time Determination



Sensing Time Determination (STD) game:

Players: Users

Strategy: Sensing Time

Utility: $\bar{u}_i = \frac{t_i}{\sum_{j \in U} t_j} R - t_i \kappa_i$

NE Computation

Leader

Followers

Sort users according to their unit costs, $\kappa_1 \leq \kappa_2 \leq \cdots \leq \kappa_n$.
$S \leftarrow \{1, 2\}, i \leftarrow 3;$
while $i \leq n \; and \; \kappa_i < \frac{\kappa_i + \sum_{j \in S} \kappa_j}{|S|}$
  $S \leftarrow S \cup \{i\}, i \leftarrow i + 1;$
end
for each $i \in U$
  if $i \in S$ then $t_i^{ne} = \frac{(|S|-1)R}{\sum_{j \in S} \kappa_j} \left(1 - \frac{(|S|-1)\kappa_i}{\sum_{j \in S} \kappa_j}\right);$
  else $t_i^{ne} = 0;$
return $(t_1^{ne}, t_2^{ne}, \ldots, t_n^{ne})$

THEOREMs 1&2: The strategy profile $t^{ne} = (t_1^{ne}, t_2^{ne}, \ldots, t_n^{ne})$ is the **unique NE** of the STD game.

Platform Reward Determination

Leader

Followers

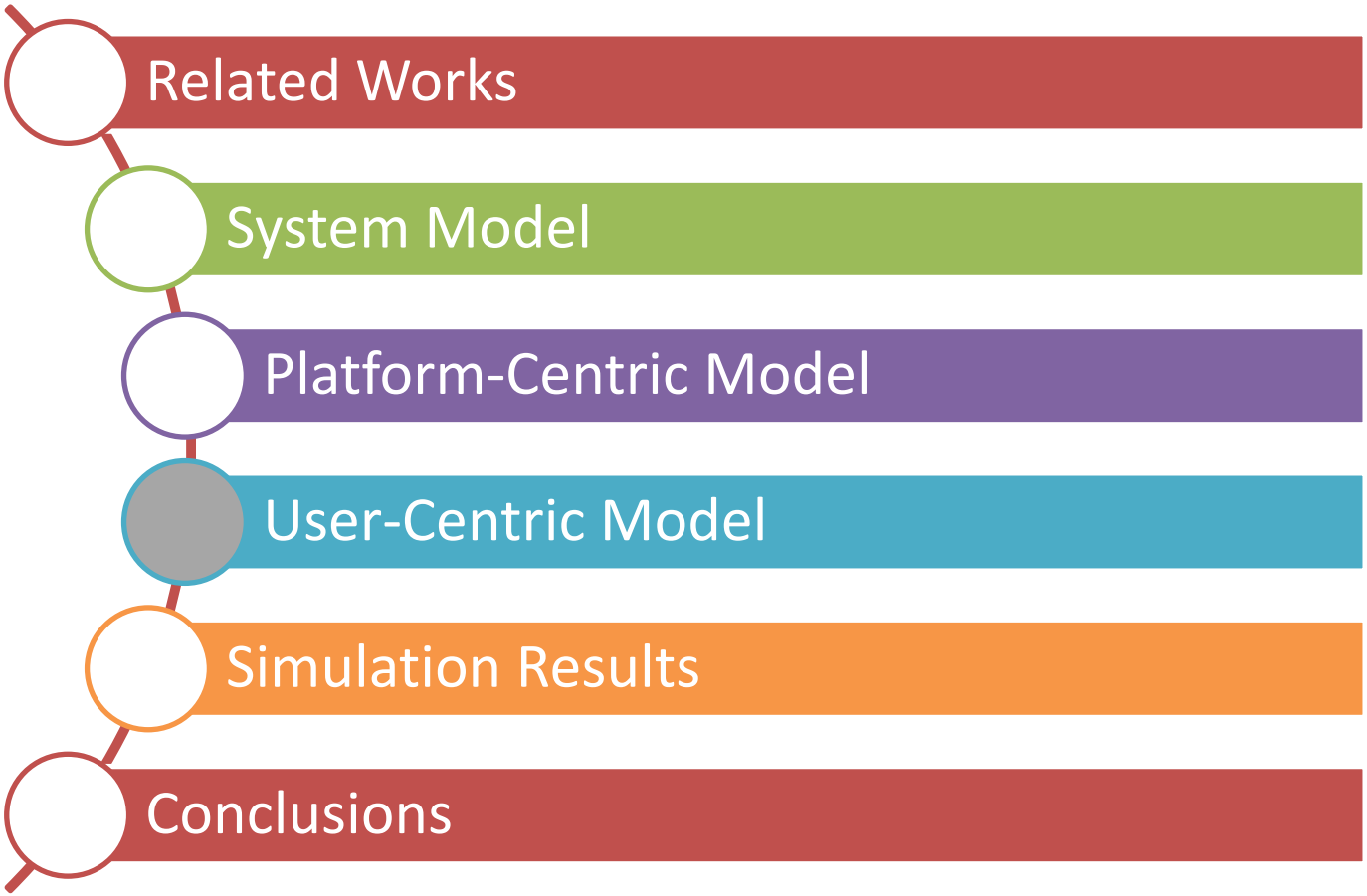
$$\bar{u}_0 = \lambda \log\left(1 + \sum_{i \in U} \log(1 + t_i)\right) - R$$

$$\bar{u}_0 = \lambda \log\left(1 + \sum_{i \in S} \log(1 + X_i R)\right) - R$$

where $X_i = \frac{(|S|-1)}{\sum_{j \in S} \kappa_j}\left(1 - \frac{(|S|-1)\kappa_i}{\sum_{j \in S} \kappa_j}\right)$

THEOREM 3: There exists a **unique SE** (R^*, t^{ne}) in the MSensing game, where R^* is the unique maximizer of the above utility function, **which is strictly concave**.

Outline/Progress



LSB Auction (Not Truthful)

$S \leftarrow \{i\}$, where $i \leftarrow \arg\max_{i \in U} f(\{i\})$;

⁕while $\exists i \in U \setminus S$ such that $f(S \cup \{i\}) > \left(1 + \frac{\epsilon}{n^2}\right) f(S)$

  $S \leftarrow S \cup \{i\}$;

if $\exists i \in S$ such that $f(S \setminus \{i\}) > \left(1 + \frac{\epsilon}{n^2}\right) f(S)$

  $S \leftarrow S \setminus \{i\}$; go to ⁕;

if $f(U \setminus S) > f(S)$ then $S \leftarrow U \setminus S$;

for each $i \in U$

  if $i \in S$ then $p_i \leftarrow b_i$;

  else $p_i \leftarrow 0$;

return (S, p)

$f(S) = \tilde{u}_0(S) + \sum_{i \in U} b_i$ is *submodular* and nonnegative

Truthful Auction

THEOREM 5: An auction mechanism is truthful if and only if, for any bidder i and any fixed choice of bid b_{-i} by other bidders,

1)The selection rule is monotonically nondecreasing in b_i;

2)The payment p_i for any winning bidder i is set to the critical value.

MSensing Auction

Winner Determination

Pricing

$S \leftarrow \emptyset, i \leftarrow \arg\max_{j \in U} \left(v_j(S) - b_j\right);$

while $b_i < v_i$ and $S \neq U$

$S \leftarrow S \cup \{i\};$

$i \leftarrow \arg\max_{j \in U \setminus S} \left(v_j(S) - b_j\right);$

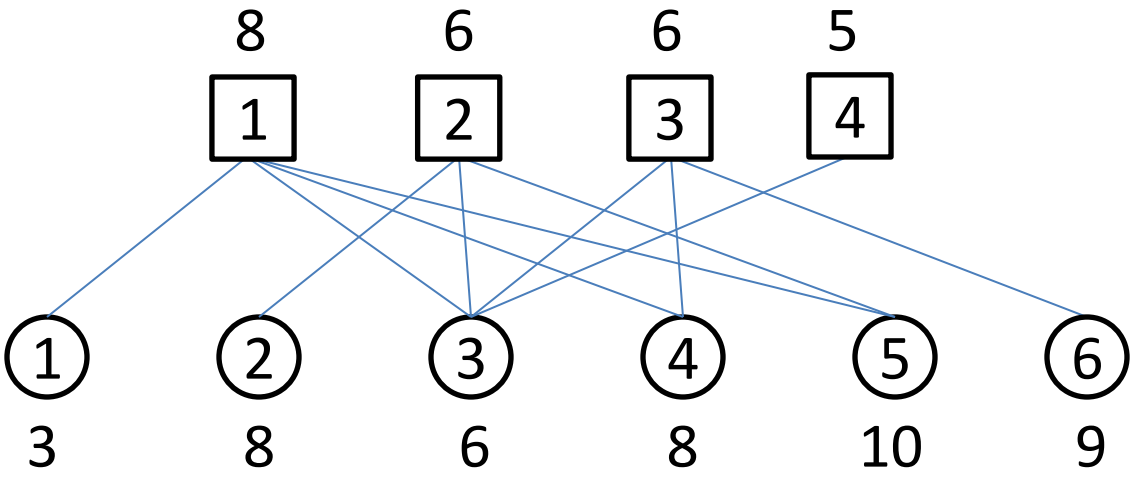
MSensing Auction

Winner Determination

Pricing

$p_i \leftarrow 0$ for all $i \in U$;
for each $i \in S$
  $U' \leftarrow U \setminus \{i\}, T \leftarrow \emptyset$;
  repeat
    $i_j \leftarrow \arg\max_{j \in U' \setminus T} (v_j(T) - b_j)$;
    $p_i \leftarrow \max\left\{p_i, \min\left\{v_i(T) - \left(v_{i_j}(T) - b_{i_j}\right), v_i(T)\right\}\right\}$;
    $T \leftarrow T \cup \{i_j\}$;
  until $b_{i_j} \geq v_{i_j}$ or $T = U'$;
  if $b_{i_j} < v_{i_j}$ then $p_i \leftarrow \max\{p_i, v_i(T)\}$;

Walk-through Example (MSensing)



Winner Selection:

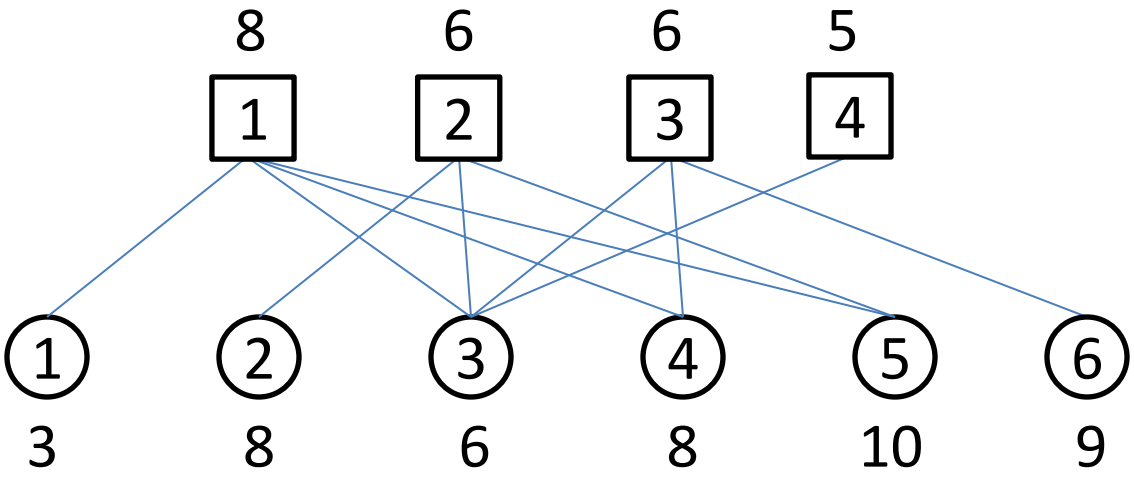
$S = \emptyset$: $v_1(\emptyset) - b_1 = \big(v(\emptyset \cup \{1\}) - v(\emptyset)\big) - b_1 = 19$, $v_2(\emptyset) - b_2 = 18$, $v_3(\emptyset) - b_2 = 17$ $v_4(\emptyset) - b_4 = 1$.

$S = \{1\}$: $v_2(1) - b_2 = \big(v(\{1\} \cup \{2\}) - v(\{1\})\big) - b_2 = 2$, $v_3(1) - b_3 = 3$, $v_4(\{1\}) - b_4 = -5$.

$S = \{1,3\}$: $v_2(\{1,3\}) - b_2 = \big(v(\{1,3\} \cup \{2\}) - v(\{1,3\})\big) - b_2 = 2$, $v_4(\{1\}) - b_4 = -5$.

$S = \{1,3,2\}$: $v_4(\{1,3,2\}) - b_4 = -5$.

Walk-through Example (MSensing)



Payment Determination:

p_1: Winners are {2,3}.
$v_1(\emptyset) - (v_2(\emptyset) - b_2) = 9$, $v_1(\{2\}) - (v_3(2) - b_3) = 0$, $v_1(\{2,3\}) = 3$. $p_1 = 9$ ≥8.

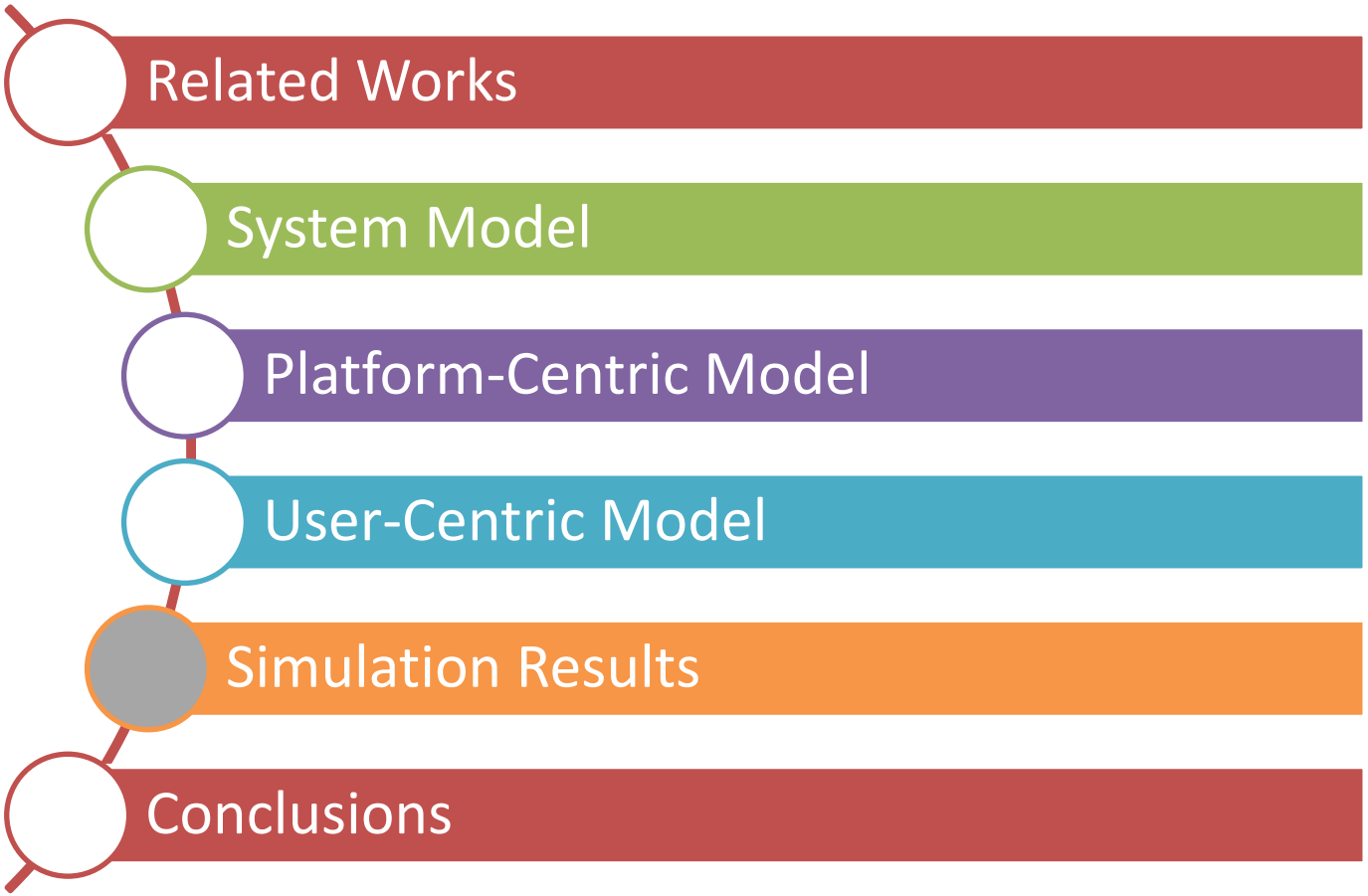
p_2: Winners are {1,3}.
$v_2(\emptyset) - (v_1(\emptyset) - b_1) = 5$, $v_2(\{1\}) - (v_3(1) - b_3) = 5$, $v_2(\{1,3\}) = 8$. $p_2 = 8$ ≥6.

p_3: Winners are {1,2}.
$v_3(\emptyset) - (v_1(\emptyset) - b_1) = 4$, $v_3(\{1\}) - (v_2(1) - b_2) = 7$, $v_3(\{1,2\}) = 9$. $p_3 = 9$ ≥6.

MSensing is Truthful

THEOREM 6. MSensing is computationally efficient, individually rational, profitable and truthful.

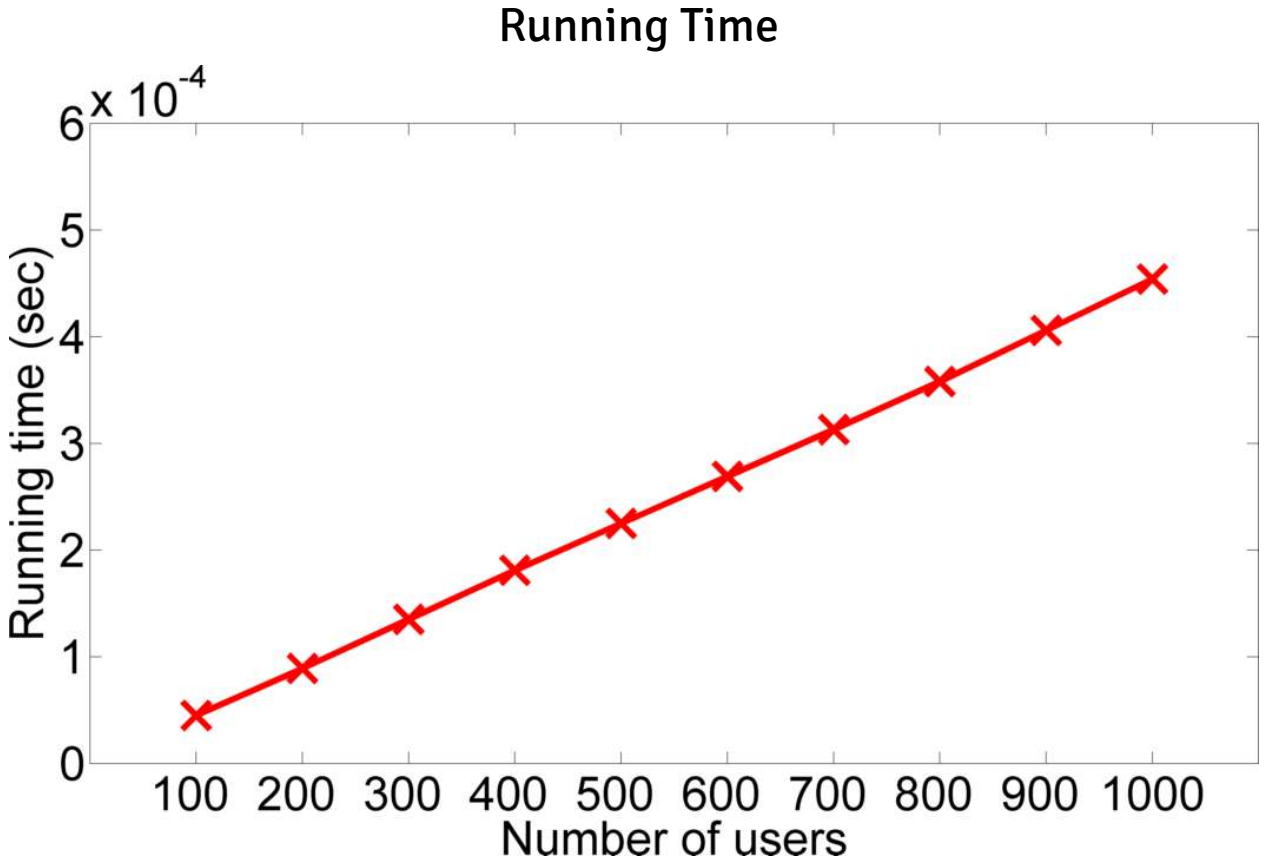
Outline/Progress



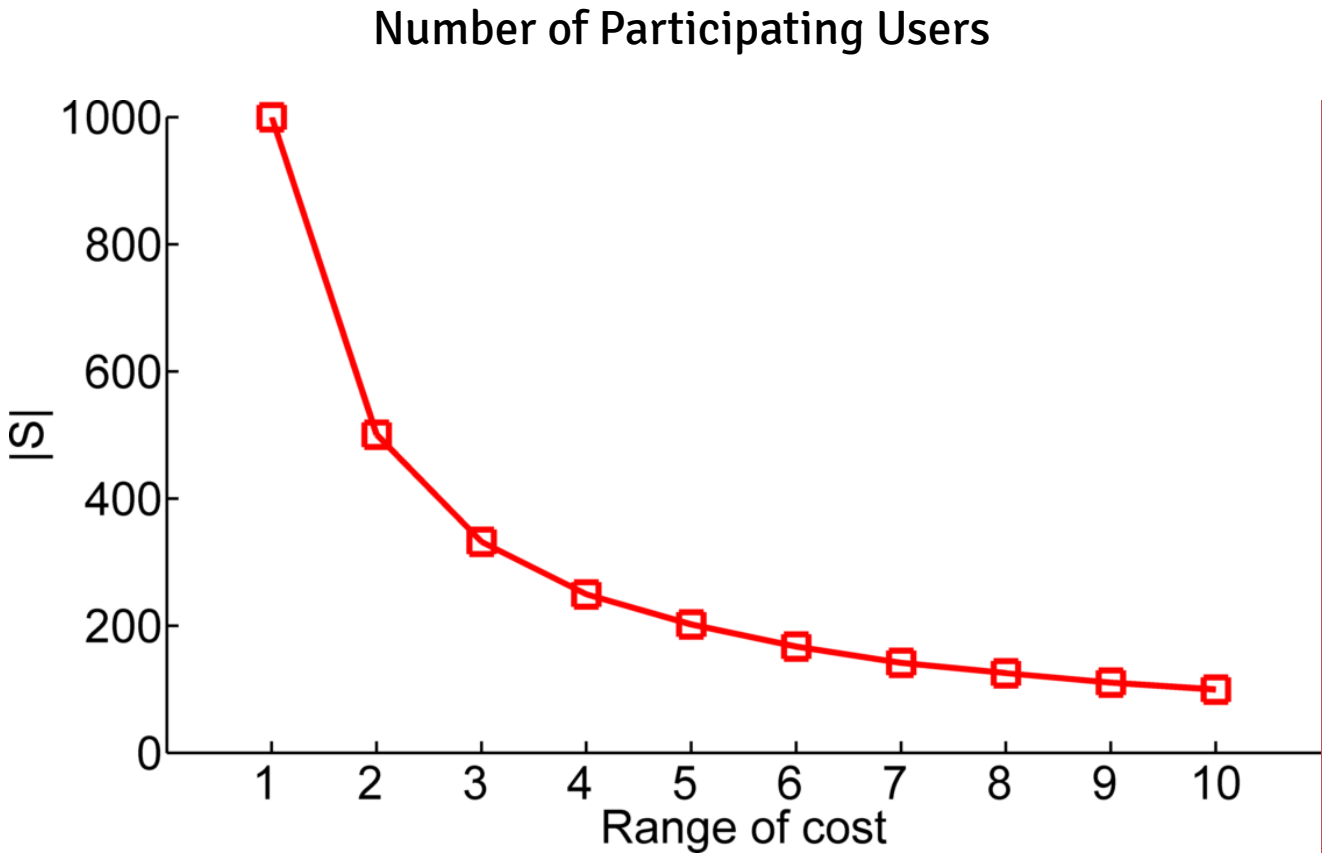
Simulation Setup

- Platform-Centric Model
  - n is varied from 100 to 1000
  - Cost is uniformly distributed over $[1, \kappa_{max}]$, where κ_{max} is varied from 1 to 10
  - λ is set to 3, 5, 10
- User-Centric Model
  - n is varied from 1000 to 10000
  - m is varied from 100 to 500
  - ϵ is set to 0.01

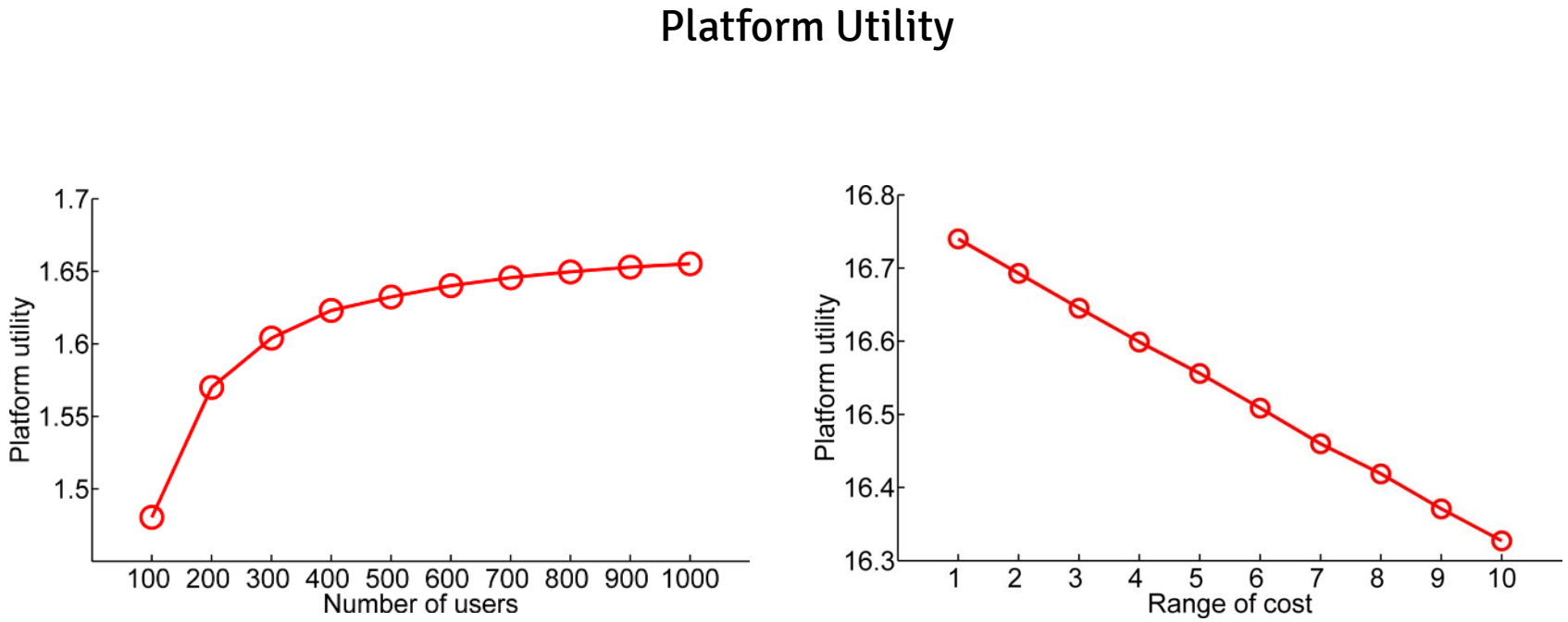
Platform-Centric Incentive Mechanism



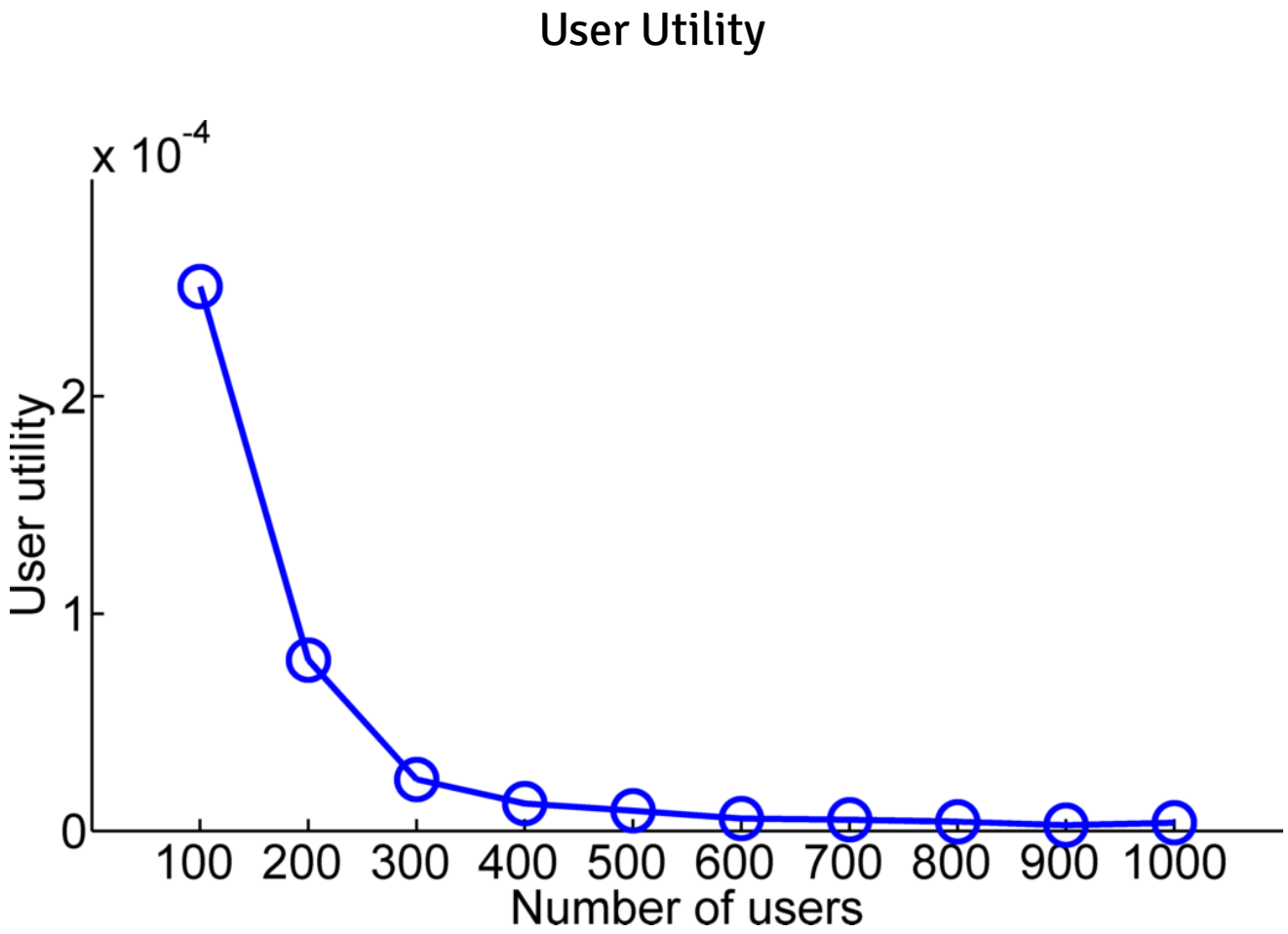
Platform-Centric Incentive Mechanism



Platform-Centric Incentive Mechanism

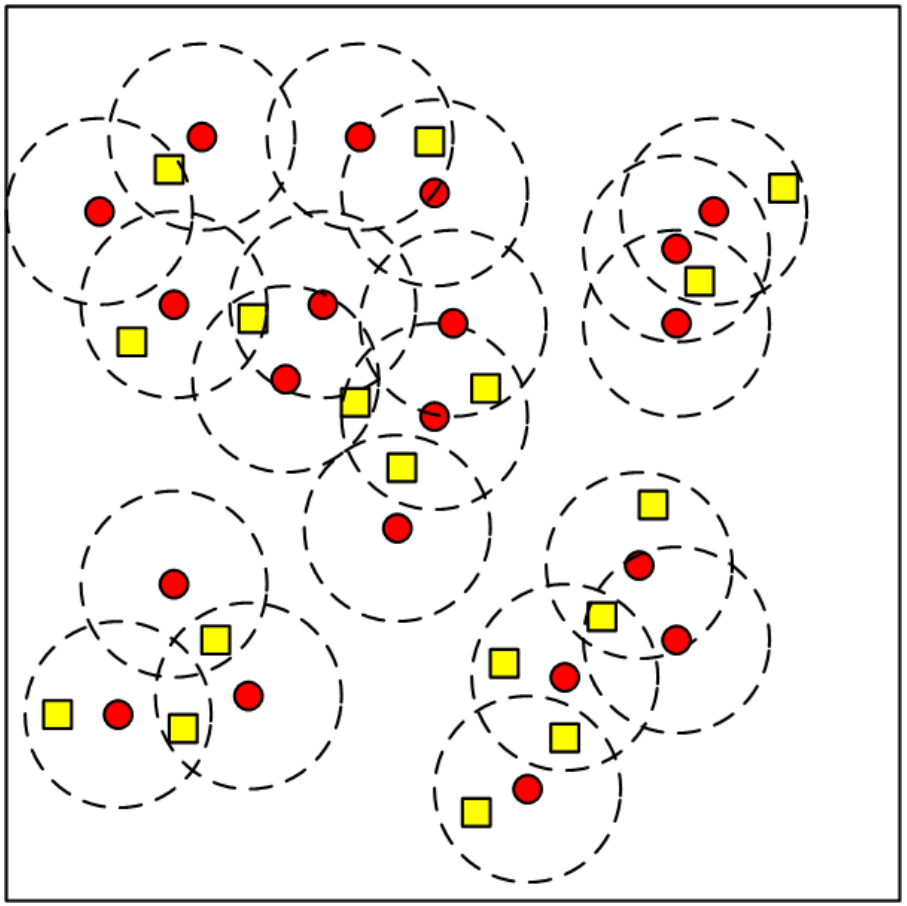


Platform-Centric Incentive Mechanism

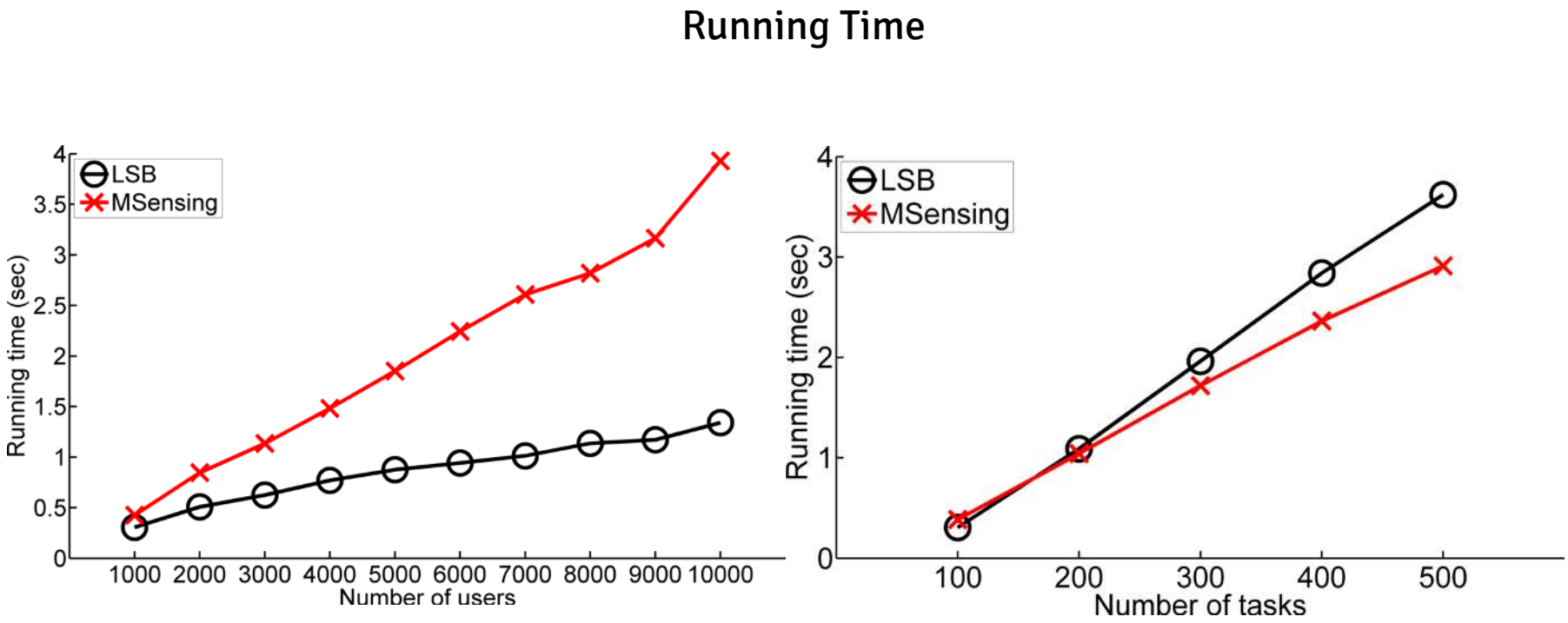


Simulation Setup

- User-Centric Model

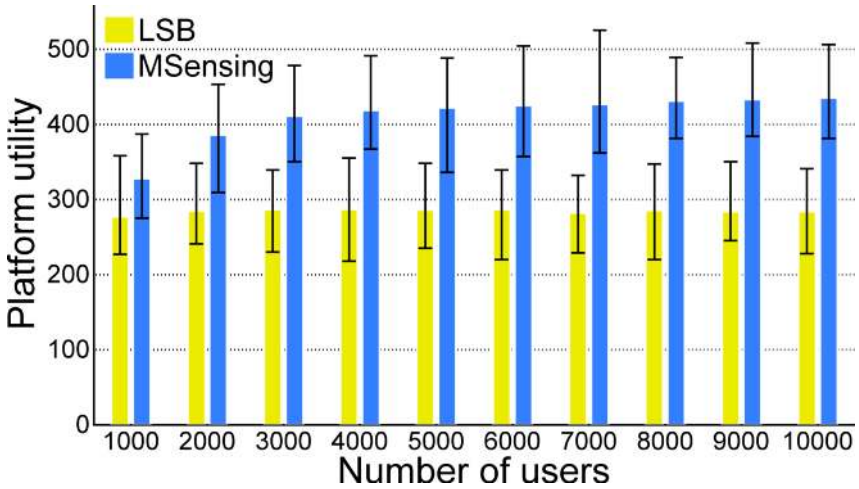


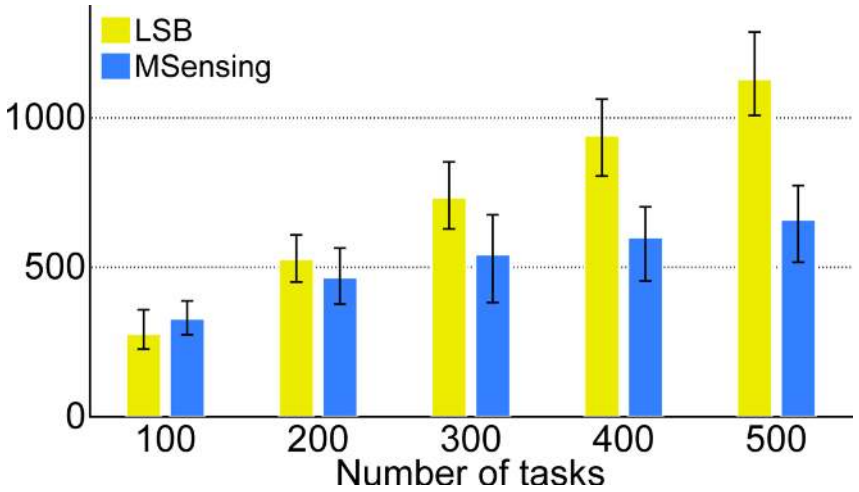
User-Centric Incentive Mechanism



User-Centric Incentive Mechanism

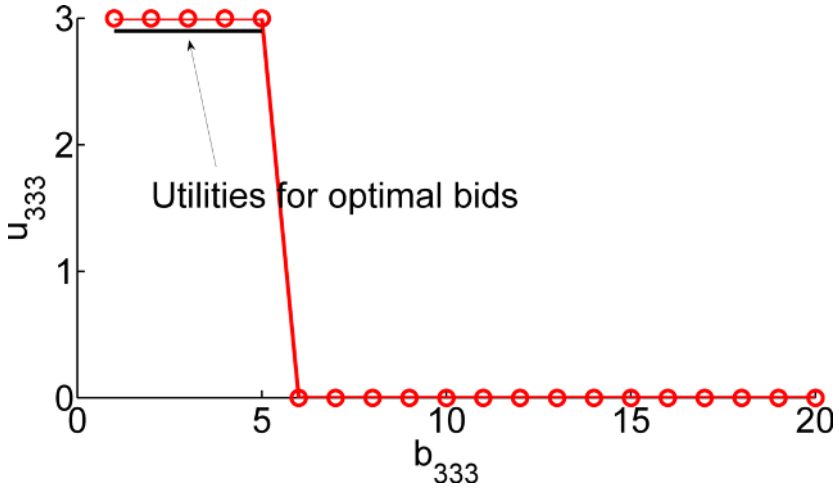
Platform Utility



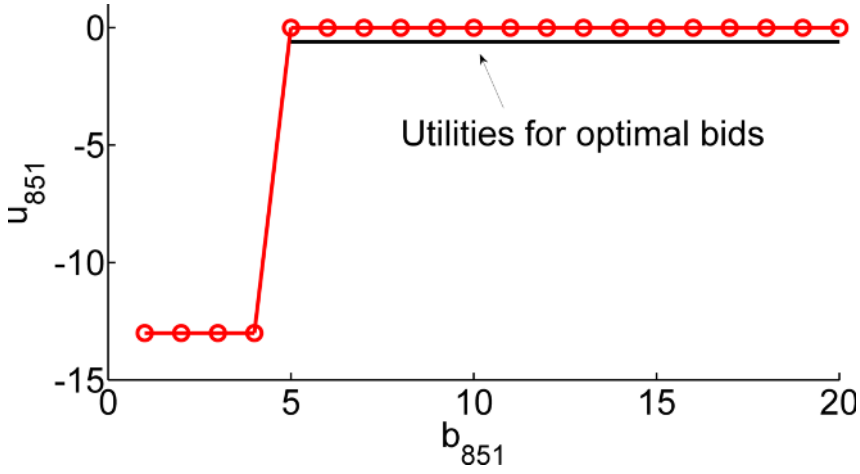


User-Centric Incentive Mechanism

Verification of Truthfulness

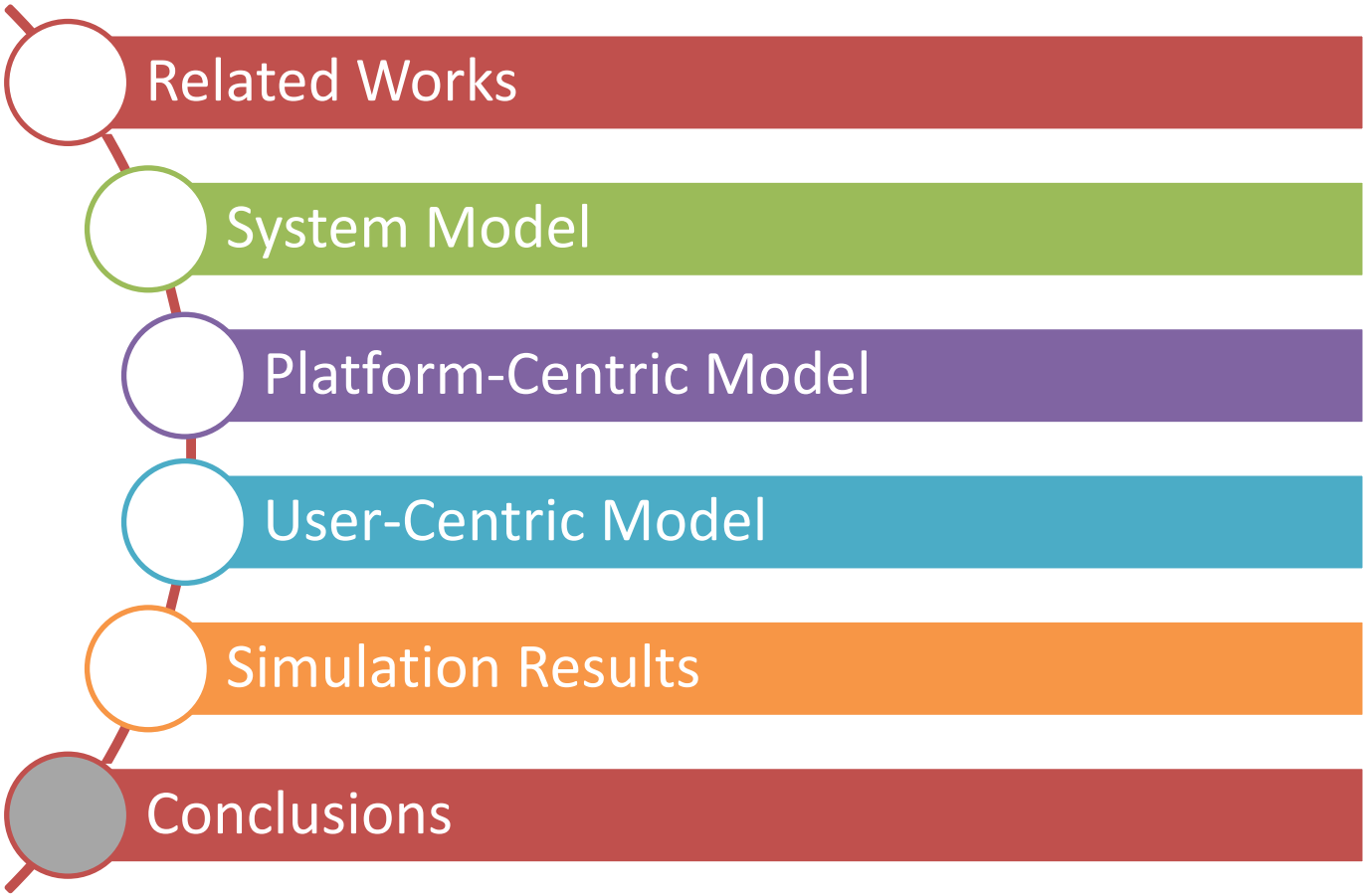


$c_{333} = 3$



$c_{851} = 18$

Outline


Related Works
System Model
Platform-Centric Model
User-Centric Model
Simulation Results
Conclusions

Conclusions

Designed incentive mechanisms for mobile phone sensing

Platform-Centric Model

- Modeled as a Stackelberg game
- Proved the uniqueness of Stackelberg Equilibrium, which can be computed efficiently

User-Centric Model

- Modeled as an auction
- Proved the computational efficiency, individual rationality, profitability and truthfulness