A Trust Transitivity Model Based-on Dempster-Shafer Theory

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***Abstract*—With the expansion of the Internet, Trust has attracted the attention of more and more researchers. This paper focuses on the trust transitivity problem and proposes a trust transitivity model based on Dempster-Shafer Theory. In our model, we show two types of trust relationship: Identity Trust and Behavior Trust based on Directness Trust and Recommendation Trust. Then we build the trust transitivity network and propose the trustworthiness propagation and combination rules. Finally, we propose a method for transforming the triple of evidence theory to a simple result in order to select the trust entity easily. We also use the nearness degree to analyze the transitivity rationality and show how to use the trust transitivity model by a shopping scenario in TaoBao and illustrate its legitimacy.**

***Index Terms*-Trust Transitivity, Dempster-Shafer Theory, Nearness**

I. INTRODUCTION

The interaction and cooperation among entities are more frequent in the open and dynamic Internet environment. Owing to features of Internet, activities among entities are more unrestrained and multiple than usual. So trust problem is more obvious in these activities and has become an important issue in Internet research.

In the social science, the degree to which one party trusts another is a measure of belief in the honesty, benevolence and competence of the other party. From this perspective, trust is a mental state, which cannot be measured directly. In psychology trust is believing the person who you trust to do what you expect [1]. Thus, trust has different definitions in diverse fields as same as in computer science. Currently, we have not a commonly accepted definition to describe trust [2-4]. In this paper we decide to quote the conception of [5] that trust is defined as a subjective judgment of an entity about the capability to which another entity or a set of entities can accomplish the given task. The degree of trust depends on the direct experience and referral information among entities [5].

As we know, interactions in the Internet are more open and extensive, which may exist between two entities that do not know each other. Under the circumstances, we should determine the trustworthiness of a given entity relying on testimonies given by other intermediate entities. That is the trust transitivity problem. It is a fundamental issue in trust field.

For now, many researchers have involved in the trust transitivity research using diverse theory. Audun Jøsang [6-8] proposed a method for modeling trust relationship, reasoning and combining trust using Subjective Logic. He also gave the algorithm for discovering the trust paths. But he did not consider how to judge whether the trust transitivity is rational. Yu [9-12] described a method for propagating and combining the trust evaluation between entities based on Dempster-Shafer Theory. But he did not pay attention to distinguish the type of trust and his propagating rules were lack of concrete calculation methods. There were also many methods for trust evaluation and trust transitivity based on diverse probability model [13,14]. They did not consider the uncertainty about trust given by subjective cognition. During the trust transitivity, the uncertainty about trust can not be ignored [15]. Mathematical probability has certain properties that make it unsuitable as a trust metric. The probability values will be meaningless unless it is based on well-defined repeatable experiments, which is impossible when dealing with most everyday real-life experiences, for example, trust relationship [16]; The Bayesian approach offers a mechanism for representing uncertainty based on probability model. But it can not distinguish the lack of belief and disbelief. The Dempster-Shafer calculus can handle the pro and con evidence explicitly. The causal relationship between a hypothesis and its negation does not exist, so lack of belief does not imply disbelief [11].

Inspiring from Audun Jøsang and Yu, we propose a trust transitivity model based on Dempster-Shafer Theory. In our model, we show two types of trust relationship: *Identity Trust* and *Behavior Trust* based on *Directness Trust* and *Recommendation Trust*. Then we construct the trust transitivity network and propose the trustworthiness propagation and combination rules (In this paper we do not describe how to obtain the initial trustworthiness value that many researchers have involved [7-11]). Finally, we propose a method for transforming the triple of evidence theory to a simple result in order to select the trust entity easily. We also use the nearness degree to analyze the

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transitivity rationality and show how to use the trust transitivity model by a shopping scenario in TaoBao and illustrate its legitimacy.

The rest of this paper is organized as follows. Section II introduces the Dempster-Shafer Theory. Section III presents our trust transitivity model. We make use of this model in an online scene and analyze the results in Section IV. Section Vconcludes our paper with a discuss of the main results and directions for future research.

II. DEMPSTER-SHAFER THEORY

In 1976, Shafer published a book named A Mathematical Theory of Evidence. It is meant to mark the birth of Dempster-Shafer Theory, also called evidence theory. It has a wide range of application on uncertainty reasoning, decision analysis and predication. Evidence theory is based on belief function and plausible reasoning. First of all, we must define a frame of discernment, indicated by the sign Θ. The sign 2^{Θ} indicates the set composed of all the subset generated by the frame of discernment. For a hypothesis set, denoted by A, $m(A) \to [0,1]$

$$\begin{aligned} & m(\varnothing) = 0 \\ & \sum_{A \in 2^{\Theta}} m(A) = 1 \end{aligned} \tag{1}$$

$\varnothing$ is the sign of an empty set. The function m is the basic belief assignment [17].

Dempster's rule of combination combines two independent sets of mass assignments [11].

$$m(\varnothing) = 0 \tag{2}$$

$$\begin{cases} m(A) = \dfrac{1}{1-K} \sum\limits_{B \cap C = A} m_1(B) m_2(C) \\ K = \sum\limits_{B \cap C = \varnothing} m_1(B) m_2(C) \end{cases} \tag{3}$$

$m(A), m_1(B), m_2(C) \to [0,1], A \neq \varnothing$

III. TRUST TRANSITIVITY MODEL BASED-ON DEMPSTER-SHAFER THEORY

A. *Trust Transitivity*

In an open community, entity A can not recognize all of entities and entity A not only can interact with someone whom it acquaints with but also with some entities that it does not know. Before it interacts or cooperates with unfamiliar ones, e.g., entity X, it must evaluate their trustworthiness in order to avoid unnecessary loss. How can entity A acquire the trustworthiness of entity X? It needs entity B that is a intermediate entity which has acquired the trust evaluation of entity X and been known by A. Entity A can reason the trustworthiness of entity X via B's trustworthiness evaluated by A and X's trustworthiness derived from B. This is the trust transitivity problem.

In the sociological and psychology science, trust reflects the expectation of people. So there are some inherent features in trust. Trust depends on the subjective cognition and judgment. So trust is often regarded as the complex knowledge for human that we can not use the precise description for trust. We must observe the *uncertainty* of trust [18]. Trust also is *transitive*. The transitivity of trust means that trust is derived from an existing trust between entities. Trust generated by this method also is called a derived trust. During the trust transitivity, trustworthiness is changing in this process. It appears as the *attenuation*. The "distance" is existed among entities and trustworthiness would loss from one entity to another [19]. As a result, we consider that trust transitivity reflects the *uncertainty, transitive, attenuation* of trust.

Types of trust are the basis of building the trust transitivity network. In this network, two basic types of trust relationship exist:

Definition 1(Directness Trust): Trust is established by direct interactions of two entities. It is the direct trust relationship. The trustworthiness is derived from direct experience. Fig.1(a) shows the *Directness Trust*.

Definition 2(Recommendation Trust): Trust of two entities that do not have any direct interactions is established by referrals of other entities. The trustworthiness is derived from other entities. Fig.1(b) shows the *Recommendation Trust*.

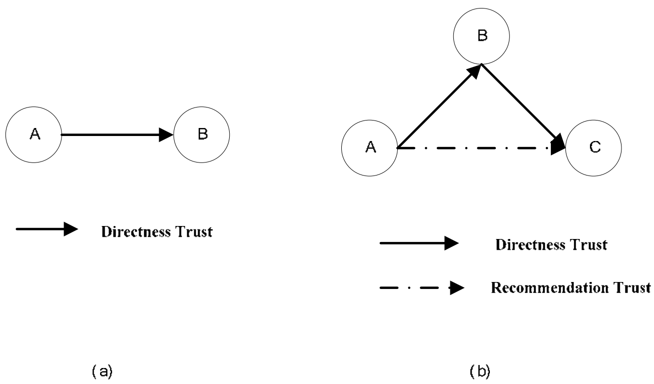

Figure 1. Directness Trust and Recommendation Trust

We can conclude that these two types of trust are distinguished by the trustworthiness acquiring methods. This is the foundation for classifying trust. In our work, we will generalize the trust into two concrete categories: *Identity Trust* and *Behavior Trust*. This classification method is based on the concrete content of trust and they are the content of *Directness Trust* and *Recommendation Trust*.

Definition 3(Identity Trust): Trust of two entities is established by validating the identity. In our work, validation is replaced by subject judgment for the familiarity degree.

Definition 4(Behavior Trust): Trust is established by the faith to which an entity can accomplish the expected activity. In our opinion, behavior trust is not a fixed conception. With different entities and different context, behavior trust has the specific meaning.

Fig.2 shows four types of trust. Entity B trusts that entity D can accomplish the given task. So the trust relationship between B and D is *Behavior Trust* which also is the content of *Directness Trust*. *Identity Trust* between A and B indicates the degree to which entity A is familiar with B. Finally, D can be trusted with a degree by A for accomplishing the given task. The trust relationship between A and D is *Behavior Trust*, which is the content of *Recommendation Trust*. Regardless of *Identity Trust* and *Behavior Trust*, both of them are the content of transitivity and be calculated by transitivity and combination rules. So calculation methods with above mentioned trust are consentaneous.

Trust transitivity is the reflection of interactions among entities with above mentioned trust relationship. A usual entity in trust transitivity has its familiar ones, called *neighbors* and unknown ones, called *strangers*. The entity can directly interact with *neighbors* and indirectly recognize the *strangers*. *Identity Trust* and *Behavior Trust* can exist between *neighbors* or *strangers* after trust transitivity. And the content of trust transitivity is not unchanging relied on the context.

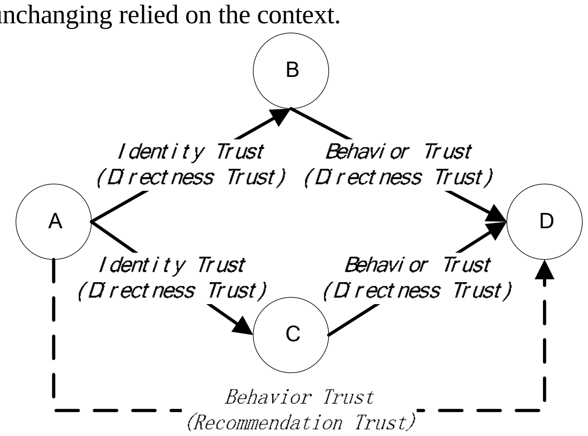

Figure 2. Trust Classification

Additionally, trust transitivity is time dependent [19]. We believe that trust transitivity in different time is essentially diverse even though the final trustworthiness is the same.

B. Trust Description

Now we introduce the key application of the Dempster-Shafer approach. Trust is a relationship among entities. Trust problems can not exist in any isolated entity.

Definition 5. Let $\Theta = \{T, \neg T\}$ be a frame of discernment. Given two entities, A and B, Let T means that entity A considers entity B to be trustworthy.

Definition 6. A basic probability assignment (bpa) is a function *m*.

Thus $m(\{T\}) + m(\{\neg T\}) + m(\{T, \neg T\}) = 1$. A bpa is a probability assignment and its domain is the subsets but not the member of Θ . Specially, $\{T, \neg T\}$ means that entity A has no idea with trusting entity B.

For the function *m*, it reflects the probability that the related proposition is true. We regard this probability as the belief degree. Except for the degree description of trust and distrust, Dempster-Shafer approach supports the uncertainty formulation for no idea that depicts the human subjective cognition.

C. Trust Transitivity Model

First of all, we should identify the entities in the trust transitivity, and then determine types of trust among entities, which is important for trust transitivity rules. At the initial state, every entity will evaluate the trustworthiness of its *neighbors* including identity trust or behavior trust or both. Then we can acquire the trustworthiness of *strangers* through trust evaluation of entities' neighbors. So we believe that the key elements of trust transitivity model include entities, types of trust among entities, entity's trustworthiness and trust transitivity rules.

So, we define the **TTM** (Trust Transitivity Model):

Definition 7. TTM = (En, Re, Ev, Ru)

En means entities in the model; **Re** means trust relationship among entities. It concludes *Directness Trust (DT)* and *Recommendation Trust (RT)*. We further distinguish the content of *DT* and *RT* with *Identity Trust (IT)* and *Behavior Trust (BT)*; **Ev** means that the trustworthiness set {t, d, u} based on **En** and **Re**, where t+d+u=1. *t* means the belief degree($m(\{T\})$)that the proposition "entity A trusts entity B" is true. *d* means the belief degree($m(\{\neg T\})$)that the proposition "entity A distrusts entity B" is true. *u* means the belief degree($m(\{T, \neg T\})$)that the proposition "entity A has no idea for trusting entity B" is true; **Ru** means the trust transitivity rules including recommendation rules and combination rules. We will discuss them in next sections;

We can describe the trust transitivity among entities through building this model. In this model, trust relationship is a type of binary relation. So we define the following expression to represent the trust.

$$R_B^A = \{t_B^A, d_B^A, u_B^A\} \tag{4}$$

R_B^A means that entity A evaluates the trustworthiness of entity B. R can be *IT* or *BT*. $\{t_B^A, d_B^A, u_B^A\}$ is consistent with the trustworthiness set defined in the trust transitivity model.

1) Trust Calculation

In the trust transitivity, entity A can obtain the trustworthiness of entity B by direct interactions or testimonies generated by other trustworthy entities. But the latter is supposed that entity A may not know entity B or can not interact directly. It will generate *Recommendation Trust*. In the open environment, users' interactions mostly depend on *Recommendation Trust*. Besides, due to *Recommendation Trust*, user can interact or cooperate with more extensive other users.

We use the following expression to represent the *Recommendation Trust* based on (4).

$$R_C^{A\to B} = \{t_C^{A\to B}, d_C^{A\to B}, u_C^{A\to B}\} \tag{5}$$

$R_C^{A\to B}$ means that entity A obtains the trustworthiness of entity C through the referral of entity B. R can be *IT* or *BT*. $\{t_C^{A\to B}, d_C^{A\to B}, u_C^{A\to B}\}$ is consistent with the trustworthiness set defined in trust transitivity model.

Now we can give the rules for trust recommendation, supposed $R_B^A = \{t_B^A, d_B^A, u_B^A\}$ means that entity A evaluates the trustworthiness of entity B with *Directness Trust*. $R_C^B = \{t_C^B, d_C^B, u_C^B\}$ means that entity B evaluates the trustworthiness of entity C with *Directness Trust*.

$$R_C^{A\to B} = R_B^A \otimes R_C^B$$
$$\begin{cases} t_C^{A\to B} = t_B^A * t_C^B \\ d_C^{A\to B} = t_B^A * d_C^B + d_B^A * t_C^B \\ u_C^{A\to B} = 1 - t_C^{A\to B} - d_C^{A\to B} \end{cases} \quad (6)$$

The sign $\otimes$ is the operator of recommendation rules and R in $R_C^{A\to B}$ is the same as in R_C^B. We can also easily know that $R_D^{A\to B\to C} = R_B^A \otimes R_C^B \otimes R_D^C$.

The degree that entity A trusts entity B , t_B^A in conjunction with the degree that entity B trusts entity C, t_C^B will completely determine $t_C^{A\to B}$. Secondly, $t_B^A * d_C^B$ means that entity A trusts entity B, t_B^A ,but entity B distrusts entity C, d_C^B, they will partiality result in that entity A distrusts entity C, $d_C^{A\to B}$. Another factor that influences $d_C^{A\to B}$ is $d_B^A * t_C^B$.

We can prove the validity of (6) as follows:

Proof: Because of the definition 7, $0 < t_B^A < 1$ and $0 < t_B^A < 1$, $t_C^{A\to B} = t_B^A * t_C^B < 1$ is consistent with definition 7. In the similar way, $0 < d_C^B < 1$ and $0 < t_C^B < 1$, so $d_C^{A\to B} = t_B^A * d_C^B + d_B^A * t_C^B < t_B^A + d_B^A = 1 - u_B^A < 1$. Finally, $t_C^{A\to B} + d_C^{A\to B} = t_B^A * t_C^B + t_B^A * d_C^B + d_B^A * t_C^B = t_B^A(1 - u_C^B) + d_B^A * t_C^B$, $t_B^A(1 - u_C^B) + d_B^A * t_C^B < t_B^A + d_B^A < 1$, so $u_C^{A\to B} < 1$.

For instance, entity A can acquire the trustworthiness of entity C by means of testimonies derived from entity B or entity D. So how entity A handles these testimonies? We consider that entity A should combine opinions of entity B and entity D. It means not only combining trust between two entities derived different opinions but also integrating the trust of many-to-one to ignore all the conflicting evidence.

We use the following expression to represent for combining trust based on (4).

$$R_C^{A,B} = \{t_C^{A,B}, d_C^{A,B}, u_C^{A,B}\} \quad (7)$$

$R_C^{A,B}$ means the joint opinion of entity A and entity B about trustworthiness of entity C after combination. R can be *IT* or *BT*. $\{t_C^{A,B}, d_C^{A,B}, u_C^{A,B}\}$ is consistent with the trustworthiness set defined in trust transitivity model.

Dempster's rule of combination strongly emphasizes the agreement between multiple sources and ignores all the conflicting evidence through a normalization factor. Use of that rule has come under serious criticism when significant conflict in the information is encountered [20]. So we use this rule for combining trust for synthesizing the opinions.

The $R_C^{A,B}$ is obtained as follows, where $R_C^A = \{t_C^A, d_C^A, u_C^A\}$ means that entity A evaluates the trustworthiness of entity B with *Directness Trust* or *Recommendation Trust*. $R_C^B = \{t_C^B, d_C^B, u_C^B\}$ means that entity B evaluates the trustworthiness of entity C with *Directness Trust* or *Recommendation Trust*.

$$R_C^{A,B} = R_C^A \oplus R_C^B$$
$$\begin{cases} t_C^{A,B} = \dfrac{t_C^A * t_C^B + t_C^A * u_C^B + t_C^B * u_C^A}{1 - (t_C^A * d_C^B + t_C^B * d_C^A)} \\ d_C^{A,B} = \dfrac{d_C^A * d_C^B + d_C^A * u_C^B + d_C^B * u_C^A}{1 - (t_C^A * d_C^B + t_C^B * d_C^A)} \\ u_C^{A,B} = 1 - t_C^{A,B} - d_C^{A,B} \end{cases} \quad (8)$$

The sign $\oplus$ is the operator of combination rules and R in $R_C^{A,B}$, R_C^A and R_C^B is the same. For example, $R_C^{A\to B}$ is the trustworthiness of entity C evaluated by A derived from path A→B→C. $R_C^{A\to D}$ is the trustworthiness of entity C evaluated by A derived from path A→D→C. $R_C^{A\to E}$ is the trustworthiness of entity C evaluated by A derived from path A → E → C. Finally, $R_C^{A\to B, A\to D, A\to E} = R_C^{A\to B} \oplus R_C^{A\to D} \oplus R_C^{A\to E}$.

2) *Trust evaluation*

In this paper, we use three belief values of evidence theory for describing trust. After using the transitivity and combination rules, we can evaluate the trustworthiness of entities by this triple. For example, entity A evaluates the trustworthiness of entity B using $R_B^A = \{t_B^A, d_B^A, u_B^A\}$, the expectation of A is that t_B^A is big and u_B^A is small. When u_B^A is small, trustworthiness of B derived A is more certain.

But this triple may not accurately represent the things that entities care about because they only pay attention to the result of selecting a trust objects based on some reasonable and simple rules. Therefore, similar to some methods [21-23], it is useful to provide an effective approach, which can combine the t_B^A with u_B^A to obtain the certain simple result of trustworthiness.

As stated as above, t means the belief degree ($m(\{T\})$) that the proposition "entity A trusts entity B" is true. u means the belief degree($m(\{T, \neg T\})$)that the proposition "entity A has no idea for trusting entity B" is true. With the pessimistic idea, we believe that the degree of uncertainty provides the minus effect for $m(\{T\})$. So we consider the $m(\{T\})$ as the master value and $m(\{T, \neg T\})$ as the slave value.

The formalized function of trust evaluation (hereafter TE) is described as:

$$TE = t * e^{-u} \tag{9}$$

As Fig.3 shows, we choose the three value of *t* (0.8, 0.6, and 0.4), so the max value of *u* is 0.2, 0.4 and 0.6. We can easily conclude that with the increment of uncertainty, the TE is decreased with nearly linearity.

We can also conclude that when *t* = 0.8 and *u* = 0.2, *d* = 0. But after computing the final trust evaluation, we found that TE<*t*, so 1-TE>*u*+*d*. this phenomenon is affected by *u*, the degree of uncertainty. Because of the pessimistic idea, the uncertainty increases the distrust degree.

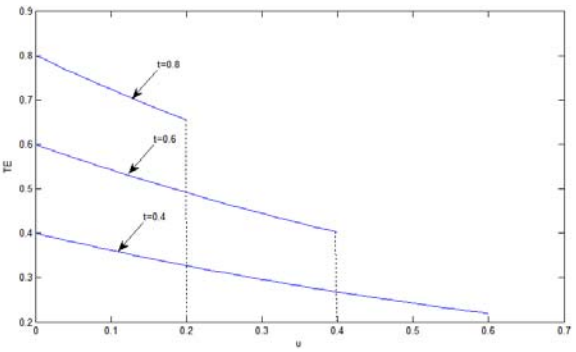

Figure 3. Trust Evaluation

3) Trust Transitivity Rationality

As we have remarked, trust will not be constant in trust transitivity but lost. With the increment of transitivity path length, trust will gradually lost. So how can we judge this process is reasonable? We propose a method to calculate the distance of different trustworthiness based on fuzzy nearness [24]. As Fig.4 shows, we can calculate R_D^A, R_D^B through trust transitivity. We will get the nearness among R_D^A, R_D^B and R_D^C. Then a threshold ∂ for describing the "distance" of different trustworthiness is assigned by expert experience to determine weather the trust transitivity is reasonable. If the trusty evaluation nearness with R_D^C is more less, we suspect that there are some "bad" referrals or external factors affecting the transitivity obviously.

Fuzzy nearness reflects the closeness of fuzzy sets. Supposed A and B are fuzz sets in discourse domain *U*; *c* is an optional parameter [24].

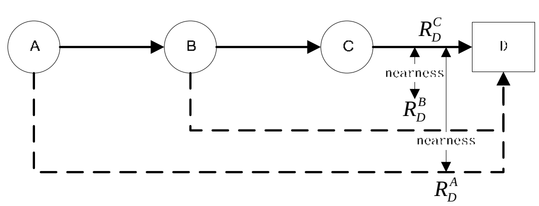

Figure 4. Trustworthiness Nearness

$$\sigma(A,B) = 1 - c[d_p(A,B)]^{\alpha}, \sigma(A,B) \to [0,1] \tag{10}$$

$d_p(A,B) = (\sum_{i=1}^{n} |\mu_A(x_i) - \mu_B(x_i)|^p)^{\frac{1}{p}}, p \ge 1$ and $\mu_A(x)$ is the membership function of A about element x. If $c = \frac{1}{n}$ and $\alpha = p$

$$\sigma(A,B) = 1 - \frac{1}{n}\sum_{i=1}^{n} |\mu_A(x_i) - \mu_B(x_i)|^p \tag{11}$$

We borrow ideas from (10) and put forward a nearness handling method for Dempster-Shafer Theory.

Suppose two trustworthiness descriptions

$R_B^A = \{t_B^A, d_B^A, u_B^A\}$ and $R_B^{\tilde{A}} = \{t_B^{\tilde{A}}, d_B^{\tilde{A}}, u_B^{\tilde{A}}\}$

$$\sigma(R_B^A, R_B^{\tilde{A}}) = 1 - \frac{1}{3}[(t_B^A - t_B^{\tilde{A}})^2 + (d_B^A - d_B^{\tilde{A}})^2 + (u_B^A - u_B^{\tilde{A}})^2] \tag{12}$$

where $n = 3$ and $p = 2$.

In (12), $\sigma(R_B^A, R_B^{\tilde{A}})$ means that the similarity between R_B^A and $R_B^{\tilde{A}}$. If $1 - \sigma(R_B^A, R_B^{\tilde{A}}) > \partial$, it means that the diversity existing in R_B^A and $R_B^{\tilde{A}}$ is obvious. We will suspect that the "bad" referral or external factor influences the judgment of entity A conspicuously. Otherwise, if $1 - \sigma(R_B^A, R_B^{\tilde{A}}) \le \partial$, we believe that the trust transitivity process is normal that means all the harmful factors have no effect in transitivity.

IV. EXPERIMENT

In this section, we will show how to use the above mentioned trust transitivity model by a shopping scene in an online shopping website-TaoBao. The scenario is described as following: there are five entities in the scene, an online shop (entity E) and four buyers (entity A, B, C and D). Entity B, C have known about entity A and A was not familiar with entity D, E. entity E once supplied good services for D, so D believed that E possessed the higher trustworthiness of its selling behavior and D have recommended this on Consumer Community of TaoBao. Entity B, C in the community considered the referral of D to be trusty. So they recommended it to A.

Because E trusts that D can supply the service well, the trust relationship between them is *Behavior Trust*, also is *Directness Trust*. Similarly, Fig.5 shows the trust relationship among other entities. Identity Trust existing between entity B and D reflects the familiarity degree between them. Yet *Behavior Trust* between A and E is the result of trust recommendation.

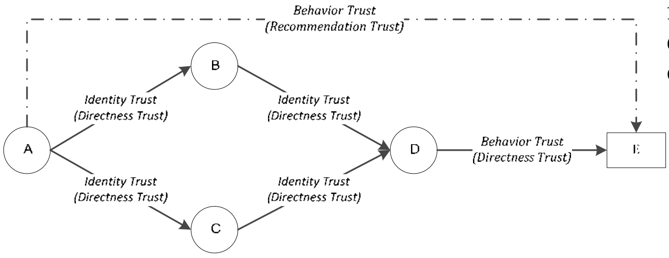

Figure 5. Trust relationship among entities

Initially, we will build a trustworthiness table for entities. The trustworthiness will be initialized that

$$m(T)=\beta\ ,\ m(\neg T)=1-(\beta+\varepsilon) \qquad (13)$$

where ε is a small random number between 0 and 0.2;all the initial belief value has one significant digit. Table Ⅰ shows the trustworthiness and trust relationship among entities [12].

TABLE I.
TRUSTWORTHINESS AND TRUST RELATIONSHIP

	Trustworthiness	Trust Relationship
R_B^A	{0.8,0.1,0.1}	Identity Trust (Directness Trust)
R_C^A	{0.8,0.1,0.1}	Identity Trust (Directness Trust)
R_D^B	{0.6,0.2,0.2}	Identity Trust (Directness Trust)
R_D^C	{0.7,0.2,0.1}	Identity Trust (Directness Trust)
R_E^D	{0.8,0.1,0.1}	Behavior Trust (Directness Trust

Now we can calculate the R_E^A in this scene using transitivity rules mentioned in Ⅲ-C. Simultaneously, we also apply other methods to obtain the result and analyze the rationality by way of comparing our rules.

$$(1)R_E^{A\to B\to D}=R_B^A\otimes R_D^B\otimes R_E^D---\{0.384,0.224,0.392\}$$
$$(2)R_E^{A\to C\to D}=R_C^A\otimes R_D^C\otimes R_E^D---\{0.448,0.24,0.312\}$$
$$(3)R_{avr}=\frac{R_E^{A\to B\to D}+R_E^{A\to C\to D}}{2}---\{0.416,0.232,0.352\}$$
$$(4)R_E^{A\to B\to D,A\to C\to D}=(R_B^A\otimes R_D^B\otimes R_E^D)\oplus(R_C^A\otimes R_D^C\otimes R_E^D)---\{0.579,0.27,0.151\}$$
$$(5)R_E^{(A\to B,A\to C)\to D}=((R_B^A\otimes R_D^B)\oplus(R_C^A\otimes R_D^C))\otimes R_E^D---\{0.562,0.244,0.194\}$$

Though method 1 and 2 got the trustworthiness of entity E, it was one-sided that they did not take full account of trust evaluation from multiple trust transitivity; method 3 used the way of weighted average that was much simpler so it did not consider the effect of uncertainty; Both method 4 and 5 have used the Dempster's rule of combination for integrating the trustworthiness, but the trustworthiness of entity E derived from D in method 4 combined the opinion with itself. It did not make sense. From another point of view, we can compute the TE of method 1, 2, 3 and 5, showed in table Ⅱ.

TABLE II.
TE OF DIFFERENT METHODS

Method	TE
1	$TE^1=0.384*e^{-0.392}=0.26$
2	$TE^2=0.448*e^{-0.312}=0.33$
3	$TE^3=0.416*e^{-0.352}=0.29$
5	$TE^5=0.562*e^{-0.194}=0.46$

Comparing with method 1, 2 and 3, method 5 synthesizes the different opinions derived from diverse recommendation paths and its TE value is also more than others. So we have chosen method 5.

Initially, the trustworthiness of entity E evaluated by D is {0.8, 0.1, 0.1} and at the end of trust transitivity, the trustworthiness of entity E evaluated by A is {0.562， 0.244， 0.194}. Fig.6 shows the t_E^A (m2({T})) with the changing of t_E^D (m1({T})). From the graph, t_E^A is always less than t_E^D after trust transitivity and the tendency of t_E^A is as same as t_E^D . We can verify that trust possesses the attenuation feature in trust transitivity.

Fig.7 shows the combination of trustworthiness R_D^A from two different transitivity paths, A →B→D and A→C→D. We can see that the element u($m(\{T,\neg T\})$) in R_D^A becomes less. It is proved that our approach decreases the uncertainty of trust evaluation and reflects the effect of integrating the multiple opinions.

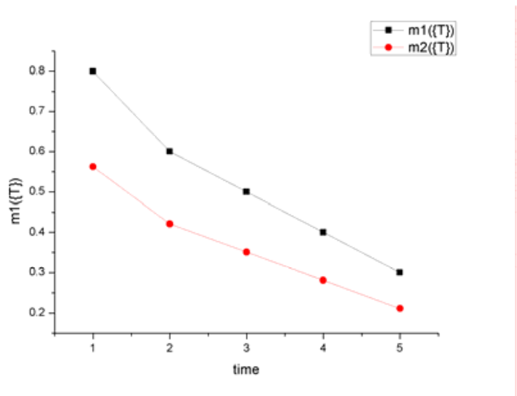

Figure 6. Comparing between t_E^A (m2({T})) and t_E^D (m1({T}))

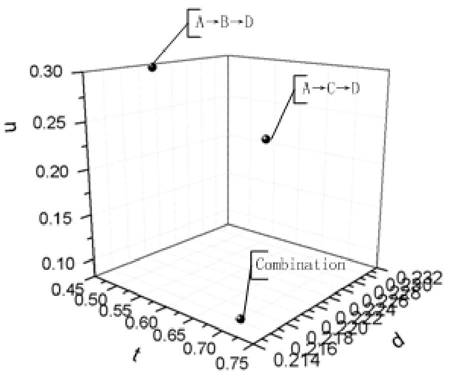

Figure 7. Trust Combination

Besides, we can get the evaluation of other entities B, C for entity E, showed in table Ⅲ.

TABLE III.
THE TRUST EVALUATION FOR ENTITY

	Trustworthiness	$\sigma(R_E^X, R_E^D)$	∂
R_E^A	{0.562,0.244,0.194}	0.971	0.05
R_E^B	{0.48,0.22,0.3}	0.948	0.05
R_E^C	{0.56,0.23,0.21}	0.971	0.05
R_E^D	{0.8,0.1,0.1}	1	0.05

As table Ⅲ shows, we can also get the nearness among other entities and entity E. From column 3, we find that the nearness between R_E^A and R_E^D is not less than R_E^B or R_E^C. It is the results of trust combination. We initialize that ∂ equal with 0.05, so the trust transitivity is rational that any "bad" factors have not influenced the normal referral. We believe that ∂ is not a constant, it can update automatically with the feedback of entities generated from the interaction or cooperation. So our research is just beginning.

V. CONCLUSION

This paper uses the Dempster-Shafer Theory for describing the trust relationship considering the uncertainty in trust and builds the trust transitivity model based trust features and trust relationship types. We also introduce the transitivity rules and combination rules for trust and illustrate them through the online shopping scene in TaoBao.

The focus of this paper is trust transitivity model based on evidence theory. We also analyze the rationality of trust transitivity but this paper does not supply the method for ensuring the rationality of transitivity. In the future work, we plan to study the special problems of "bad" factors in trust transitivity. We also plan to study the trustworthiness updating mechanism and protective method for preventing the prejudice and trickery of malice referral.

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