

Towards Efficient Team Formation for Crowdsourcing in Non-Cooperative Social Networks

Wanjuan Wang, Jiuchuan Jiang, Bo An, Yichuan Jiang*, *ef D*, *e e*

Crowdsourcing has become a popular service computing paradigm for requesters to integrate the ubiquitous human-intelligence services for tasks that are difficult for computers but trivial for humans. This paper focuses on crowdsourcing complex tasks by team formation in social networks (SNs) where a requester connects to a large number of workers. A good indicator of efficient team collaboration is the social connection among workers. Most previous social team formation approaches, however, either assume that the requester can maintain information of all workers and can directly communicate with them to build teams, or assume that the workers are cooperative and be willing to join the specific team built by the requester, both of which are impractical in many real situations. To this end, this paper first models each worker as a selfish entity, where the requester prefers to hire inexpensive workers that require less payment and workers prefer to join the profitable teams where they can gain high revenue. Within the non-cooperative SNs, a distributed negotiation-based team formation mechanism is designed for the requester to decide which worker to hire and for the worker to decide which team to join and how much should be paid for his skill service provision. The proposed social team formation approach can always build collaborative teams by allowing team members to form a connected graph such that they can work together efficiently. Finally, we conduct a set of experiments on real dataset of workers to evaluate the effectiveness of our approach. The experimental results show that our approach can 1) preserving considerable social welfare by comparing the benchmark centralized approaches and 2) form the profitable teams within less negotiation time by comparing the traditional distributed approaches, making our approach a more economic option for real-world applications.

Team formation, social networks, crowdsourcing, multiagent, non-cooperative, negotiation



$$A$$
$$\rightarrow A$$

$$A$$
$$1, 2 \dots n$$
$$\in K$$
$$la R It DI Wt v t$$
$$la$$

$$R$$
$$s \in R$$
$$It$$
$$s It$$
$$la DI$$
$$Wt$$
$$DI Wt$$
$$v t$$
$$t$$

$$v_{\kappa}(t) = \begin{cases} v_{\kappa}(\frac{DI_{\kappa} + Wt_{\kappa} - t}{DI_{\kappa} - It_{\kappa}})^{\delta}, & t \leq DI_{\kappa} + Wt_{\kappa} \\ 0 & , t > DI_{\kappa} + Wt_{\kappa} \end{cases}$$
$$v$$
$$la$$
$$It$$
$$t$$
$$DI v t$$
$$It Wt$$
$$DI Wt$$

$$|$$
$$\in$$
$$\forall \in \exists \in \cdot \in$$
$$\emptyset$$
$$\bullet$$
$$\in$$
$$\bullet$$
$$\forall \in \exists \in \cdot \in$$
$$\bullet$$
$$\in$$

• Ev

Wt

$$Ev(\kappa, \tau) = \frac{\int_{\tau+Wt_{\kappa}}^{Dl_{\kappa}+Wt_{\kappa}} v_{\kappa}(t)dt}{Dl_{\kappa}-\tau}$$

• Sr

$, \quad Sr\ T = -|us|/|R|$

• Re

$$Re(T_{\kappa}) = \sum_{(a_i, s_j, p(a_i, s_j)) \in Cont(\Omega_{\kappa}, \kappa, P_{\kappa})} p(a_i, s_j)$$

$p\ a, s$

s

$p\ a\ s$

a

a

a

Y

partial fulfilled team T , Cont, P , $us >$ at time step ,

the team manager la estimated profit is:

$$Ep(T,) = Sr(T) Ev() - Re(T)$$

a
 la
 $la T a ns$
 $q H \emptyset, max Ep T th Ev |R|$
 $s \in as a R c a s_i \leq \leq c a s_i as a_i R |$
 $\leq$
 $\otimes U$
 Y
 $\notin$
 $\backslash \otimes U U \leq | \cap$
 $\in$
 $\leq$
 Y
 $\otimes U U$
 $Y Y$
 Y
 $ns \emptyset$
 $Offe O la T a ns a$
 a
 max
 th
 th
 la
 a
 $as a R$
 $Ep T \otimes nsUs_i,$
 la
 $nsUs_i$
 $Ep T \otimes nsUs_i$
 la
 a
 $s_j \in nsUs_i$
 $Cont$
 $T \otimes nsUs_i$
 la
 T
 $T \otimes nsUs_i$
 ns
 $T \otimes ns$
 a
 max
 $s_i c a s_i$
 th
 a_k
 $T \otimes nsUs_i$
 $T \otimes ns$
 a
 s_i
 T
 $T \otimes nsUs_i$
 $U_q p \leq |as a_i R |s_p a$
 $rs T \setminus T \otimes nsUs_i$
 a
 s_i
 a
 rs
 $cs = U_q p \leq |as a_i R |s_p \cap rs$
 $T \otimes nsUs_i$
 cs

H
 CS
 $Ep T \otimes nsUs_i UH$
 $H T \otimes nsUs_i$
 $max la$
 a
 s_i
 la
 ns
 $ns \neq \emptyset la$
 $T \otimes CS$
 $/*cs: the set of skills that the team T hires and this function re-$
 $turns the team configuration after team T hires skill set cs*/$
 $la a$
 $Cont$
 $s_j \in CS$
 $,P$
 a_k
 $s_j \in CS$
 T

Given a team T and a redundant freelancer a with the available skills $Z = X \cup Y$, $X, Y \neq \emptyset$ and $X \cap Y = \emptyset$, then $Ep(T \otimes Z) = Ep(T \otimes X) + Ep(T \otimes Y) - Ep(T)$ where $T \otimes X$ is the updated team of T by contributing the skills X to T (defined in Algorithm 4).

Ep
 $T \otimes Z ($
 $)$
 X

$$Ep(T_k \otimes X, \tau) = Ep(T_k, \tau) + (|X| - |rs_X|) \cdot th - (\sum_{s_j \in X} c(a_i, s_j) - \sum_{s_j \in rs_X} p(\cdot, s_j))$$

$th = Ev$
 $|R|$
 rs_X

$$\begin{aligned}
 & X \cap Y = \emptyset \\
 & Ep(T_k \otimes X, \tau) + Ep(T_k \otimes Y, \tau) \\
 & = 2Ep(T_k, \tau) + (|X| + |Y| - |rs_X| - |rs_Y|) \cdot th \\
 & \quad - (\sum_{s_j \in X \cup Y} c(a_i, s_j) - \sum_{s_j \in rs_X \cup rs_Y} p(\cdot, s_j)) \\
 & = Ep(T_k, \tau) + Ep(T_k \otimes Z, \tau)
 \end{aligned}$$

$\otimes$
 $\otimes$
 $\otimes$
 $\square$
 $\otimes$
 Σ
 $\otimes$
 $\cup$
 $\forall$
 $\emptyset$
 $\cap$
 $\emptyset,$
 $\otimes$

$$\begin{cases}
 Ep(T_k \otimes Z) = Ep(T_k \otimes \bigcup_{1 \leq i \leq n-1} X_i) + Ep(T_k \otimes X_n) - Ep(T_k) \\
 Ep(T_k \otimes \bigcup_{1 \leq i \leq n-1} X_i) = Ep(T_k \otimes \bigcup_{1 \leq i \leq n-2} X_i) + Ep(T_k \otimes X_{n-1}) - Ep(T_k) \\
 \vdots \\
 Ep(T_k \otimes \{X_1 \cup X_2\}) = Ep(T_k \otimes X_1) + Ep(T_k \otimes X_2) - Ep(T_k)
 \end{cases} \quad (8)$$

n
 $Ep T \otimes Z = \sum_{i=1}^n Ep T \otimes X_i - n Ep T$
 $\square$

Given a redundant freelancer a that la is negotiating with, Algorithm 3 returns the optimal skill contribution of a that produces the maximal estimated profit for la .

Alg

$$\begin{aligned} & \Theta \text{ Alg} \cap \text{Opt} \\ & = \text{Alg} \setminus \Theta \\ & = \text{Opt} \setminus \Theta \\ & = W \end{aligned}$$

$$\begin{aligned} & \text{Opt Alg} \\ & = \emptyset. \end{aligned}$$

la

$$T \otimes \text{Alg}$$

$$c a s_i \leq \leq c a s_i$$

$$\begin{aligned} & s_i \in \\ & \text{Alg} \cup s_i \quad \text{Ep } T \otimes \text{Alg} \end{aligned}$$

$$\begin{aligned} & s_i \in \text{US} \quad c a s_i \text{ th} \\ & \text{Opt} \\ & c a s_i \leq \text{th} \end{aligned}$$

$$\begin{aligned} & s_i \notin \text{US} \quad \& c a s_i \quad \min \text{ th } c a s_i \\ & a_k \\ & s_i \end{aligned}$$

$$\begin{aligned} & \text{Opt} \\ & s_i \notin \text{US} \quad \& c a s_i \quad \min \text{ th } c a s_i \\ & s_i \end{aligned}$$

$$\text{Ep } T \otimes \text{Alg}$$

$$\begin{aligned} & r s \subseteq \text{Alg } s \\ & T \otimes \text{Alg} \end{aligned}$$

rs

$$c s \subseteq s_i \quad T \otimes \text{Alg} \cup s_i$$

s

$$T \otimes \text{Alg}$$

$$\begin{aligned} \Rightarrow & \otimes \quad \cup \quad \cup \\ \Rightarrow & \otimes \quad \cup \end{aligned}$$

Opt

$$\begin{aligned} & \otimes \quad \otimes \cup \quad \cup \quad \cup \\ & \otimes \quad \otimes \quad \otimes \quad \cup \quad \otimes \quad \cup \\ & < \quad \otimes \quad \otimes \quad \otimes \quad \cup \end{aligned}$$

Opt

$$\begin{aligned} \Rightarrow & \otimes \quad \geq \quad \otimes \quad \otimes \cup \quad \cup \\ & \otimes \quad \geq \quad \otimes \quad \otimes \quad \otimes \quad \cup \quad \cup \end{aligned}$$

$$\Theta \cap \quad \cup \quad \emptyset$$

W

$$= \emptyset.$$

□

a

la a

la k

O la T a ns

a

Fully-contracted Partial-contracted

Free a

During social team formation,

the agent who initiates a task or has been a member of a fulfilled team is in state ; the agent who has been a member of a partial team is in state ; and the agent who neither initiates a task nor has joined a team is in state .

a

W

a

T

pas

cas

a

pas cas

s

a

a

O la T a ns

T

T

T

O T

a

T a

$$Er(a_i, T_{\kappa^*}, \tau) = \frac{Sr(T_{\kappa^*}, \tau) \sum_{(a_i, s_j, p(a_i, s_j)) \in \text{Cont}(\Omega_{\kappa^*}, \kappa^*, P_{\kappa^*})} p(a_i, s_j)}{Wt_{\kappa^*}}$$

$$\begin{aligned} & Er a T^* \\ & Sr T \end{aligned}$$

$$Sr T = -|us|/|R|) DI$$

$$\sum_{(a_i, s_j, p(a_i, s_j)) \in \text{Cont}(\Omega_{\kappa^*}, \kappa^*, P_{\kappa^*})} p(a_i, s_j) \quad Wt$$

O la T a ns a

$$Er(a_i, T_{\kappa^*}, ns, \tau) = \frac{Sr(T_{\kappa^*}, \tau) \sum_{s_j \in ns} c(a_i, s_j)}{Wt_{\kappa^*}}$$

T *

T * a
la *

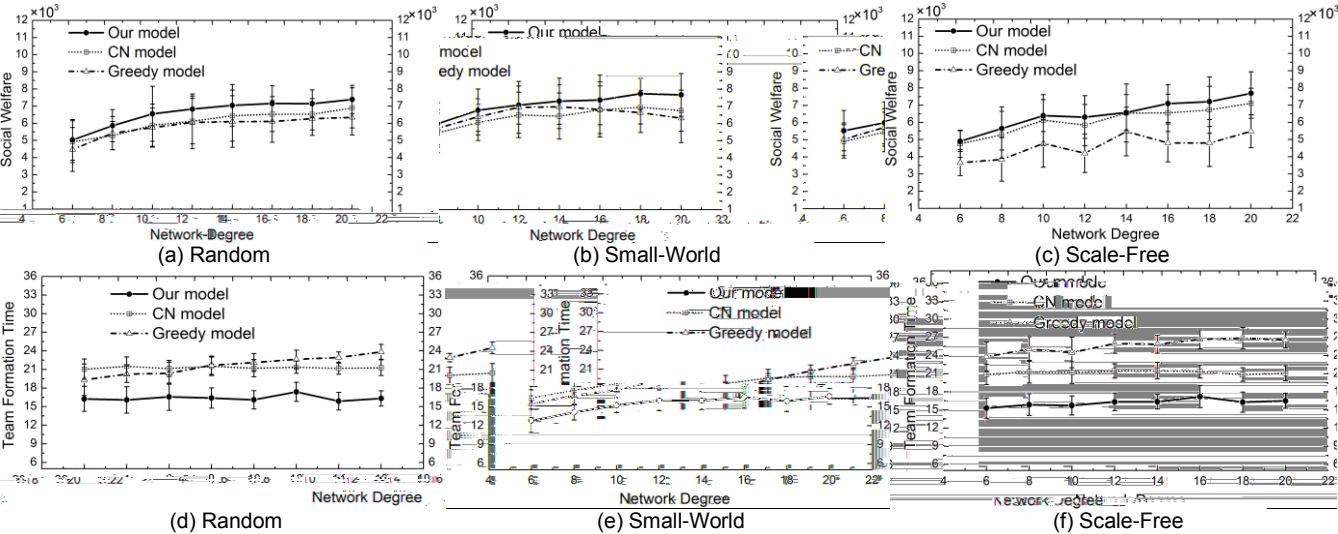


Fig. 1. The effect of network degree on different social team formation models social welfare (a c) and team formation time (d f).

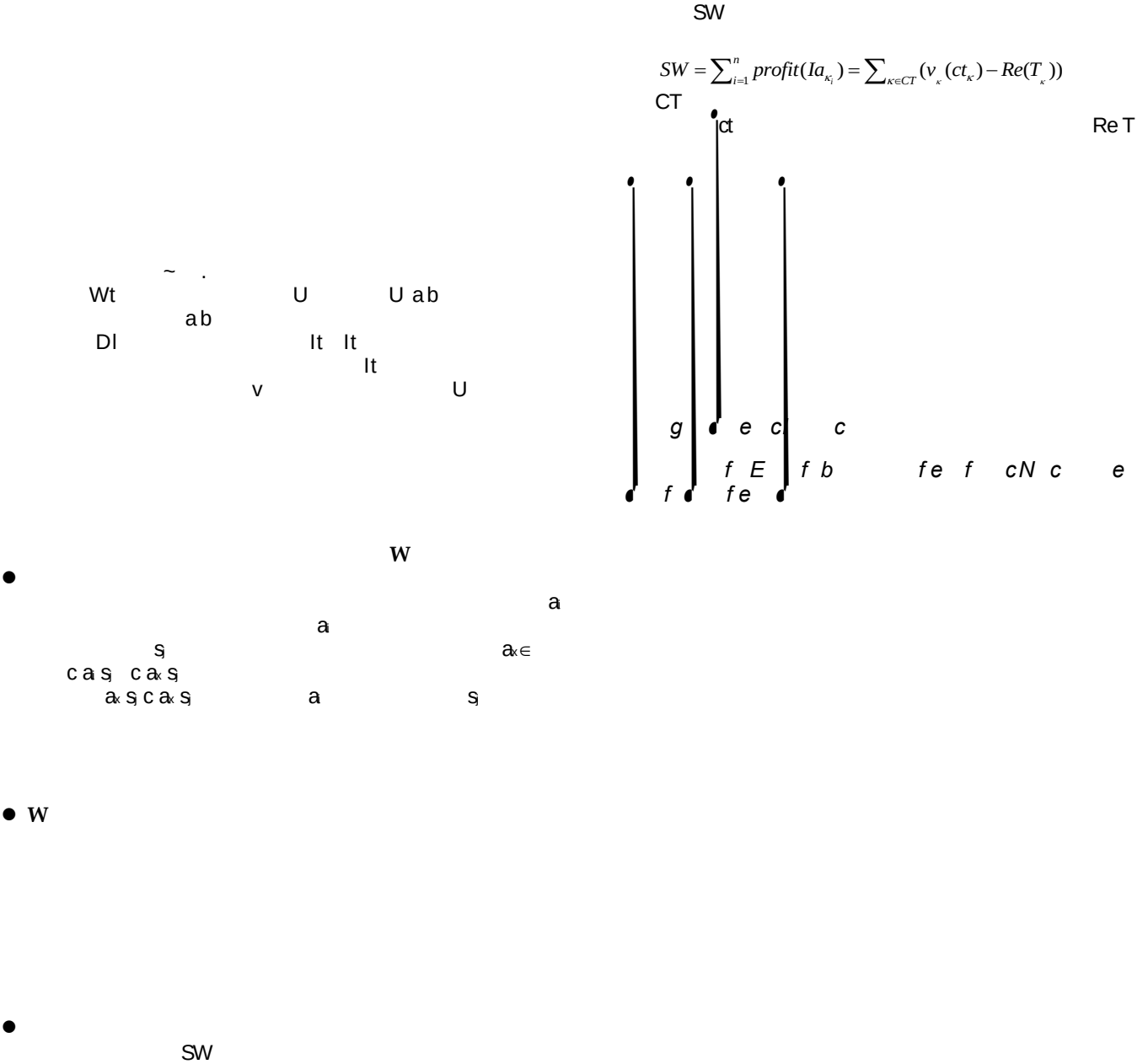


Table 3 The properties of net orks

Net ork \ Propert	Net ork Degree											
	=6			=10			=14			=18		
		<i>gc</i>	<i>c</i>		<i>gc</i>	<i>c</i>		<i>gc</i>	<i>c</i>		<i>gc</i>	<i>c</i>
Random	7.0	4.0	0.007	5.1	3.3	0.011	4.9	3.0	0.015	4.0	2.7	0.019
Small-World	7.5	4.5	0.22	5.2	3.5	0.24	5.0	3.1	0.25	4.0	2.8	0.26
Scale-Free	6.0	3.5	0.03	5.0	2.9	0.035	4.0	2.7	0.045	4.0	2.5	0.053

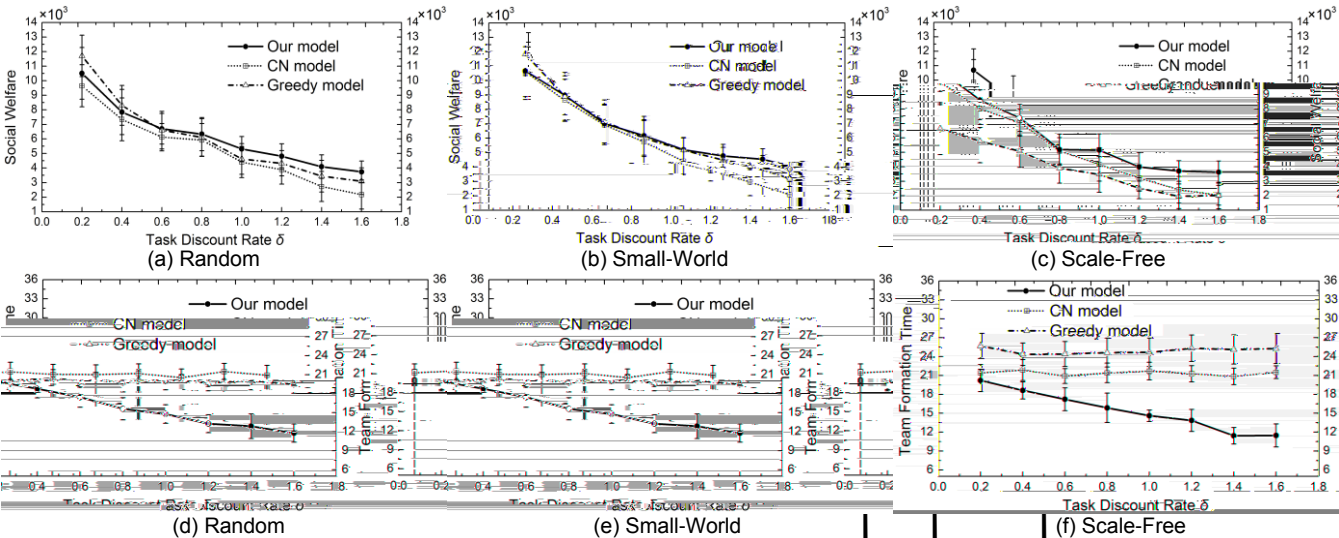


Fig. 2. The effect of task discount rate on different social team formation models social elfare (a c) and team formation time (d f).

e f b f e l f e f c N c

th Ev |R|

IEEE Software

Intelligence (ICTAI-14)

Proceedings of the Second AAAI
Conference on Human Computation and Crowdsourcing (HCOMP -
14)

IEEE Transactions
on Parallel and Distributed Systems

IEEE Transactions on Cybernetics

IEEE Transactions on Cybernetics

Proceedings of the
21st international conference on World Wide Web (WWW-12)

IEEE Transactions on Cybernetics

IEEE Transactions on Cybernetics

Proceedings of the 15th ACM
SIGKDD international conference on Knowledge discovery and data
mining (KDD-09)

Proceedings of the
18th ACM SIGKDD international conference on knowledge discovery
and data mining (KDD-12)

Journal of Artificial
Intelligence Research

Artificial Intelligence

IEEE Transactions on
Cybernetics

Proceedings of the 21st international Conference on
World Wide Web (WWW-12)

Knowledge and Information Systems

Proceedings of the
European Conference on Machine Learning and Principles and Practice
of Knowledge Discovery in Databases (ECML-PKDD-12)

Proceedings of the 22nd International
Conference on World Wide Web (WWW-13)

IEEE Transactions on Parallel and
Distributed Systems

Proceedings of the Eighth ACM International Conference on Web
Search and Data Mining (WSDM-15)

Proceedings of the 9th
International Conference on Autonomous Agents and Multiagent
Systems (AAMAS-10)

Proceedings of the 2014 IEEE International Conference on Tools with Artificial

Proceedings of the 13th
International Conference on Autonomous Agents and Multiagent
Systems (AAMAS-14)

Proceedings of the 13th International
Conference on Autonomous Agents and Multiagent Systems (AAMAS-
14)

IEEE Transactions on Systems, Man, and
Cybernetics: Systems

Proceedings of the 15th International Conference on
Autonomous Agents and Multiagent Systems (AAMAS-16)

Proceedings of the 3rd Symposium on Social Networks and Multiagent
Systems (SNAMAS-11)

