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A Multidimensional Reputation Evaluation Model for Mobile Crowd Sensing

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***Abstract*—The participant's reputation is vital to improve the quality of service for Mobile Crowd Sensing (MCS). A multidimensional reputation evaluation model was proposed in this paper to evaluate the participant's reputation more objectively. Different from the existing strategies, the service delay and the count of the successful as well as the failed transactions were additionally utilized to evaluate the participant's reputation. An algorithm based on Analytic Hierarchical Process (AHP) was presented to establish the reputation evaluation weight matrix. Besides, a fuzzy logic based mechanism was proposed to normalize the value of the four criteria and a dual-threshold mechanism was designed to achieve admission control more properly. Finally, extensive simulations were conducted and the simulation results confirmed the effectiveness of the reputation evaluation model.**

***Keywords*—mobile crowd sensing network; reputation evaluation; analytic hierarchical process.**

I. INTRODUCTION

The boom of the mobile device and the built-in functional sensor has triggered a new kind of data acquisition paradigm, namely Mobile Crowd Sensing (MCS)[1][2][3]. In MCS scenario, the task publisher submits the task to the cloud-based platform firstly. Subsequently the platform recruits phone users to contribute their data. Through collecting and analyzing the multidimensional information, MCS facilitates the application which requires a lot of information, such as environmental monitoring, health caring and traffic tracking. Related applications include the NoiseTube[4], SignalGuru[5], Vtrack[6], SmartTrace[7], *etc*.

The success of MCS depends on the quantity of the participant's data. However, most of individuals are reluctant to share their information without any feedback generally. Therefore it is essential to properly design the incentive mechanism for MCS. Recently extensive attention has been paid to the incentive mechanism design[8][9][10][11]. However, it is possible that some malicious participants submit false or outdated data in order to maximize their returns. Therefore it is important to take the quality of data into account. Among the existing strategies, none of them took the service delay, the number of successful and failed transactions into consideration. However, these factors have a deep influence in the quality of service provided by MCS. For example, the data is time-bound for some applications which have hard real-time requirements. To this end, these factors were considered in this proposal. Specifically, the participant's reputation was evaluated according to the quantity of the data contributed by the participant, the service delay, and the count of the successful as well as failed transactions.

The contributions of this paper were listed as follow. The reputation evaluation model which took the quantity of data, the service delay, the number of successful and failed transactions into consideration was proposed firstly. Subsequently the algorithm which was based on the Analytic Hierarchical Process (AHP) was presented in detail. Finally, experiments were conducted via simulations to verify the effectiveness of the model.

The reminders of the paper were organized as follow. Section II presented the related works in brief. The multidimensional reputation evaluation model was detailed in section III. Subsequently, the corresponding experiments were conducted via simulations in section IV, followed by section V which concluded the paper and also pointed out some future research directions.

II. RELATED WORKS

As stated above, it is of great importance to prompt the phone user to contribute the data. Recent years have witnessed numerous strategies aimed at evaluating the participant's reputation so as to improve the quality of service of MCS. Sun, *et al*. proposed a reputation-aware incentive mechanism (RAIM) with the properties of truthfulness and individual rationality to improve the quality of sensing data as well as maximize the weighed social welfare of the whole system[12]. Pouryazdan, *et al*. proposed a new metric, namely collaborative reputation scores to evaluate the participant's reputation on the basis of two existing approaches that quantify crowd-sensed data trustworthiness and are statistical-based and vote-based reputation scores respectively[13]. Zhou, *et al*. proposed a truthful online mechanism for the location-aware task in mobile crowd sensing[14]. In their proposal, a truthful one-round auction which comprises of an approximation algorithm for solving the one-round WDP and a payment scheme for computing remuneration to winners were proposed. In addition, an online algorithm framework that employs the one-round auction as a building block towards a flexible mechanism that makes on-spot decisions on dynamically arriving bids were proposed respectively.

Although lots of mechanisms which aim at improving the quality of data via evaluating the participant's reputation exist, none of them take multiple criteria into consideration. In fact, except the quality of the data, the service delay, the number of successful and failure transactions are also needed to be taken into account, which are exactly what were considered in this paper to improve the quality of MCS.

III. MULTIDIMENSIONAL REPUTATION EVALUATION MODEL

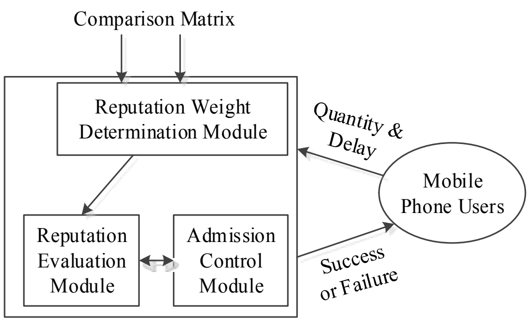

Fig.1 *Multidimensional Reputation Evaluation Model*

Fig.1 shown the multidimensional reputation evaluation model which was proposed in this paper. It consists of three modules which are the reputation the weight determination module, the reputation evaluation module, and the admission control module respectively. Compared with the strategies of Refs.[8-12], this paper took the service delay and the transaction history of the participant into consideration except the quantity of the data. Two metrics which are the number of successful transactions and that of the failed transactions reflect the transaction history to some extent. Therefore through the model, both the quality and the quantity of the data were utilized to achieve admission controlling.

A. Reputation Evaluation Model

$$\Re = \begin{pmatrix} R_{11} & R_{12} & \dots & R_{14} \\ R_{21} & R_{22} & \dots & R_{24} \\ \vdots & \vdots & \dots & \vdots \\ R_{41} & R_{42} & \dots & R_{44} \end{pmatrix} \tag{1}$$

$$\Re' = \begin{pmatrix} \frac{R_{11}}{\sum 1} & \frac{R_{12}}{\sum 2} & \dots & \frac{R_{14}}{\sum 4} \\ \frac{R_{21}}{\sum 1} & \frac{R_{22}}{\sum 2} & \dots & \frac{R_{24}}{\sum 4} \\ \vdots & \vdots & \dots & \vdots \\ \frac{R_{41}}{\sum 1} & \frac{R_{42}}{\sum 2} & \dots & \frac{R_{44}}{\sum 4} \end{pmatrix} \tag{2}$$

In this module, the reputation of a participant is evaluated on the basis of the reputation evaluation matrix. The level of reputation is adopted to achieve admission control, which plays an important role in improving the quality of service for MCS. Besides, it also has a great influence in the number of successful transactions conversely.

B. Reputation Matrix Determination Module

It has been proven that the Analytic Hierarchical Process (AHP) method is effective in solving the multicriteria problem[15]. It is a structured technique for organizing and analyzing complex decisions, therefore it was adopted to determine the reputation weight matrix in this paper. Specifically, once the comparison matrix is input, a judgment matrix $\Re$ is constructed firstly as Expression (1) shown. The entity $R_{ij}\,(i, j \in \{1,2,3,4\})$ denotes the importance degree of criterion i to j. In practice, the comparison matrix is usually constructed empirically. Subsequently, all the elements of $\Re$ in the same column add up to be

$$\sum j = \sum_{i=1}^{4} R_{ij} \quad (j = 1, 2, 3, 4) \tag{3}$$

Then the standard judgment matrix $\Re'$ is established according to Expression (2). Subsequently the reputation weight matrix W_r^T is obtained as follow

$$W_r^T = (w_1 \quad w_2 \quad \dots \quad w_4), \tag{4}$$

where an arbitrary element $w_i\ (i = 1, 2, 3, 4)$ can be determined as follow.

$$w_i = \frac{\sum_{j=1}^{4} \frac{R_{ij}}{\sum j}}{4} \quad (i = 1, 2, 3, 4) \tag{5}$$

To verify the effectiveness of the judgment matrix $\Re$ in Expression (1), The value of $\lambda_{\max}$ is calculated as follow

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} \frac{P_i}{w_i}}{n} \quad (p_i \in P^T, i = 1, 2, 3, 4), \tag{6}$$

where the matrix P^T is denoted as following Expression,

$$P^T = w_1 \cdot \begin{pmatrix} R_{11} \\ R_{21} \\ \vdots \\ R_{41} \end{pmatrix} + w_2 \begin{pmatrix} R_{12} \\ R_{22} \\ \vdots \\ R_{42} \end{pmatrix} + \dots + w_4 \cdot \begin{pmatrix} R_{14} \\ R_{24} \\ \vdots \\ R_{44} \end{pmatrix}. \tag{7}$$

Then the Coincident Index (*CI*) is obtained as Expression (8).

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (n = 4) \tag{8}$$

Finally, the consistency Ratio (*CR*) is determined as Expression (9) to determine the effectiveness of matrix $\Re$.

$$CR = \frac{CI}{RI}, \tag{9}$$

where *RI* refers to the Random Index, whose value depends on the order of the judgment matrix $\Re$. The relationship between *RI* and the matrix order can be obtained from Ref.[1]. According to Ref.[1], the judgment matrix $\Re$ is effective if the value of CR is less than 0.1. When this condition is met, the reputation weight matrix obtained is valid.

$$\mu(q) = \begin{cases} 0, & q < q_{\min} \\ \frac{q - q_{\min}}{q_{\max} - q_{\min}}, & q_{\min} \le q \le q_{\max} \\ 1, & q > q_{\max} \end{cases} \tag{10}$$

As the criteria have different unit and value range, it is necessary for them to be normalized. To achieve normalization, a kind of membership function

$\mu(x) : [L, H] \to [0,1]$ was adopted which maps a certain value $x \ (x \in [L, H])$ to range from 0 to 1 in this paper.

$$\mu(d) = \begin{cases} 1, & d < d_{\min} \\ \dfrac{d_{\max} - d}{d_{\max} - d_{\min}}, & d_{\min} \le d \le d_{\max} \\ 0, & d > d_{\max} \end{cases} \quad (11)$$

$$\mu(s) = \begin{cases} 0, & s_{\min} < s \\ \dfrac{s - s_{\min}}{s_{\max} - s_{\min}}, & s_{\min} \le s_{\max} \\ 1, & s > s_{\max} \end{cases} \quad (12)$$

$$\mu(f) = \begin{cases} 1, & f < f_{\min} \\ \dfrac{f_{\max} - f}{f_{\max} - f_{\min}}, & f_{\min} \le f \le f_{\max} \\ 0, & f > f_{\max} \end{cases} \quad (13)$$

In this paper, the membership functions of the four criteria were designed as shown in Expressions (10-13). The values of $q_{\min} \sim f_{\max}$ depend on the type of the task published. For example, they are related with the condition whether it is delay-sensitive or confidence-sensitive.

C. Reputation Evaluation and Dual-threshold Admission Control Module

Once a participant arrives, the corresponding criteria matrix recorded in the platform is normalized to be $c_i = (\mu_i(q) \quad \mu_i(d) \quad \mu_i(s) \quad \mu_i(f)), c_i \in C$, where C denotes the normalized criteria matrix whose entities represent the quantity, service delay, the number of success and failure respectively. Subsequently the reputation level R_i is determined as following Expression,

$$R_i = W_r^T \cdot (\mu(q) \quad \mu(d) \quad \mu(s) \quad \mu(f)) \quad (14)$$

To achieve proper admission control, the cloud-based platform generates a threshold R_{Thr} according to the following Expression

$$R_{Thr} = W_r^T \cdot C_{thr} \quad (15)$$

where the matrix C_{thr} represents the threshold value of the participant's criteria matrix. Once the reputation level R_i is established, it is compared with R_{Thr}. Only the participant whose reputation level is greater than or equal to R_{Thr} is assumed to be honest and gains the authorization. To avoid excessive punishment, another threshold R_{ThrMIN} was defined in this paper. For those refused by the platform, their reputation level R_i is designed to be a monotone increasing concave function of the time. Therefore, the probability of regaining authorization increases with time. In the paper, the function of $R_i(t)$ of time *t* was defined as follow,

$$R_i(t) = R_{ThrMIN} + 0.01t^2, \ (0 \le t \le 0.1\sqrt{R_{Thr} - R_{ThrMIN}}) \quad (16)$$

IV. SIMULATION AND RESULTS

In this section, the experiments were conducted via simulations. The parameters used in the simulation were listed as shown in Table.1. Assume the application was delay-sensitive and quantity-sensitive, so the emphasis was put on the service delay and the failed transaction count. $w_i \ (i = 1, ..., 4)$ denotes the element of the reputation weight matrix W_r^T which can be obtained through the AHP-based method. It is obvious that it complies with the consistency check with conditions $\lambda_{\max} = 4.2439$ and $CR = 0.0903 < 0.10$ are both met. According to Section II, the judgment matrix $\Re$ is effective. In the experiment setting, the matrix C_{thr} was fixed to be $(0.6 \quad 0.8 \quad 0.5 \quad 0.7)^T$, so the value of R_{Thr} was obtained to be 0.711. This section changed the value of the R_{ThrMIN} to get the optimal value for the simulation.

TABLE.1 THE PARAMETERS USED IN THE SIMULATION

Name	Value	Name	Value	Name	Value
w_1	0.1556	q_{min}	450Kbyte	s_{min}	6
w_2	0.4404	q_{max}	750Kbyte	s_{max}	10
w_3	0.0860	d_{min}	150ms	f_{min}	1
w_4	0.3179	d_{max}	300ms	f_{max}	3

To evaluate its performance, the Multidimensional Reputation Evaluation model (DRE) was compared with what was proposed in Ref.[10] (for convenience, it was denoted as RP in this section). To facilitate the discussion following, some metrics were defined firstly. The Ratio of Honest participant count to Dishonest participant count (RHD) was compared to verify the credibility of the model. Besides, the Count of the Successful Transactions (CST) was also defined to intuitively evaluate the performance of the model. Finally, the Average Reputation (AR) of the participant with the different values of R_{ThrMIN} was also analyzed to show the influence that R_{ThrMIN} has on the model.

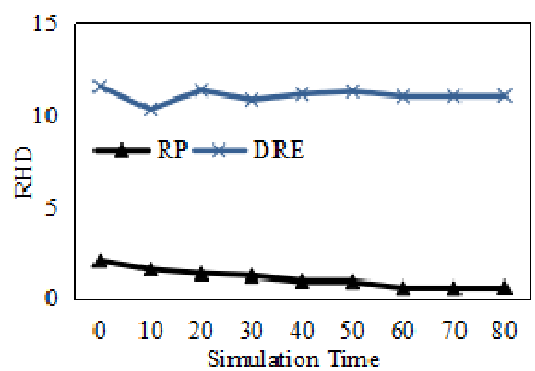

Fig.2 *RHD Comparisons Between DRE and RP*

Fig.2 shown the comparisons of RHD between DRE and RP. The values of them were 11.32 and 0.56 respectively. Because four application-related criteria were utilized to evaluate the participant's reputation, the RHD of DRE was much higher. Fig.3 shown how the dual-threshold mechanism avoids excessive punishment. The value of CST of our proposal was much larger than that of RP. As discussed above, there also existed some honest participants with accidentally low reputation level. Therefore it is essential for them to be offered a second opportunity to be admitted. The curves in Fig.3 certified the effectiveness of the dual-threshold mechanism. Fig.4 shown how AR varies with the value of R_{ThrMIN} . Specifically, the smaller R_{ThrMIN} is, the higher the probability of the low-reputation participant's being admitted is. However, it also gives the opportunity for the dishonest participant, which leads to the decline of the value of AR. Therefore, the value of R_{ThrMIN} should be designed properly. As shown in Fig.4, the values of AR were the largest on the whole when R_{ThrMIN} was set to be 0.5. The average reputation level was approximately 0.73, which was much larger than that of R_{Thr} . It guaranteed that only the honest participant has a second opportunity to be admitted according to the assumption aforementioned.

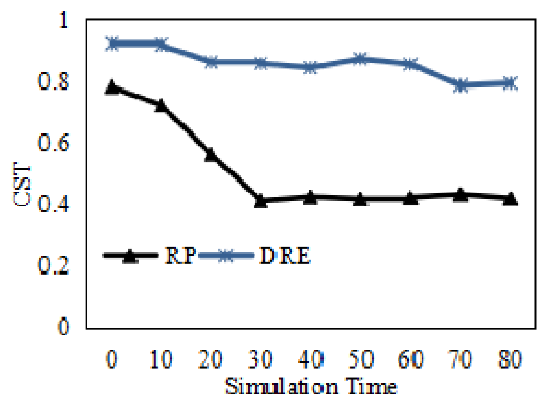

Fig.3 *CST Comparisons Between DRE and RP*

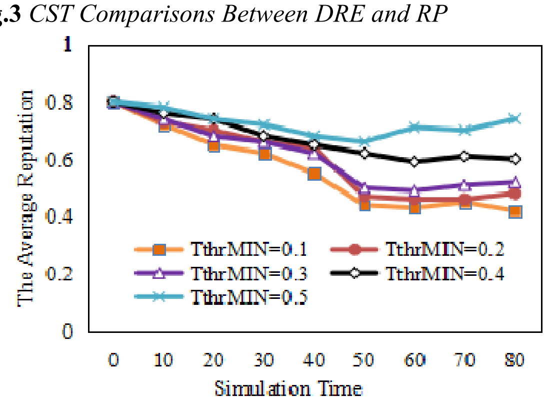

Fig.4 *Relationship between the AR and* R_{ThrMIN}

V. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

A multidimensional reputation evaluation model was proposed in this paper. The quantity of data, the service delay, the count of successful and failed transactions were considered together to provide a better service. An AHP-based method was proposed to determine the reputation weight matrix. Besides, a dual-threshold mechanism was also presented for the admission control. Finally, experiments were conducted via simulations and the simulation results certified the effectiveness of the model.

To provide high-quality, high-coverage measurements of a certain phenomena, it is vital to prompt enough participants to contribute their data. Therefore the design of incentive mechanism is of great importance for MCS. In the future research, more emphasis would be paid on the incentive mechanism.

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