Abstract—Most of trustworthy web service selection simply focus on individual reputation and ignore the collaboration reputation between services. To enhance the collaboration trust during web service selection, a reputation model called collaboration reputation is proposed. The collaboration reputation model is built on web service collaboration network (WSCN), and it provides the elimination mechanism of false web service to guarantee the trustworthy web service selection. The collaboration reputation can be assessed by invoking reputation and invoked web service. Then web service selection based on collaboration reputation in WSCN is designed. Experimental results confirm that our model has a better ability to perform service combination. With the collaboration reputation guaranteed, the selection efficiency and the solution’s trustworthiness are both increased.

Index Terms—Web Service Selection; Trust; Collaboration Reputation; Web Service Collaboration Network; Community

I. INTRODUCTION

As the large number of web services providing similar functionalities have been built and deployed, customer faces difficult task of choosing the best service to meet the requirement. The efficiency of selecting web service with QoS guaranteed increasingly becomes a critical issue.

One of major problem in this field is that QoS cannot reflect the real situation of web service because the dynamic environment imposes the stochastic nature on web service. However, some enhanced QoS measurement algorithms based on the fuzzy theory are proposed to eliminate the uncertainty, such as literature [1-2].

Actually, some web service providers may intentionally exaggerate their QoS values, the QoS measurement cannot reveal this malicious action, thus, the trust model is the indispensable part. However, the trustworthy web service selection usually considers to combine the web services with high level reputation, and the global optimization of composite web service’s credibility can be guaranteed. However, the local trust may not be optimal, and the local trust denotes credibility of web services which have invoking relationship in a composite web service. Actually, a client or web service may not interact with a web service without knowing it, thought it has a high level of reputation. In such case, trustworthy collaboration among web service should be taken into considered. That means the local trust optimization in trustworthy web service selection. Therefore, an ideal trust-aware service selection should be able to exclude the web service with low reputation to collaborate with customer and other services, and provide the most appropriate and trustworthy web service for them.

In this paper, we aim to provide a trust model which cannot only consider individual’s reputation but also the collaboration reputation. The main contributions of our work include the followings:

• We construct a WSCN to support trust web service selection. The service selection based on WSCN is proposed, and the collaboration reputation model is introduced. Thus, the selection algorithm not only increases the selection efficiency, but also improves the solution’s trust.

• We propose the collaboration reputation model, which is evaluated by invoking and invoked reputation. The invoking reputation depends on the community structure hiding in WSCN, thus, a web service with more recommenders indirectly proves its credibility. In addition, the invoking reputation evaluate the collaboration frequency among web services with invocation relationship. Thus, the collaboration reputation is assessed by the two metrics.

• We conduct experiments to evaluate the effectiveness of web services selection with collaboration reputation guaranteed.

The paper is organized as follows. In Section 2, a related work has been discussed. In Section 3, the definition about WSCN and the selection algorithm in WSCN is designed. In addition, community structure detection in WSCN is given. At last, the two types of reputation evaluation methods are designed. In Section 4, we conduct experiments to prove the concept and the related results. In Section 5, we draw some conclusions.

II. RELATED WORK

Recently, a number of research works have recognized the importance of reputation in web service selection, and a number of solutions have been proposed. The proposed solutions use different techniques, and study different aspects to establish trust among web services. Literature [3] discussed the trust QoS applying into web service selection, and present the further research direction. Literature [4] collected the user’s reporter on QoS, then rank and select web service based on the past QoS data’s prediction. Literature [5] identified the deviation between the QoS provided by their service providers and the QoS values determined by monitors and service user.
feedbacks to improve the trustworthiness of the QoS information. The method might result the fake rating when the user’s feedback is taken into account. In addition, the fuzzy theory is applied to enhance the QoS trust, literature [6] proposed a fuzzy matrices are defined on the transaction history to establish transaction trust. Except to this fuzzy model, literature [7] added the query model and underlying data to the fuzzy trust management framework which represents and queries customer’s perception. Except the fuzzy theory, the Bayesian network is often introduced into the trust evaluation, literature [8] used Bayesian networks to model a consumers assessment of a services QoS. Their approach provides consumers to combine different QoS attributes. Literature [9] developed a Bayesian network can punish and reward services in terms of QoS property accurately with incomplete observations so that consumers can prevent themselves from interacting services with unsatisfying QoS. In general, all these mentioned methods merely consider that web service act individually and not collaborate with others. To address the collaboration trust, literatures [10-11] proposed a framework aiming to select trust web service in a community, which is collection of web service with common functionality. The collaboration definition in our paper is different with those literatures, we focus on the invocations to accomplish a paper. The collaboration relationship is similar to that in scientific collaboration network, the vertex’s importance analysis has been studied in community structure [12]. In addition, the community structure is applied into the web service field. Literature [13] used the real-world data set to analyze the topological landscape of web service’s networks, and concludes that the network exhibit small world network and power-law-like to some extent. Literature [14] analyzed the logs of the execution engine to discover the web service community, and applying these closely interactive web services into composition process. Literature [15] presented a novel web service management based on collaboration network, where the network is undirected and has a weighted edge. In addition, it introduces some metrics to reflect the web service properties. Distinguish to the above construction method of WSCN, the community detected in our WSCN can effectively reflect the collaboration relationship, and is more suitable for our reputation evaluation.

III. TRUSTWORTHY WEB SERVICE MODEL

A. Web Service Collaboration Network

In this section, we will introduce some definitions about WSCN.

Definition 1. Vertex A vertex \( v \) in WSCN represents a web service \( ws \), each \( v \) has 2-tuples, \( \{N, R\} \)

\[ N = \{Neib_{i}, Neib_{o}, Neib_{c}\} \] is set of neighbors in WSCN, including three types. \( Neib_{i} = \{ws_{i1}, ws_{i2}, \ldots, ws_{in}\} \) for the input neighbors. \( Neib_{o} = \{ws_{o1}, ws_{o2}, \ldots, ws_{on}\} \) for the output neighbors, and \( Neib_{c} = \{ws_{c1}, ws_{c2}, \ldots, ws_{cn}\} \) for the invoking neighbors, which are combined to provide the output parameters for satisfying \( ws \in Neib_{o} \).

\[ R = \{R_{i}, R_{o}\} \] is the set of reputation metrics. \( R_{i} \) denotes the invoked reputation, which can evaluate the invocation frequency between \( ws \in Neib_{i} \) and \( ws \in Neib_{o} \). \( R_{o} \) denotes the invoking reputation, it obtains from the recommendation. the recommendation depends on the Trust Recommendation Vertex (shorted by TRV) in community structure. Thus, Collaboration Reputation (CR) can be evaluated by \( R_{i} \) and \( R_{o} \).

Definition 2. Edge An edge in collaboration network describes the web service collaboration relationship.

The collaboration relationship is similar to that in scientific collaboration network. A web service in a compound web services like an author in a paper, web services working together can be considered as the authors to accomplish a paper. Thus, they should be connected. The common compound web service includes four types: sequence, concurrency, conditional and loop. The basic collaboration networks are depicted in Fig. 1.

![Collaboration Network of Common Structure](image-url)
Definition 3. WSCN It’s an undirected graph, it consists of some subWSCNs in time interval \([t_1, t_2, \ldots, t_{n-1}, t_n]\), each subWSCN contains the collaboration relationship among web service in specific time interval \([t_i, t_{i+1}]\).

B. Web Service Selection Based on WSCN

Given a requirement \(R_e\), the web service selection process in the WSCN is to select a service \(ws\) such that:\( I_{Re} \supseteq I_{ws}; O_{Re} \subseteq O_{ws}; Q_{Re} \leq Q_{ws}\) and \(\max(CR)\), where the 3-tuple \(R_e = \{ I_{Re}, O_{Re}, Q_{Re}\}\) represents the customer’s functional and non-functional requirement, \(\max(CR)\) is to ensure the web service selected with optimal collaboration reputation. There are two types of service selection algorithm: simple and complex web service selection. Thus, the \(CR\) assessment is different. In following section, we will introduce the service selection in WSCN and the \(CR\) computation.

Simple Selection. Different with the method to select web service by matching interfaces, the simple service selection based on WSCN can depend on the web service’s neighbors. The selection algorithm is defined as follows:

\[
ws = \bigcap_{neib=i}^{n} Neib(\bigcup_{intf=j}^{k} ws_j) \tag{1}
\]

The union operator is to find the web service \(ws_{intf}\) which satisfies the customer’s interface requirement \(intf\), and \(\bigcup_{intf=j}^{k} ws_j \subseteq I_{Re} \cup O_{Re}\). The final solutions \(ws\) are obtained by intersecting all \(ws_{intf}\)’s neighbors \(Neib\) (if \(intf \supseteq O_{Re}\) or \(Neib\)’s if \(intf \subseteq I_{Re}\)). The \(\max(CR)\) of simple web service \(ws\) can be obtained by \(\max(\text{R}_{i_{ws}}, \text{R}_{o_{ws}})\).

Complex Selection. The complex selection is to find the composite web service with higher \(CR\) guaranteed. The searching process can be considered as a multistage graph as shown in Fig. 2.

In the multistage graph, \(ws_c \in Neib_c\) and \(ws_o \in Neib_o\) consists of a node. Thus, a node’s reputation can be evaluated by \(CR\), it can be obtained in the following equations:

\[
CR_{i_{ws}}^{[t_i, t_{i+1}]}(t) = \frac{\sum_{m=1}^{m} R_{i_{ws}}^{[t_i, t_{i+1}]}(t)}{m} \tag{2}
\]

\[
CR_{o_{ws}}^{[t_i, t_{i+1}]}(t) = \frac{\sum_{m=1}^{m} R_{o_{ws}}^{[t_i, t_{i+1}]}(t)}{m} \tag{3}
\]

The above equations present us the \(CR\) of a node. Therefore, the optimal solution of complex selection algorithm is listed in Algorithm 1.

Algorithm uses breadth-first traversal method to combine the matched web service \(Neib_c(ws)\) and \(Neib_o(ws)\) to construct a node, the node is add to the each stage by method \(addStage()\). The node’s collaboration reputation is assessed by \(CR_{node}\). Thus, the \(CR\) of the optimal solution is computed by \(\sum CR_{node}^{[t_i, t_{i+1}]}(t)\) after obtaining all stages. The time complexity of algorithm is \(\Theta(m^2)\), \(m\) denotes the number of \(ws\).

C. Web Service Community Detection

The WSCN in each time interval presents us a community structure. Thus, the community detection can be applied to find the cooperation web service group, and the invoking reputation score of a web service can be evaluated from TRV, which denotes a vertex having intra-connection to other communities.

In many community detection algorithms, CNM\(^{[17]}\) belongs to a condense algorithm, and its basic idea is to combine community until the Q reaches to the maximum. The modularity Q defines as follows:

\[
Q = \sum_i (e_{ii} - a^2) \tag{4}
\]

In CNM algorithm, we add a method to count \(TRV\) during the each merging process. The operation cost \(\Theta(m)\), \(m\) denotes the iteration number, and it’s a constant. Thus, the algorithm’s time complexity is still \(\Theta(n \log^2 n)\).

By using the above community detection algorithm, we can obtain collaboration community among web services. The following web service collaboration community is generated from a WSCN in \([t_i, t_{i+1}]\), and the other web service related parameter setting will be illustrated in the evaluation section. The web services are generated by WSBen\(^{[18]}\), which is inspired by extensive studies on real web services to support various web service network topologies and distributions. We use NeSVA\(^{[19]}\) to present the community structure in WSCN.

In Fig. 3, a vertex with 00000 appending at the end of its tag denotes the deceptive web service, which publishes the fake QoS information. After a period of \([t_i, t_{i+1}]\), some bad web services have a few connections to the other web service, thought some are still divided in the community with many numbers of good web service. In this figure, the outbound degree of the good web service is twice as much as that of web service. The final result of the bad web service will be divided into the community with a few and new web services. In our reputation evaluation, a web service’s invoking reputation has something to do with the number of TRV, thus,
the recommender number will result in the distinction between the bad and good services after a period.

D. Reputation Measurement

Web service locates in the open, distributed environment, there is an underlying collaboration relationship among them. The collaboration reputation based on WSCN provides us a method to measure collaboration reputation. It includes two types: invoked reputation and invoking reputation.

Invoking Reputation. The invoking reputation is a significant metric to evaluate how importance a web service is. As we know, there are shortcomings in reputation mechanism, which merely depends on the invoked reputation. As we mentioned above, repeatedly submitting a same composite web service can improve the invoked reputation level, but the recommenders simply limit to some specific ones. The web service which joins various compositions will result in more recommenders. Thus, the invoking reputation plays an important role in the reputation mechanism. In this section, we will give the invoking reputation score in terms of the collaboration community.

The community has a characteristic that the dense connec-
tions within community but sparse connections among communities. The vertex which has more connections to the vertex locating in other communities will have higher trustworthiness. Therefore, a vertex in community C which has more closer to the TRV in the same community C reflects it has more higher invoking reputation. Let \( R_{t_1,t_n}^{[1]} \) be the invoking reputation value during the time interval \([t_1, t_n]\). This value is computed in following.

\[
R_{t_1,t_n}^{[1]} = \frac{\sum_{t=1}^{n} (\Delta T_i \sum_{k \in TRV_{t_1,t_n}^{[1]}} \frac{NormQ(k)}{Dist_k + 1})}{\sum_{t=1}^{n} \frac{1}{t}}
\]  

(5)

\( Dist_k \) is the shortest path from web service \( ws_i \) to \( ws_k \), where \( ws_k \in TRV_{C}^{[1,t_n]} \) and \( ws_j, ws_k \) belongs to same community C. \( NormQ(k) \) is the importance evaluation for a \( ws \), and is defined as:

\[
NormQ = \frac{\sum_{i=1}^{n} QoS_i}{n}
\]  

(6)

In \( NormQ \), \( QoS \) denotes the value of the common QoS attribute of \( ws \), such as reliability, availability, etc. The normalized value represents the self’s importance.

In formula \( R_{t_1,t_n}^{[1]} \), the trust value is related to collaboration community C in period of \([t_1, t_n] \). \([T_1, T_2, \ldots, T_n] \) are time intervals in \([t_1, t_n] \), \( T_1 = [t_1, t_i+1] \). The time weight \( \Delta T_{i+1} > \Delta T_i \) because the latest trust recommendation is more persuasive. Thus, the decay function \( \Delta T_i \) is defined:

\[
\Delta T_i = \frac{1}{\sum_{i=1}^{n} \frac{1}{T_i}}
\]  

(7)

According to \( R_{t_1,t_n}^{[1]} \), the web service which has a fewer chance to connect to \( TRV_{C}^{[1,t_n]} \) will result in lower invoking reputation level. Thus, the web service which hardly appears in the invocation logs won’t obtain a higher invoking reputation.

**Invoked Reputation.** Although invoked reputation might result misleading, it can be considered as a metric to assess the interaction frequency between invoking and invoked web service. As we know, the PageRank\(^{[20]} \) algorithm is the classic algorithm to assess the page’s importance. The algorithm’s characteristic is to propagate the importance from one web page toward others until the iteration process is convergence. The measurement method is defined as follows:

\[
PR(p) = \frac{1 - d}{N} + d \sum_{j \in B} \frac{PR(j)}{|F_p|}
\]  

(8)

In this equation, \( d \) is a scale factor, which determines ratio between the self’s importance of a page and importance obtained from the other linking pages. \( N \) is the web page set. \( F_p \) denotes the degree of outbound linking to that page \( p \), and \( B \) are the pages connecting to \( p \).

In equation \( PR(p) \), the value can converge after several iterations, while the importance of a web service sequently transmits to the end. Thus, it leads the invoked reputation of a web service in front to be less than that of web service in back of composite web service. For simplicity, we consider the importance to propagate to its directed neighbor. Thus, the \( PR(p) \) is revised as follow:

\[
R_{t_1,t_n}^{[1]} = (1 - d)NormQ + \sum_{i=1}^{n} \frac{d}{n} W_{ij} \Delta T_i NormQ
\]  

(9)

In equation \( R_{t_1,t_n}^{[1]} \), \( d \) is the same as the original PageRank algorithm. \( NormQ \) is assessment of web service’s inherent importance, which is mentioned above. In addition, \( ws_i \) invoking \( ws_j \) often involves with matched interface, thus, the importance propagation between \( ws_i \) and \( ws_j \) is related to the matched interface number in once invocation. \( W_{ij} \) denotes the ratio that the matched interface number and the whole interface number in invoked one. In addition, \( R_i = \{R_{i_1}, R_{i_2}, \ldots, R_{i_n}\} \) represents the invoked reputation \( R_i \) which accumulate from web service \( ws_{j_1}, ws_{j_2}, \ldots, ws_{j_n} \) during \( T_n \). In each \( R_i \), we limit the maximum invocation number of \( ws_i \) invoking \( ws_j \) for computing \( R_{ij} \).

According to reputation measurement model, Algorithm 2 presents the reputation calculation process.

**Algorithm 2 Calculate Web Service Reputation**

**Input:** \( Set_{t_1}(ws), Set_{t_2}(ws), \ldots, Set_{t_n}(ws) \)

**Output:** \( R \)

for each \( T_i \) in \( set_{t_1}(ws) \) do

end for

As the algorithm shows, in each time interval \( T_i \), we assess the \( R_i \) and \( R_r \) for each \( ws_i \). In the last loop, we sum \( R_{t_1}(ws_i) \) and \( R_{t_2}(ws_i) \) evaluated to get the final reputation results in \( T_i \). The most time cost emerges at the invoking relationship collection and community detection. The maximum time complexity \( \Theta(mn^2+n^2 \log^2 n) \), where \( m \) denotes the number of \( T_i \) and \( n \) is web service number.

**IV. EVALUATION**

In this section, we will show the simulation experiments to prove the effectiveness of our web service trust evaluation model. To generate web service execution logs, we merely...
consider the reliability, the successfully executed composition web service will be stored in log. Suppose that there are three types of service model, good, normal, bad. The bad service provides unsatisfied reliability, whereas good services provide the satisfying reliability, and the normal constant changes. The good service and bad web service is in terms of reliability. To attract customers, the bad web service publishes the same reliability value as the good web service does. We adopt and adapt the WSPR algorithm to construct the composite web service, the key factor of combining services depends on the three metrics \(< f, m, p >\), \(m\) denotes the matched interface number, \(p\) is the interface' popularity. \(f\) denotes the failure number in web service’s collaboration history, it has the same meaning with \(k\) mentioned above, when \(f > k\), \(ws_1\) won’t collaborate with \(ws_2\). In each \(\Delta T\), some requirements are proposed by each customer, some proposed requirements are also included.

### Table I

<table>
<thead>
<tr>
<th>Parameter Settings</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Cycles</td>
<td>100</td>
</tr>
<tr>
<td>Each Cycles (\Delta T)</td>
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</tr>
<tr>
<td>Customer Number</td>
<td>100</td>
</tr>
<tr>
<td>Web Service Number</td>
<td>1000</td>
</tr>
<tr>
<td>Bad Web Service Number</td>
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</tr>
<tr>
<td>Good Web Service Number</td>
<td>30%</td>
</tr>
<tr>
<td>Normal Web Service Number</td>
<td>40%</td>
</tr>
<tr>
<td>Reliability of Good</td>
<td>[0.9,1]</td>
</tr>
<tr>
<td>Reliability of Bad</td>
<td>[0,0.3]</td>
</tr>
<tr>
<td>Reliability of Normal</td>
<td>[0.3,0.9]</td>
</tr>
<tr>
<td>Failure Rate</td>
<td>normal distribution</td>
</tr>
</tbody>
</table>
Reputation Measurement. In the following experiments, we are interesting to observe the reputation level of different type of web service.

Fig. 4 shows the invoking and invoked reputation distribution in terms of the above parameter settings. The vertexes mainly concentrate in area $[0.05 \ 0.15]$. The vertexes which are closer to 1 in invoking reputation dimension demonstrate that they have more connections to the TRV. In addition, it also reflexes that these web services have more inbound and outbound link. Thus, the popular web service with reputation guaranteed will has more chance to be assigned for various tasks. The bad web service mainly concentrates in the area of $[0 \ 0.005]$ due to the less recommenders and less invocation frequency. The reputation value range of normal web service is between those two reputation level, but inclines to bad reputation due to the unstable reliability.

Fig. 5 illustrate the reputation rank of web services which have a same input parameter. There are 200 input parameters, each parameter contains 3 good or normal web service and 1 bad service. The lower invoking reputation level of bad web service demonstrates they are gradually eliminated from the neighbors.

Web Service Selection. The following the experiments show success rate of composite service and the efficiency. We test the different number of web service in a solution, which has 25 web services at most.

Fig. 6 shows that the computation efficiency is half less than that of WSPR since the search process simply considers the forward searching. Although the collaboration reputation computation cost some extra time, the search space in WSCN limit in neighbors while WSPR need to match all web services.
In Fig. 7, deep color histogram indicates that the composition process only selects the web service with a high-level reputation, while that of the light color bar considers the collaboration reputation. With collaboration reputation guaranteed, its success rate has obvious advantages, and increase by about 20%. The selection which only combining the web service with high-level reputation leads to much more web services involving with the composite one due to less consideration of interface optimal matching. Since each atom web service has a certain failure rate, thus, it results in higher failure rate for the service selection which only combining the services with a high-level reputation.

V. Conclusion

In this paper, a collaboration reputation is proposed based on WSCN, and the related web service selection algorithm is introduced. According to the experiment results, the reputation model can fairly and effectively evaluate the web service’s trust degree and the collaboration closeness degree, especially effectively distinguish good and bad web service, which provides the same functionality. In addition, the solution’s success rate increases as the interaction round increases, and the bad web service is excluded in the composition process, moreover, the selection efficiency is also guaranteed.

In fact, we can use network science and data mining technology as the foundation to conduct some research about trust relationship evolution among web services. Our further research is to propose a trust management model based on evolution to establish full credibility of the assessment mechanism.

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References


