Abstract

Mobile crowdsourcing network is a promising technology utilizing the mobile terminal’s sensing and computing capabilities to collect and process data. However, because the mobile users (MUs) have selfish characteristics, the MUs only aim at maximizing their benefits. Therefore, how to design an appropriate long-term incentive mechanism for the service provider (SP) in dynamic environments is an urgent problem. In this work, we investigate the reputation-based dynamic contract for mobile crowdsourcing network. A two-period dynamic contract is first investigated to deal with the asymmetric information problem in the long-term crowdsourcing tasks. Reputation strategy is introduced to attract the MUs to complete the long-term tasks. The incentives of the contract and the implicit incentives of the reputation strategy are used together to encourage MUs to complete the long-term crowdsourcing tasks. The optimization strategy is formulated by adjusting the reputation coefficient to maximize the SP’s utility. The impact of MUs’ risk attitude and reputation impact factors on the incentive mechanism is studied through experiments. Numerical simulation results demonstrate that the optimal reputation-based contract design scheme is efficient in the Mobile crowdsourcing networks.

Keywords: Mobile crowdsourcing network; Incentive mechanism; Contract theory; Reputation strategy; asymmetric information

1 Introduction

Nowadays, with the popularity of using the smartphones and various wearable sensing devices, a wide range of processors, sensing devices and enormous memories are equipped in mobile devices [1]. A novel paradigm will be offered by these devices to gather data about human society, surroundings, and individuals. There are various mobile crowdsourcing applications around the world, such as CrowdDB [2] for querying and answering, OpenStreetMap [3] for structuring an openly confirmed map of the world, Medusa [4] for environment sensing and data processing, and Honeybee [5] for face detection.

Nevertheless, how to design an effective mobile crowdsourcing network (MCN) [6] is considerably difficult. The service provider (SP) first recruits mobile users (MUs) to complete the crowdsourcing task. Each MU will consume its resource (i.e., memory, battery, and time) when participating in missions. Then, rational MUs control mobile devices in MCNs, aiming at maximizing their benefits. Private information [7] may be contained in the data, such as location information. Moreover, MUs would be unwilling to complete the long-term tasks without additional incentives. Thus, incentive mechanisms are essential to accomplish the mutual benefit in the long-term corporation.
Unfortunately, due to MUs’ mobility and the dynamic nature of the mobile wireless environment, SPs may not be able to obtain certain crowdsourced information (i.e., MUs’ crowdsourcing efforts), which leads to asymmetric information problem between the SP and MUs [8]. The MUs’ crowdsourcing action may not be monitored by the SP all the time. Then, the MUs will deviate from the incentive mechanism. Therefore, we first investigate the contract-based incentive mechanism to deal with this problem. Contract theory [9] researches how to make a choice under inconclusive situations or sign a contract with asymmetric information in economic issues.

Moreover, in order to motivate MUs more strongly to participate in long-term crowdsourcing tasks, the reputation strategy is introduced to provide the implicit incentive. Therefore, in this paper, the reputation-based dynamic contract incentive mechanism is proposed to create mutual benefits in long-term crowdsourcing tasks. Our contributions are summarized as follows.

(1) New solution technique: we consider the MUs’ effort for the MCNs under asymmetric information scenario. As far as we know, the reputation-based dynamic contract incentive mechanism for MCNs has not been investigated.

(2) Optimal incentive mechanism design: we study a two-period dynamic contract incentive mechanism between the MUs and the SP. For purpose of attracting the MUs to complete the long-term crowdsourcing tasks, reputation theory is introduced. A two-period dynamic contract design based on the reputation effect is proposed. The necessary and sufficient conditions for the incentive compatibility and individual rationality based on the reputation effect are systematically described.

(3) Performance analysis: numerous simulations demonstrate that the optimal reputation-based dynamic contract incentive mechanism is efficient.

The remaining of this article is organized as follows. Section “Related work” introduces the research which has been done about the mobile crowdsourcing and the incentive. Section “System model for crowdsourcing incentive mechanism” introduces the system model about the crowdsourcing incentive mechanism. Section “Two-period contract-based incentive mechanism without reputation strategy” describes the detailed design for the optimal two-period dynamic contract in the long-term task. In section “Two-period contract-based incentive mechanism with reputation strategy,” we describe the detailed design for the optimal two-period dynamic contract with the reputation strategy in the long-term crowdsourcing task. The experiments and discussion about the results are presented in section “Numerical results.” Finally, section “Conclusion” summarizes this article.

2 Related works
There are three primary incentive mechanisms for MCNs, which are service-based, monetary-based, and entertainment-based mechanisms [10]. The service-based incentive mechanism draws each MUs’ attention to the participation in making essential contributions to crowdsourcing [11–13]. The entertainment-based incentive mechanism means that to alter the tasks into playable games [14, 15]. The monetary-based incentive mechanism means workers can get rewards through participating in the crowdsourcing [16–18]. Since the prior two incentive mechanisms should acquire the particular information, such as artificial intelligence and computer theory.
The monetary-based mechanism is more appropriate for ecumenical crowdsourcing scenarios. However, the network information asymmetry problems have not been taken into consideration by most of these researches.

Contract theory [9] is proposed to make a choice under inconclusive situations or sign a contract with asymmetric information in economic issues. Lately, many practical problems have applied it successfully, for instance, cooperative relay [19–21], mobile crowdsourcing [22], and cooperative spectrum trading [23]. Zhang et al., investigated the method with the incentive mechanism to deal with the asymmetric information in the optimal compensation package [24]. Our previous work researched an efficient contract model for adverse selection and moral hazard problems [21] in the wireless nodes’ hidden relay actions. Nevertheless, there are many long-term crowdsourcing tasks need to be completed. Therefore, the long-term incentive mechanism for MCNs needs to be investigated.

Reputation theory which is kind of long-term incentive mechanism based on implicit reputation factor was presented to motivate MUs more strongly to participate in long-term tasks [25]. Jin et al., proposed a Reputation-based Multi-Auditing algorithmic mechanism (RMA) [26]. The reputation of the relationship between enterprises and tourism enterprises is investigated by Ma et al. [27]. Liu et al., investigated sustainable cooperation based on reputation and habit formation [28]. However, in these works, the network information asymmetry problems have not been taken into consideration.

3 System model for crowdsourcing incentive mechanism

In Fig 1, there are three essential parts contained in an MCN: an SP, N MUs, and end users. End users first transmit their crowdsourcing requirements to the SP. Then, these requirements are divided into several small tasks by the SP. Next, these small tasks are published on the crowdsourcing platform to attract the MUs to participate. When MUs finish these crowdsourcing tasks, the final service will be provided to the end users.

However, due to the selfish characteristics of the service provider and mobile users, crowdsourcing participants only aim at maximizing their own benefits. This paper investigates the long-term incentive mechanism between the above two parties to create mutual benefits. Mobile crowdsourcing is modeled as a labor market. The SP, as the employer, offers the contract to recruit the certain MUs for crowdsourcing. The contract is composed of a set of different items about the various combinations of basic wage and performance bonus. Each MU, as an employee, chooses one item from the contract when participating in crowdsourcing tasks.

3.1 Utility of MUs

Suppose that the crowdsourcing effort $e_i$ of the $i^{th}$ MU is first offered to acquire reward from the SP. Then, the SP’s profit $\pi_i$ can be accomplished. Considering some measurement errors and the impact of the dynamic environment, we suppose that a noisy signal to be the SP’s real profit $\pi_i$, which is written as

$$\pi_i = \theta_i e_i + \varepsilon,$$  

(1)
where \( \theta_i \) is the profit unit crowdsourcing effort, and \( \varepsilon \) is a normally distributed random variable with \( \varepsilon \sim N(0,\sigma^2) \).

Suppose that the SP provides the \( i \)th MU with the linear payment \( s_i \) \[29\]

\[
s_i = \alpha_i + \beta_i \pi_i,
\]

(2)

where \( \alpha_i \) is the basic wage, and \( \beta_i \in [0,1] \) is incentive coefficient which is connected with the MUs’ performance.

Then, the reward \( w_i \) to the \( i \)th MU is defined as the payment \( s_i \) minus the crowdsourcing cost \( C_i(e_i) \), that is,

\[
w_i = s_i - C_i(e_i).
\]

(3)

As the consumption of crowdsourcing resources increasing, the cost of crowdsourcing for MU payments will increase. Then, we can consider that the larger crowdsourcing effort \( e_i \) is, the more rapidly \( C_i(e_i) \) will grow. Therefore, \( C_i'(e_i) > 0 \) and \( C_i''(e_i) > 0 \). For simply, the crowdsourcing cost \( C_i(e_i) \) of the \( i \)th MU is supposed to be quadratic as \( C_i(e_i) = \frac{c_i}{2}(e_i)^2 \), where \( c_i \) is crowdsourcing cost coefficient of \( i \)th MU to describe the cost information (i.e., battery, computing power, and memory). Notice that crowdsourcing costs might be diverse in different crowdsourcing scenarios. Since the \( \pi_i \) is a random signal, the reward \( w_i \) is approximatively normally distributed with means

\[
E\ [w_i] = \alpha_i + \beta_i \theta_i e_i - \frac{c_i}{2}(e_i)^2,
\]

(4)
and variances

\[ \text{Var} [w_i] = (\beta_i)^2 \sigma^2. \] (5)

In this paper, each MU is assumed having the constant absolute risk aversion (CARA) preference [30]. Thus, the negative exponential utility function of the \(i^{th}\) MUs’ can be written as

\[ u(w_i) = -e^{-\eta_M w_i}, \]

where \(\eta_M > 0\) is the parameter of absolute risk aversion. Therefore, the expected utility \(U_i\) of the \(i^{th}\) MUs’ can be defined as

\[
U_i = E[f(w_i)] = E[-e^{\eta_M w_i}],
\]

\[
= -\frac{1}{2\pi \text{Var}[w_i]} \int_{-\infty}^{\infty} e^{-\frac{(w_i)^2}{2\text{Var}[w_i]} + 2\text{Var}[w_i]\eta_M w_i} dw_i
\]

\[
= -e^{-\eta_M [E[w_i] - \frac{1}{2} \text{Var}[w_i] \eta_M]}
\]

\[
= -e^{-\eta_M \left[ \alpha_i + \beta_i \theta_i e_i - \frac{c_i}{2} (e_i)^2 - \frac{1}{2} \eta_M (\beta_i)^2 \sigma^2 \right]}. \] (6)

For simple discussion, let \(u_i = \alpha_i + \beta_i \theta_i e_i - \frac{c_i}{2} (e_i)^2 - \frac{1}{2} \eta_M (\beta_i)^2 \sigma^2\). Then, the MUs’ expected utility can be defined as \(U_i = -e^{-\eta_M u_i}\). Since \(\frac{\partial U_i}{\partial u_i} = \eta_M e^{-\eta_M u_i} > 0\), the MUs’ expected utility can be simplified as

\[ u_i = \alpha_i + \beta_i \theta_i e_i - \frac{c_i}{2} (e_i)^2 - \frac{1}{2} \eta_M (\beta_i)^2 \sigma^2. \] (7)

3.2 Utility of SP

Then, the SP’s utility \(u_s\) is the achievable profit obtained from the MUs’ crowdsourcing effort \(e_i\) minus the payment \(s_i\) to MUs, which is defined as

\[ u_s = \sum_{i=1}^{N} \left( \pi_i - s_i \right), \] (8)

with the expectation means \(E[U_s] = \sum_{i=1}^{N} (1 - \beta_i) \theta_i e_i - \alpha_i\); and variance \(\text{Var}[U_s] = \sum_{i=1}^{N} (1 - \beta_i)^2 \sigma^2\).

3.3 Problem formulation

Due to the depletable resources and selfishness of MUs, MUs might tend to be shirked or unsatisfactory during the completion of tasks. For instance, because the MUs’ resources may be consumed, the MUs would expect to acquire maximum utilities from the SP with little crowdsourcing effort. Moreover, the crowdsourcing actions of the participants are undetectable, which results in the asymmetric information problem. Thus, the dynamic contract incentive mechanism is investigated to motivate the MUs to complete the tasks effectively and reliably.

Moreover, there are many everlasting work crowdsourcing tasks need to be completed, but few MUs are willing to participate in the long-term tasks. In order to
motivate the MUs to participate in the long-term tasks, reputation strategy is introduced in the dynamic contract incentive mechanism, which can provide the implicit incentive to the MUs.

Figure 2 shows the reputation-based dynamic contract \( \{s_1^i(\pi_1^1), s_2^i(\pi_2^2 | \pi_1^1)\} \) model of two periods, where the \( \pi_1^1 \) and \( \pi_2^2 \) represent the SP’s profit in the period 1 and period 2. The contract includes a series of projects to the latent MUs. Then, the MUs need to inform the SP of their options after adopting contract items. Next, the crowdsourcing tasks will be provided to the employed MUs while the MUs receive the MUs’ confirmations. Then, the MUs offer the effort \( e_1^i \) to participate in period 1 crowdsourcing. After the received data being proved successful, the SP pays \( s_1^i(\pi_1^1) \) to the MUs according to their contracts. Similar to period 1, due to the reputation information being taken into consideration, the effort in period 1 will affect the payment in period 2. Therefore, the SP needs to pay \( s_2^i(\pi_2^2 | \pi_1^1) \) to the MUs according to their contracts. Nevertheless, while the information is invalid or insufficient to the demand, the participants can’t obtain reward. Considering that limited interaction will happen in the cooperation, the reputation-based dynamic contract incentive mechanism is easy to accomplish, and can efficiently reduce telecommunications and calculated amount.

![Figure 2: Time sequence of reputation-based dynamic contract incentive model](image)

### 4 Methods

#### 4.1 Two-Period contract-based incentive mechanism without reputation strategy

Since reputation strategy can bring implicit incentives in two-period or more long-term mobile crowdsourcing tasks. In order to contrast with incentive mechanisms that consider reputation strategies, in this section, a two-period dynamic contract is investigated to avoid asymmetric information. First of all, the SP’s expected utility of period 1 can be written as

\[
u_s^1 = \sum_{i=1}^{N} [\pi_1^i - s_1^i(\pi_1^1)]. \tag{9}\]

In period 2, the SP’s expected utility can be defined as

\[
u_s^2 = \sum_{i=1}^{N} [\pi_2^i - s_2^i(\pi_2^2 | \pi_1^1)] = \sum_{i=1}^{N} [\pi_2^i - (\alpha_2^i + \beta_2^i \pi_1^1)]. \tag{10}\]

Finally, we can obtain the SP’s expected utility in the two periods as

\[
u_s = u_s^1 + \delta u_s^2 = \sum_{i=1}^{N} [\pi_1^i - s_1^i(\pi_1^1)] + \delta \sum_{i=1}^{N} [\pi_2^i - s_2^i(\pi_2^2)], \tag{11}\]
where $\delta > 0$ is a discount factor. Similar to (6), the utility of the $i^{th}$ MUs in the two-period can be defined as

$$u_i = E \left[ s_1^i (\pi_1^i) - C(e_1^i) \right] + \delta E \left[ s_2^i (\pi_2^i) - C(e_2^i) \right]$$

$$- \frac{1}{2} \eta_M \text{Var} \left[ s_1^i (\pi_1^i) + \delta s_2^i (\pi_2^i) \right].$$

(12)

Based on the backward induction, the contract in period 2 should be considered to design in the first.

In period 2, we should design a contract to ensure that each MU can maximize its utility $u_2^i$ by choosing the optimal effort $e_2^i$. Similar to (6), the utility of the $i^{th}$ MUs’ in period 2 can be defined as $u_2^i = \alpha_2^i + \beta_2^i \theta_i e_2^i - c_i^2 (e_2^i)^2 - \eta M (\beta_2^i)^2 \sigma^2$.

Therefore, the incentive compatibility (IC) constraint can be defined as

$$\max_{e_i^2 \geq 0} u_i^2 = \alpha_2^i + \beta_2^i \theta_i e_2^i - \frac{c_i}{2} (e_2^i)^2 - \frac{\eta M}{2} (\beta_2^i)^2 \sigma^2.$$ 

(13)

Consequently, in order to assure that each MU’s received utility is higher than its retained utility $\bar{U}$, the individually rational (IR) constraint should be satisfied:

$$u_2^i = \alpha_2^i + \beta_2^i \theta_i e_2^i - c_i^2 (e_2^i)^2 - \eta M (\beta_2^i)^2 \sigma^2 \geq \bar{U}.$$ 

(14)

Therefore, based on the above IC and IR constraints, the optimal problem is designed to obtain the SP’s maximum expected utility $u_2^s$, which can be written as

$$\max_{\{\alpha_2^i, \beta_2^i\} \geq 0} u_2^2 = \sum_{i=1}^{N} E \left[ \pi_2^i - (\alpha_2^i + \beta_2^i \pi_1^i) \right].$$

s.t. (13) and (14) (15)

From the above IC constraint (13), the offer effort $e_2^{*2}$ of period 2 can be written as

$$e_2^{*2} = \frac{\beta_2^i \theta_i}{c_i}.$$ 

(16)

From the IR constraint (14), for purpose of accomplishing the SP’s maximum expected utility $u_2^s$ in (10), we should obtain the minimum $\alpha_2^i$ from (14). Therefore, we can obtain the basic wage $\alpha_2^{*2}$ of period 2

$$\alpha_2^{*2} = \bar{U} - \beta_2^{*2} \theta_i e_2^{*2} + \frac{c_i}{2} (e_2^{*2})^2 + \frac{\eta M}{2} (\beta_2^{*2})^2 \sigma^2.$$ 

(17)

Accordingly, we can substitute (16) and (17) for (15). Then, the SP’s expected utility maximum problem can be simplified as

$$\max_{\beta_2^i \geq 0} \sum_{i=1}^{N} E \left[ \pi_2^i - (\alpha_2^i + \beta_2^i \pi_1^i) \right].$$ 

(18)
Any optimal local solution of period 2 (denoted as $\hat{\beta}_2^i$) to the problem of (18) satisfies
\[
\frac{dE[u_2^s]}{d\beta_2^i} \bigg|_{\beta_2^i = \hat{\beta}_2^i} = \frac{(\theta_i)^2}{c_i} - \frac{(\theta_i)^2}{c_i}\hat{\beta}_2^i - \eta_M\sigma^2\hat{\beta}_2^i = 0. \tag{19}
\]

Next, we can further obtain the second-order derivative of the problem about (18) is
\[
\frac{d^2E[u_2^s]}{d(\beta_2^i)^2} \bigg|_{\beta_2^i = \hat{\beta}_2^i} = -\frac{(\theta_i)^2}{c_i} - \eta_M\sigma^2 < 0. \tag{20}
\]

Therefore, the optimal solution of the incentive coefficient $\beta_2^*^i$ to (18) is obtained as
\[
\beta_2^*^i = \frac{(\theta_i)^2}{(\theta_i)^2 + \eta_Mc_i\sigma^2}. \tag{21}
\]

Since the period 2 has been guaranteed to be optimal, in order to contrast with the two-period reputation-based dynamic contract design, the optimization problem of period 1 can be convert to optimizing the two-period dynamic contract design. Similar to the case of period 2, the IC constraint in the two periods can be defined as
\[
\max_{\alpha_1^1_i \geq 0} \left[ E[s_1^1(\pi_1^1) - C(e_1^1)] + \delta E[s_2^1(\pi_2^1) - C(e_2^1)] \right.

\left. - \frac{1}{2}\eta_M\text{Var}[s_1^1(\pi_1^1) + \delta s_2^1(\pi_2^1)] \right]. \tag{22}
\]

Consequently, in order to assure that each MU’s utility is no less than its retained utility $\bar{U}$ in the two periods, the IR constraint should be satisfied:
\[
u_i = E[s_1^1(\pi_1^1) - C(e_1^1)] + \delta E[s_2^1(\pi_2^1) - C(e_2^1)]

- \frac{1}{2}\eta_M\text{Var}[s_1^1(\pi_1^1) + \delta s_2^1(\pi_2^1)] \geq \bar{U}. \tag{23}
\]

Therefore, based on the above IC and IR constraints, the optimal problem is designed to obtain the SP’s maximum expected utility, which can be written as
\[
\max_{(\alpha_1^1_i, \beta_1^1_i) \geq 0} \left\{ u_i \right\} = \sum_{i=1}^{N} \left\{ E[s_1^1(\pi_1^1) - (\alpha_1^1_i + \beta_1^1_i\pi_1^1)] + \delta E[s_2^1(\pi_2^1) - (\alpha_2^1_i + \beta_2^1_i\pi_2^1)] \right\}. \tag{24}
\]

From the IC constraint (22), by substituting the $\alpha_1^2*$ and $\beta_2^*^i$ into (23), we can have the offer effort $e_1^1*$ of period 1
\[
e_1^1* = \frac{\beta_1^1*\theta_i}{c_i}. \tag{25}
\]
Similar to period 2, from the IR constraint (23), by substituting the $\alpha_i^{2*}, \beta_i^{2*}$ into (23), we can obtain the basic wage $\alpha_i^{1*}$ of period 1

$$
\alpha_i^{1*} = \bar{U} - \beta_i^{1*} \theta_i e_i^{1*} - \delta \left[ \alpha_i^{2*} + \beta_i^{2*} \theta_i e_i^{2*} \right] + \frac{1}{2} \eta_M (\beta_i^{1*})^2 \sigma^2 \\
+ \frac{1}{2} \eta_M \delta^2 (\beta_i^{2*})^2 \sigma^2 + \eta_M \delta \beta_i^{1*} \beta_i^{2*} \sigma^4 + \frac{c_i}{2} (e_i^{1*})^2 + \frac{c_i}{2} \delta (e_i^{2*})^2. 
$$

(26)

Furthermore, by substituting (25) and (26) in (24), the SP’s utility maximization problem can be further simplified as

$$
\max_{\beta_i^{1*} \geq 0} \sum_{i=1}^{N} \{ E \left[ \pi_i^{1} - (\alpha_i^{1} + \beta_i^{1} \pi_i^{1}) \right] + \delta E \left[ \pi_i^{2} - (\alpha_i^{2} + \beta_i^{2} \pi_i^{2}) \right] \}. 
$$

(27)

Therefore, the local optimal solution of the incentive coefficient in period 1 (denoted as $\beta_i^{1*}$) to the problem of (27) is

$$
\beta_i^{1*} = \frac{(\theta_i)^2 - \delta c_i \eta_M \sigma^4 \beta_i^{2*}}{(\theta_i)^2 + \eta_M c_i \sigma^2}. 
$$

(28)

4.2 Two-Period contract-based incentive mechanism with reputation strategy

In this section, in order to motivate MUs more strongly to participate in long-term crowdsourcing tasks, reputation strategy is introduced. It can provide the implicit incentive to the MUs. Therefore, based on the explicit incentives of the contract and the implicit incentives of the reputation, MUs can be attracted to complete the long-term crowdsourcing tasks.

A reputation effort will be obtained by the SP, through the observation of the MUs’ mobile crowdsourcing task completion in period 1. The reputation strategy can bring implicit utility income which can be assumed to be $\lambda \pi_i^1$ ($\lambda > 0$ is external reputation parameters). While the mobile user performs better in the current period, its external reputation parameters will be greater, and its externality reputation effect will be also greater. Based on the completion of period 1 of the MUs’ crowdsourcing task, the SP determines the payment $s_i^2(\pi_i^2 | \pi_i^1)$ of period 2. While the reputation effect is considered in the two-period crowdsourcing tasks, the utility of MUs in the two periods can be written as

$$
\pi_i = \frac{1}{2} \eta_M \text{Var} \left[ s_i^1(\pi_i^1) + \delta s_i^2(\pi_i^2 | \pi_i^1) \right] + \lambda \pi_i^1. 
$$

(29)

Similar to the previous section, the SP’s expected utility of period 1 can be defined as

$$
N \sum_{i=1}^{\pi_i} \left[ \pi_i - s_i^1(\pi_i^1) \right]. 
$$

(30)
In period 2, the SP’s expected utility can be defined as
\[ u_2^s = \sum_{i=1}^{N} [\pi_i^2 - s_i^2 (\pi_i^2 | \pi_i^1)]. \] (31)

Finally, we can obtain the SP’s expected utility of the two periods as
\[ u_s = \sum_{i=1}^{N} [\pi_i^1 - s_i^1 (\pi_i^1)] + \delta [\pi_i^2 - s_i^2 (\pi_i^2 | \pi_i^1)]. \] (32)

While considering the reputation effect, the payment of period 2 will be affected by the completion of the crowdsourcing task in period 1. Similar to (6), the utility of the MUs’ in period 2 can be defined as
\[ u_2^i = \alpha_i^2 + \beta_i^2 (\theta_i \hat{e}_i^2 + (\pi_i^1 - \theta_i \hat{e}_i^1)) - \frac{c_i}{2} (\epsilon_i^2)^2 - \frac{\eta_M}{2} (\beta_i^2)^2 \sigma^2 (1 - \sigma^2). \] (33)

We can get the calculation formula of conditional expectation [31] defined as
\[ E[\pi_i^2 | \pi_i^1] = \theta_i \hat{e}_i^2 + (\pi_i^1 - \theta_i \hat{e}_i^1), \] (34)
where \(\hat{e}_i^1\) and \(\hat{e}_i^2\) are estimated value, which are the prediction of the degree of effort of MUs.

Next, we also can obtain the formula of the conditional variance which is defined as
\[ Var[\pi_i^2 | \pi_i^1] = (\beta_i^2\sigma^2 (1 - \sigma^2)) \sigma^2. \] (35)

Then, by substituting (34) and (35) into (33), the utility of the MUs in period 2 can be obtained
\[ u_2^i = \alpha_i^2 + \beta_i^2 (\theta_i \hat{e}_i^2 + (\pi_i^1 - \theta_i \hat{e}_i^1)) - \frac{c_i}{2} (\epsilon_i^2)^2 - \frac{\eta_M}{2} (\beta_i^2)^2 \sigma^2 (1 - \sigma^2). \] (36)

Then, the IC constraint can be simplified as
\[ \max_{\epsilon_i^2 \geq 0} \alpha_i^2 + \beta_i^2 [\theta_i \hat{e}_i^2 + (\pi_i^1 - \theta_i \hat{e}_i^1)] - \frac{c_i}{2} (\epsilon_i^2)^2 - \frac{\eta_M}{2} (\beta_i^2)^2 \sigma^2 (1 - \sigma^2) \geq \bar{U}. \] (37)

However, in order to assure that each MU’s received utility is no less than its retained utility \(\bar{U}\), the IR constraint should be satisfied:
\[ \alpha_i^2 + \beta_i^2 [\theta_i \hat{e}_i^2 + (\pi_i^1 - \theta_i \hat{e}_i^1)] - \frac{c_i}{2} (\epsilon_i^2)^2 - \frac{\eta_M}{2} (\beta_i^2)^2 \sigma^2 (1 - \sigma^2) \geq \bar{U}. \] (38)

Therefore, based on the above IC and IR constraints, the optimal problem is designed to obtain the SP’s maximum expected utility \(u_s^2\), which can be written as
\[ \max_{\{\alpha_i^2, \beta_i^2\} \geq 0} u_s^2 = \sum_{i=1}^{N} E [\pi_i^2 - s_i^2 (\pi_i^2 | \pi_i^1)], \] (39)
s.t. \( (37) \) and \( (38) \).
Under the assumption of rational expectation, when equilibrium is achieved, level of effort \( e_1^i, e_2^i \) chosen by the MU will be equal to the estimated value of effort level \( \hat{e}_1^i, \hat{e}_2^i \). From the IC constraint, we have the offer effort \( e_2^{i*} \) of period 2

\[ e_2^{i*} = \frac{\beta_2^{i*} \theta_i}{c_i}. \]  

(40)

From the IR constraint (37), for purpose of obtaining the SP’s maximum expected utility \( u_2^s \) in (31), we should get the minimum \( \alpha_2^i \) from (38). Then, we can obtain the basic wage \( \alpha_2^{i*} \) of period 2 through

\[ \alpha_2^{i*} = \bar{U} - \beta_2^{i*} \theta_i \hat{e}_2^{i*} + \frac{c_i}{2} (\hat{e}_2^{i*})^2 + \frac{\eta M}{2} (\beta_2^{i*})^2 \sigma^2 (1 - \sigma^2). \]  

(41)

Accordingly, the SP’s utility maximization problem can be further simplified by substituting (40) and (41) in (39) to

\[ \max_{\beta_2^i \geq 0} \sum_{i=1}^{N} E \left[ \pi_1^2 - s_1^2 (\pi_1^1 | \pi_1^1) \right]. \]  

(42)

Similar to the case of the previous section, the optimum solution to (42) is

\[ \beta_2^{i*} = \frac{(\theta_i)^2}{(\theta_i)^2 + \eta_M c_i \sigma^2 (1 - \sigma^2)}. \]  

(43)

The optimization problem of the SP in period 1 can be transformed into optimizing the two-period dynamic contract design. Similar to period 2, we can obtain the \( i^{th} \) utility \( u_i \) in (29). Therefore, the IC constraint in the two periods can be defined as

\[ \max_{e_1^i \geq 0} \ E \left[ s_1^1 (\pi_1^1) - C(e_1^1) \right] + \delta E \left[ s_1^2 (\pi_1^2 | \pi_1^1) - C(e_2^1) \right] \]

\[ - \frac{1}{2} \eta M Var \left[ s_1^1 (\pi_1^1) + \delta s_1^2 (\pi_1^2 | \pi_1^1) \right] + \lambda \pi_1^1. \]  

(44)

Consequently, we need to that the utility which each MU received is no lower than its retained utility \( \bar{U} \) in the two periods, the IR constraint should be satisfied:

\[ E \left[ s_1^1 (\pi_1^1) - C(e_1^1) \right] + \delta E \left[ s_1^2 (\pi_1^2 | \pi_1^1) - C(e_2^1) \right] \]

\[ - \frac{1}{2} \eta M Var \left[ s_1^1 (\pi_1^1) + \delta s_1^2 (\pi_1^2 | \pi_1^1) \right] + \lambda \pi_1^1 \geq \bar{U}. \]  

(45)

Therefore, based on the above IC and IR constraints, the optimal problem is designed to obtain the SP’s maximum expected utility \( u_s \), which can be written as

\[ \max_{(\alpha_1, \beta_1) \geq 0} u_s = \left\{ E \left[ \pi_1^1 - s_1^1 (\pi_1^1) \right] + \delta E \left[ \pi_1^2 - s_1^2 (\pi_1^2 | \pi_1^1) \right] \right\}, \]  

s.t. (44) and (45)  

(46)
Similar to period 2, from the IC constraint, we can have the offer effort \( e_1^* \) of period 1

\[
 e_1^* = \frac{(\beta_1^1)^* \theta_i + \lambda \theta_i}{c_i}.
\]  

(47)

From the IR constraint (45), the basic wage \( \alpha_1^* \) of period 1 can be obtained

\[
 \alpha_1^* = \bar{U} - \beta_1^1 \theta_i e_1^* - E[\delta s_2^2(\pi_1^1)] - \lambda \pi_1^1 + C(e_1^*)
 + \delta C(e_1^2) + \frac{1}{2} \eta_M \left[ (\beta_1^1)^2 \sigma^2 + \delta^2 (\beta_2^2)^2 (1 - \sigma^2) \sigma^2 + \delta \beta_1^1 \beta_2^2 \sigma^3 \right].
\]  

(48)

Accordingly, in order to further simplify the SP’s expected utility maximization problem, we can substitute (47) and (48) in (46) to

\[
 \max_{\beta_1^i \geq 0} \sum_{i=1}^{N} \left\{ E\left[ \pi_1^i - s_1^i(\pi_1^i) \right] + \delta E\left[ \pi_2^i - s_1^i(\pi_2^i \mid \pi_1^i) \right] \right\}.
\]  

(49)

Then, we can obtain the optimal local solution of the incentive coefficient in period 1 (denoted as \( \beta_1^* \)), which is written as

\[
 \beta_1^* = \frac{(\theta_i)^2 - \delta c_i \eta_M \sigma^3 \beta}{(\theta_i)^2 + \eta_M c_i \sigma^2}.
\]  

(50)

5 Performance results and discussion

In this section, numerical results are presented to evaluate the performance of the proposed dynamic incentive mechanism strategy. In all the experiments, the parameter settings are as follows, \( \eta_M = 0.3, \sigma^2 = 0.81, c_i = 0.4 \). And other variables parameters are set different values as the situation changes.

Figure 3–6 demonstrates that the variation tendency of the MUs’ crowdsourcing effort \( e_1^* \) and \( e_2^* \), optimal basic wage \( \alpha_1^* \) and \( \alpha_2^* \) and bonus coefficient \( \beta_1^* \) and \( \beta_2^* \) while the \( \theta_i \) increases. The different parameter settings are as follows, \( \bar{U} = 0.2, \delta = 0.6, \lambda = 0.3 \).

From the performance of the experiment, we can obtain that the \( i^{th} \) MU’s per crowdsourcing effort will increase when \( \theta_i \) becomes large. Therefore, the optimal crowdsourcing effort \( e_1^* \) and \( e_2^* \) will increase and the SP should allocate a larger bonus \( \beta_1^* \) and \( \beta_2^* \) to draw the MUs attention to afford enough effort. In this way, as a result of \( \beta_1^* \) and \( \beta_2^* \) increases, a lesser basic wage \( \alpha_1^* \) and \( \alpha_2^* \) should be offered to the MUs by the SP to obtain enough help. Moreover, under the reputation strategy situation, the basic wage \( \alpha_1^* \) and \( \alpha_2^* \) will decrease faster than the situation without the reputation strategy. Furthermore, the basic wage in the reputation strategy are smaller than without reputation strategy. Therefore, we can obtain that SP needs to offer little payment to the MUs for enough help.

Figure 7–10 shows the capability of the MUs’ effort-incentive with three participants in period 1 and period 2 under different conditions. All of the simulation parameter settings are the same as in Figure 3–6. Only when the MUs select the optimal crowdsourcing effort \( e_1^* \) and \( e_2^* \), do they achieve their maximum utilities.
Therefore, in this paper, the MUs are attracted to take absolute responsibility for the tasks. Thus, contract-based dynamic incentives can break the network infor-
Figure 5: Period 1 of two-period dynamic contract without reputation strategy

Figure 6: Period 1 of two-period dynamic contract with reputation strategy

In addition to the endowment function, we consider information asymmetry problems. Moreover, the reputation-based incentive mechanism motivates the MUs to offer maximum crowdsourcing efforts in the long-term co-
operation. Thus, the optimal crowdsourcing effort $e_i^{1*}$ and $e_i^{2*}$ in the reputation strategy will be larger than without reputation strategy.
Figure 9: Period 2 of two-period dynamic contract without reputation strategy

Figure 10: Period 2 of two-period dynamic contract with reputation strategy

Figure 11 shows the variation tendency of the SP’s optimal expected utility, while the MUs’ risk-averse degree $\eta_M$ and reputation effect parameter $\lambda$ change. The
profit unit crowdsourcing effort $\theta_i$ is the same as in Figure 3–6. From the result, we can notice that if the absolute risk-averse coefficient of the MUs’ become smaller and the reputation effect parameter $\lambda$ become larger, the SP’s optimal expected utility will be larger. Therefore, the SP will obtain more utility while the MUs work harder.

![Figure 11: SP’s optimal expected utility ($\bar{U} = 0$)](image)

Figure 11 shows that the maximum expected utility of SP with different incentives. It can be found that the maximum expected utility of SP under the reputation strategy incentives is greater than that under the contract incentives. At the same time, as the reputation strategy factor coefficient increases, the maximum expected utility of software service providers will also increase.
Figure 12: Comparison between the service provider’s (SP’s) optimal expected utility with the various incentive mechanisms

6 Conclusion
In this work, the crowdsourcing incentive mechanism between the SP and the MUs is proposed in the dynamic environments. Given that the MUs have selfish characteristics, the two-period dynamic contract incentive mechanism is proposed to deal with the asymmetric information scenario problem. Moreover, for purpose of attracting the MUs to complete the long-term crowdsourcing task, the reputation information is introduced. Therefore, the contractive explicit incentive and the implicit incentives for reputation altogether attract the MUs to participate in the long-term crowdsourcing task. The impact of the reputation factor has been proposed experimentally and analytically. Simulation results demonstrate that the investigated reputation strategy can improve the quality of crowdsourcing and achieve mutual benefit.

Abbreviations
MCN: Mobile Crowdsourcing Network; SP: Service Provider; MUs: Mobile Users; CARA: Constant absolute risk aversion

Author’s contributions
MHW conceived this research as well writing this paper, NZ designed this research as well modifying this paper, QXW designed reputation-based dynamic contract incentive mechanism, XZ and YHJ performed all experiments.

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Competing interests
The authors declare that they have no competing interests.

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**Figure Title and Legend Section**

Figure 1; Mobile crowdsourcing network system; It describes the basic system diagram of the mobile crowdsourcing network and the main stakeholders.

Figure 2; Time sequence of reputation-based dynamic contract incentive model; It describes the entire contract signing and completion process.

Figure 3; Period 2 of two-period dynamic contract without reputation strategy; It demonstrates that the variation tendency of the MUs’ crowdsourcing effort $e_1^{2*}$, optimal basic wage $\alpha_i^{2*}$ and bonus coefficient $\beta_i^{2*}$ while the $\theta_i$ increases in the period 2 of two-period dynamic contract without reputation strategy.

Figure 4; Period 2 of two-period dynamic contract with reputation strategy; It demonstrates that the variation tendency of the MUs’ crowdsourcing effort $e_1^{2*}$, optimal basic wage $\alpha_i^{2*}$ and bonus coefficient $\beta_i^{2*}$ while the $\theta_i$ increases in the period 2 of two-period dynamic contract with reputation strategy.

Figure 5; Period 1 of two-period dynamic contract without reputation strategy; It demonstrates that the variation tendency of the MUs’ crowdsourcing effort $e_1^{1*}$, optimal basic wage $\alpha_i^{1*}$ and bonus coefficient $\beta_i^{1*}$ while the $\theta_i$ increases in the period 1 of two-period dynamic contract without reputation strategy.

Figure 6; Period 1 of two-period dynamic contract with reputation strategy; It demonstrates that the variation tendency of the MUs’ crowdsourcing effort $e_1^{1*}$, optimal basic wage $\alpha_i^{1*}$ and bonus coefficient $\beta_i^{1*}$ while the $\theta_i$ increases in the period 1 of two-period dynamic contract with reputation strategy.

Figure 7; Period 1 of two-period dynamic contract without reputation strategy; It describes that each MU can only obtain the optimal incentive utility after the completion of the crowdsourcing task in the Period 1 of two-period dynamic contract without reputation strategy according to the contract incentive design.

Figure 8; Period 1 of two-period dynamic contract with reputation strategy; It describes that each MU can only obtain the optimal incentive utility after the completion of the crowdsourcing task in the Period 1 of two-period dynamic contract with reputation strategy according to the contract incentive design.

Figure 9; Period 2 of two-period dynamic contract without reputation strategy; It describes that each MU can only obtain the optimal incentive utility after the completion of the crowdsourcing task in the Period 2 of two-period dynamic contract without reputation strategy according to the contract incentive design.

Figure 10; Period 2 of two-period dynamic contract with reputation strategy; It describes that each MU can only obtain the optimal incentive utility after the completion of the crowdsourcing task in the Period 2 of two-period dynamic contract with reputation strategy according to the contract incentive design.

Figure 11; SP’s optimal expected utility ($\bar{U} = 0$); It shows the variation tendency of the SP’s optimal expected utility, while the MUs’ risk-averse degree $\eta_M$ and reputation effect parameter $\lambda$ change.
Figure 12: Comparison between the service provider’s (SP’s) optimal expected utility with the various incentive mechanisms. It describes the effect of introducing reputation strategies and long-term incentive mechanisms that only consider contract incentives to the expected utility of software service providers in mobile crowdsourcing.