Trust and Reputation Ontologies for Electronic Business

Stefan Schmidt[1], Elizabeth Chang[2], Member, IEEE, Tharam Dillon[3], Fellow, IEEE, and Robert Steele[4], Member, IEEE

[1,3,4] Stefan Schmidt, Tharam Dillon and Robert Steele, Faculty of IT, University of Technology, Sydney, Australia,
e-mail: (sschmidt, tharam, rsteele)@it.uts.edu.au
[2] Elizabeth Chang, IT School of Information systems, Curtin University of Technology, Perth, Australia,
e-mail: elizabeth.chang@cbs.curtin.edu.au

Abstract - **The emergence of social networks in centralized and distributed virtual communities is one of the hottest topics in today's research communities. Trust and reputation ontologies which capture the social relationships and concepts among interacting parties offer a standardized and common understanding of a problem domain such as electronic business in autonomous environments. To improve interoperability, ontologies can be shared among interacting agents and form the basis for many of the autonomous activities of intelligent agents. The ontologies presented in this paper concentrate on the formalisation of business discovery, business selection, and business interaction QoS review concepts. Special focus is put on trust and reputation relationships which form among the entities involved.**

Index Terms—**Trust, Reputation, Credibility, Ontology, P2P, e-business**

I. INTRODUCTION

E-commerce platforms have grown enormously over the past decade, and in many areas e-commerce business models have overtaken traditional models. The accessibility of the internet results in better choice and better prices for consumers through increased competition and reduced costs. Therefore, e-commerce businesses enjoy increasing popularity over traditional businesses. However, the sheer vastness of the internet and its offerings is overwhelming for many consumers. Consumers often find it hard to determine the reputation of e-businesses and their products or services. Hence, they have little confidence due to a lack of trust. A solution to these problems offer autonomous agents which search e-commerce platforms on behalf of their owners, the consumer. They can discover products or services, select appropriate business partners, negotiate and place contracts, oversee contract execution, and determine the success and quality of business transactions. All these activities are very time and resource consuming and the concept of truly autonomous computing which addresses this problem is a compelling idea.

Yet the adoption of autonomous computing concepts into e-commerce models is still in its infancy. The integration of social values such as trust, reputation and credibility represent a challenge to achieve the vision of autonomous interactions between intelligent agents. Current frameworks, which put the underlying concepts of the service oriented architecture (SOA) into practice, often offer security models which deal with data integrity and encryption as well as identity management but lack integration of sophisticated social protection mechanisms. These social protection mechanisms are, however, the decisive factor for human interaction. Centralized environments such as e-commerce portals or virtual marketplaces which are designed to complement or even replace time and resource consuming direct human interactions currently lack an interoperable, accessible and extensible interface to their various social protection mechanisms. This problem is even more important in next generation digital ecosystems which will operate in truly decentralized peer-to-peer (P2P) environments. While P2P based e-business environments [1] offer great features such as enhanced privacy, independence, scalability and accessibility, the management of social security during the formation of such virtual communities will require highly sophisticated and standardized frameworks. These frameworks need explicit and formal specifications of the concepts found in e-business domains, and the relations among them [2] with regard to social security mechanisms such as trust, reputation and credibility.

Human beings base most of their decisions on subconscious judgements about the trustworthiness, reputation or credibility of a business partner, a company, a business context, a service or a product before they engage in any interactions. They are able to continuously adjust their assessment of these entities such as the quality of the service or the trustworthiness of a business partner. For human beings these adjustments are subconscious, and, therefore, such feelings are hard to grasp with words, let alone integrate into calculation methodologies for autonomous agents. Hence, such decisive factors are mostly disregarded during interactions between agents in the digital world where security standards are only concerned with traditional aspects such as identification, authentication, access control, integrity, confidentiality and non-repudiation [3].

This lack of integration of more sophisticated social protection mechanisms is due to two factors. First, the fuzzy nature [4] of these social values increases the complexity for their integration into autonomous environments. Second, there is a strong need for the formalisation of trust, reputation and reputation concepts tailored to the specific conditions that characterize relationships for e-business. While a number of researchers have recognized and addressed the need for appropriate methodologies to calculate social ratings based on trust, reputation and credibility, there is a need for the formalisation of these concepts through ontologies with special focus on social protection mechanisms.

This paper extends the initial work by Chang et al. [5] who propose a number of generic ontologies for the integration of trust and reputation concepts into the SOA.

The integration and formalisation of notions for trust, trustworthiness, reputation and credibility into the core specifications of e-commerce frameworks is a first step to achieve interoperability across existing e-commerce portals such as ebay, amazon.com or product search and comparison portals such as froogle or cnet.com. Currently, these portals and platforms offer basic reputation mechanisms based on consumer and/or expert reviews and ratings. However, these reputation systems are not interoperable and are generally not sufficient to protect consumers and businesses from risks such as fraud, risks related to inadequate product or service quality, and contract settlement risks. Furthermore, businesses must also deal with risks such as counterparty risk where a customer may cancel his payment after the product or service has been delivered. Another risk for both parties is the dependence and limitation of e-commerce marketplace or platforms themselves. Service consumers and service providers are at the mercy of these commercial service brokers in several ways; they have to agree to legal conditions imposed by a service broker, they have no control over the correctness or accuracy of ranking calculations or reputation mechanisms for their offerings or requests; and they cannot control their privacy since all data, transaction logs, and service details are stored in inaccessible databases controlled by the service broker.

To overcome these limitations and risks we have proposed a reputation aware service brokering architecture for service oriented environments which are run in a peer-to-peer setting [6]. The main purpose of this architecture is its independence of centralized service brokers and the integration of trust and reputation measurement mechanisms to ensure a secure and balanced community of business service providers and consumers. This decentralized architecture offers flexibility, reliability, independence and better security and, thus, helps to increase consumers' confidence. Ultimately, this confidence will lead to the increased adoption of autonomous agents who will act on the behalf of, both, service providers and service consumers.

In the following section, we discuss related work with focus on social protection mechanisms in virtual communities. In section 3, we introduce trust and reputation ontologies for business discovery and selection before addressing a business execution review ontology in section 4.

II. BACKGROUND

The formation of virtual communities in decentralized, autonomous environments is one of the most researched topics in recent years. Several researchers have proposed the integration of social information into the semantic web in order to support the formation of a more secure and stable digital ecosystem [7] [8] [9] [10] [5]. While most of those publications concentrate on inference methodologies for these social values, few have addressed the structural relationships of all involved entities in a more formal semantic

structure of an ontology. In the following we briefly discuss existing approaches that formalize the integration of social data into the semantic web as well as the calculation of this data.

One of the early approaches was proposed by Marsh [9] who introduces very broad concepts in his trust model which is based on observations from social science or even biology. However, Marsh's model is not applicable to specific contexts such as e-business without wide-ranging prior adjustments and extensions to meet the requirements of current and future e-business settings. Abdul-Rahman and Hailes [7] propose a trust calculation model that takes agent reputation and third party opinions into account but fails to formalize and describe the complex relationships between all parties in detail. Instead their work concentrates mostly on the calculation of trust values.

Eysenbach [8] proposes a specialized ontology that formalizes the collaboration of agents in the medical domain. He provides detailed information about the semantics of interacting entities such as individuals, organisations and regulators and their relationships with regards to trust, reputation and general security. He discusses the opportunities and problems arising from the semantic web and the 'web of trust', but his proposed ontology for e-health is not intended for usage outside this domain. Golbeck et al. [10] discuss the formation of the 'web of trust' in social networks. They extend the Friend-Of-A-Friend (FOAF) RDF schema [11] by integrating nine levels of trust. However, important concepts for trust calculations such as reputation and credibility as well as their relationships with regards to the trust concept are missing. Furthermore, this research concentrates on more general trust relationships in distributed social networks and does, therefore, not reflect the more complex relationships required for autonomous e-business interactions.

Chang et al. [5] have published the most extensive and formalized trust and reputation related definitions, ontologies and calculations in this area so far. Their work concentrates on general trust and reputation concepts and relationships for in service oriented architectures. In this paper we extend their general trust and reputation ontologies with detailed concepts that identify and realize specific e-business-related requirements. In our previous work we have proposed the *Deco Arch* framework [6], a new approach for the formation of virtual communities based on contextual interdependencies between the reputation of businesses and the contexts they belong to.

III. REPUTATION AND TRUST ONTOLOGY FOR E-BUSINESS

In the following we describe the static concepts and relationships for a trust and reputation ontology for e-business. We base our concepts on the generic trust and reputation ontologies introduced by Chang et al. [5] as depicted in Fig. 1. An agent to be assessed for trustworthiness, credibility or reputation is called reputation queried agent or trusted agent and acts as service provider or seller. The agent assessing

the reputation queried agent's trustworthiness is called trusting agent and acts as a consumer. Peer agents which share information about their past experiences with the requesting agent are called recommending agents [12] [5].
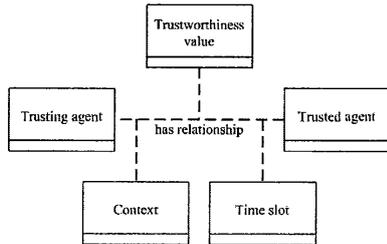

Fig. 1 Generic Trust Ontology for SOA [5]

In the following subsections we introduce a number of extensions to this generic ontology with the necessary details which are required for e-business specific scenarios such as service, product or business provider discovery, business selection, and review of the contract execution on completion.

Business Discovery

The discovery of services, products or business partners is generally initialized by the consumer. The consumer defines his preferences and constraints in a business need profile. This *business need profile* is described in detail through a set of *criteria* where each criterion has an *importance* assigned to it. A criterion may be of simple nature if it is described through *semantic attributes* providing details about the service or product. Such semantic attributes are for example a book title, a company name, a quantity or a maximum price. In addition a criterion may also be expressed as a *policy* which links itself to other complex concepts such as *quality of service, privacy, currency, delivery, payment, time* restrictions, etc. Depending on the context other policies can be added by agents to satisfy individual requirements. On the other hand businesses are specified through a *business profile* which is composed of a set of criteria and thus follow a similar semantic structure as the business need profile defined by the consumer.

The information provided in the business need profile is used to query e-commerce marketplaces for potential businesses. Results can then be matched by comparing the criteria expressed in the business need profile and the business profile which describe the services, products or business partners. These matching calculations serve as an initial filter to reduce the number of candidate business partners.

In a next step the consumer needs to select the final product or service as well as the business partner. Depending on the existing information about a potential business partner, service or product the consumer agent chooses between two different approaches for the service selection. The first approach is a service selection *without* referral. We demote the term 'referral' as a recommendation or an opin-

ion that the recommending agent offers to the trusting agent about the quality or the trustworthiness of a product or service offered by the recommendation queried agent. An opinion could also contain trustworthiness information about the recommendation queried agent itself. The trusting agent will only use the business selection without referral approach if it already possesses sufficient data about the service, product or service provider from previous transactions in the same context and the same timeslot. Furthermore it is imperative that this data is reasonable current since we assume that social ratings decay over time [12].
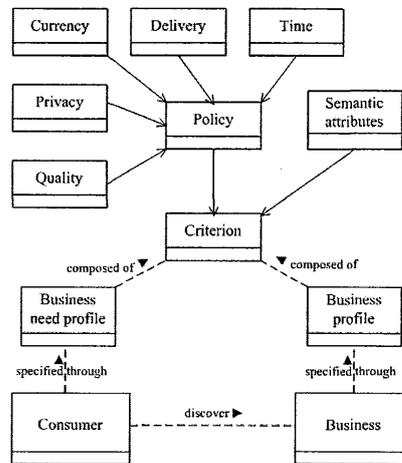

Fig. 2 Business Discovery Ontology for E-business

Business selection without Referral

Fig. 3 depicts an extended e-business ontology which defines the relationships between the consumer and the business concept for the *service selection without referral* scenario. In order to increase the confidence during service selection and contract negotiation a *trust relationship* needs to be established between both parties. This trust relationship is strongly dependant on reputation values for the various entities involved. These entities which are rated through reputation values are classified as follows:

Consumer concept
- A consumer is represented through an agent which is rated by its reputation.

Business concept
- A business is rated by its reputation, this includes:
  - o individual service or product ratings
  - o service provider or manufacturer ratings.
- A business is part of a group alliance [6] which is rated by a collective reputation.
- A business is represented through a supplier agent which is rated by its reputation.
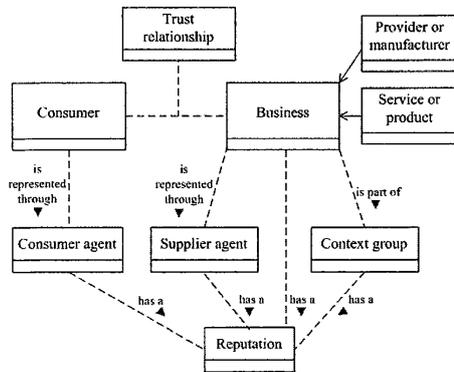
Fig. 3 Business Selection without Referral

For example, in a scenario where a company clerk wishes to purchase a new stack of printer paper, he assigns the task of discovering suitable office material suppliers, selecting the appropriate paper quality and type and its supplier, negotiating a contract and the monitoring of the contract execution, to his autonomous agent. The agent already has historical data available for all potential suppliers and their products offered from past interactions. Based on this existing data from past experiences it evaluates its business risk as low and, therefore, it chooses to select the supplier without the need to obtain additional opinions from recommending agents.

The business concept can have several public reputation values. First, the business (e.g. manufacturer or producer) itself has a reputation of 3.79 on a scale of 0-5. Furthermore, a specific product offered by this business has a reputation of 2.45. Second, the business has a group alliance reputation of 2.89 which is a weighted average of the 'printer paper supplies' context which is calculated across reputation values for businesses in the same group alliance. And finally, the specific supplier agent has a reputation value of 2.46. All four reputation values are of interest to the service consumer which uses these values as part of its trustworthiness value calculations. The trustworthiness value is used primarily for service selection but also provides decision support during contract negotiations [13].

On the other hand, the supplier agent has information about the service consumer from past interactions and is, thus, able to calculate a public reputation value of 3.76 which provides the supplier with important information about its reliability and standing within the community. This information is especially useful during contract negotiations where the reseller specifies the payment conditions.

Similar to the generic trust ontology (Fig. 1), the extended ontology for service selection without referral (Fig. 3) defines a trust relationship between the consumer and the business concept. This trust relationship is defined by a context, a timeslot and a trustworthiness value (Fig. 4). As mentioned earlier, trustworthiness, reputation and credibility values loose significance over time as ratings and opinions

about services or products are updated, or businesses are ranked differently based on their recent performance. This dynamic behaviour of the trustworthiness and the reputation value is represented by the trend concept depicted in the detailed view of the trust relationship concept in Fig. 4. The trend concept provides a valuable indication about the recent changes in the trustworthiness or reputation value and can have the following states [*decreasing, neutral, increasing*] [6]. A second concept called confidence expresses the strength of a reputation or trustworthiness value. This strength value is depending on the number of past experiences or opinions from which the value was previously calculated. The more past experiences with a potential business, supplier, service or product exist, or the more opinions these calculations are based on, the higher the confidence in the resulting reputation or trustworthiness value.
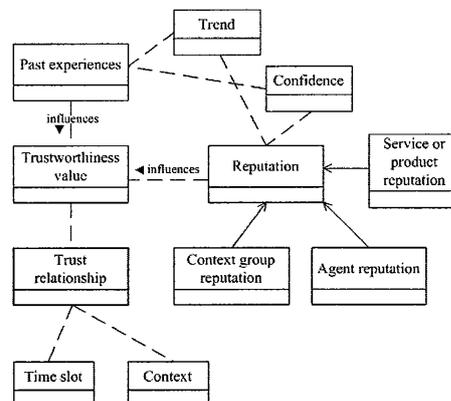

Fig. 4 Trust Relationship Concept Details

Business selection with Referral

In the more common case where the consumer agent does not possess sufficient data about the service, product, provider, manufacturer, or supplier from previous transactions in the same context and the same timeslot, it will ask neighbouring agents (recommending agents) to provide opinions on these entities. In this case there is a need to take the credibility and trustworthiness of the recommending agent into account and, therefore, we need to extend the previously discussed ontology as depicted in Fig. 5.

The consumer and the business need to build a trust relationship which is based on third party opinions supplied by recommending agents as well as its own past experiences with the business if the consumer and the business had previous contact. If the consumer and the business had a previous relationship but this information alone was considered as not sufficient for a comprehensive trustworthiness evaluation it can still use this information in the same structure as introduced in the previous section (see Fig. 4). In order to complete the information about a potential business partner, the trusting agent (consumer representative) needs to extend

this relationship by allowing third party recommending agents to contribute their opinions about their previous interactions with the recommendation queried agent (business representative). These opinions are then integrated into the previously introduced trust relationship concept as depicted in Fig. 6.
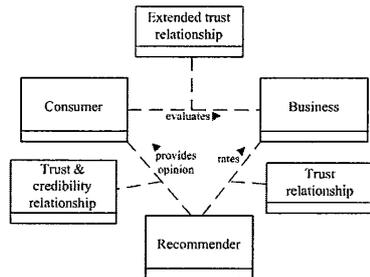

Fig. 5 Business Selection with Referral

In the extended trust relationship concept the third party opinion concept is the second input for the trustworthiness value along with the reputation value calculated from past experiences. If no past experiences with the recommendation queried agent exist, the trustworthiness value may be calculated solely from third party opinions. A third party opinion is evaluated by several factors. Firstly, there is a need to assess the credibility of the recommending agent in its capability and willingness to provide correct information and, hence, the trustworthiness of the opinion [5]. Secondly, the trusting agent needs a notion for the confidence or strength of the opinion provided. This confidence will be high if the opinion is provides datasets containing information about multiple interactions with the recommendation queried agent instead of just one. Similar to the reputation value the recommender credibility value is also refined by a confidence and trend value to deal with its aforementioned dynamic behaviour.

The trust and credibility relationship between the trusting agent and the recommender agent is based on the pre-existing trust relationship between both parties (if present) and the credibility of the recommending agent to share truthful information. Opinions contain data about past experiences between the recommending agent and the recommendation queried agent which the recommending agent is prepared to share.

The recommending agent has a high interest in sharing truthful information since his credibility is at stake [14]. The credibility value ultimately influences its reputation value and, thus, its standing within the community. Agents with a low reputation value face several problems such as exclusion from information sharing, lower authority during contract negotiations and lower chance of being chosen by consumers if they are businesses or even rejection by businesses if they are consumers. Therefore agents have an apparent interest to increase their credibility and reputation values by sharing opinions about their past experiences. If a recom-

mending agent is totally unknown to the consumer agent and, thus, has no credibility, then the opinion has no influence in the actual trustworthiness value calculations of the consumer. However, the opinions can be evaluated after the actual business interaction and, hence, the credibility value of the recommending agent can be adjusted accordingly. Growing trustworthiness, reputation and credibility ratings will influence the standing and success of the business in future. The interdependencies of the trust and credibility relationship are depicted in Fig. 7.
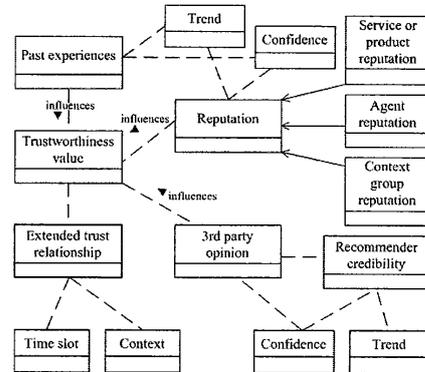

Fig. 6 Extended Trust Relationship Concept Details

The trust and credibility relationship is influenced by the accuracy of past opinions which the recommending agent shared with the consumer agent. The accuracy is generally assessed after the business interaction took place and the actual quality of service or performance can be compared with the original opinions provided by the recommending agents [12]. Furthermore, the dynamic nature of the opinion accuracy value is recognized by a trend and a confidence value similar to the trend and confidence values used to refine the reputation of the recommending agent.
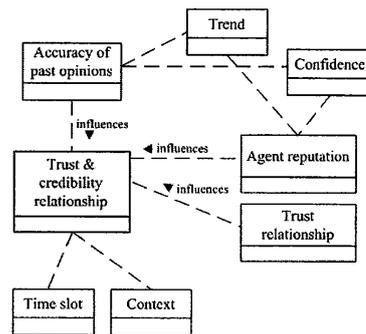

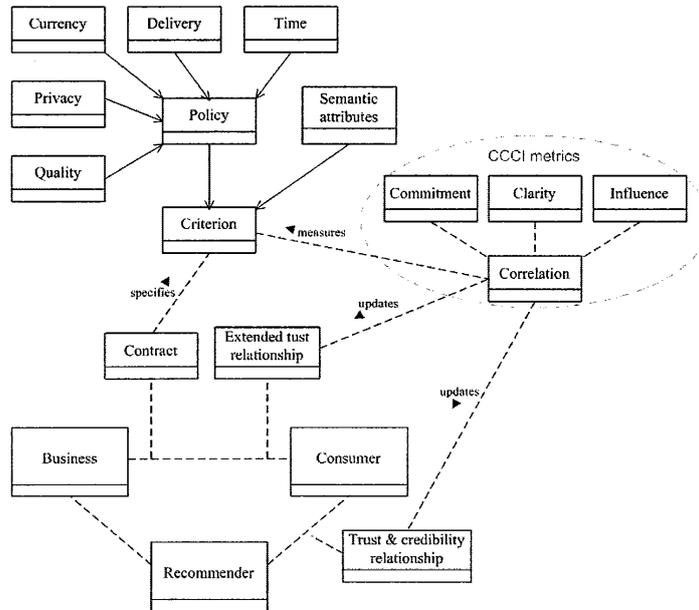Fig. 7 Trust & Credibility Relationship

Fig. 8 QoS Review Ontology

Another factor in the relationship between the consumer agent and the recommending agent is their previous trust relationship which provides details about the general reliability and trustworthiness of both interacting parties. However, if no trust relationship between both parties exists or the trust relationship refers to a different context or different time slot, both parties have to rely solely on reputation calculations based on third party opinions. In this case both parties need to evaluate their business risks and limit their interactions accordingly [15].

The relationship between the recommending agent and the recommendation queried agent is the same trust relationship we introduced earlier; hence, we omit a detailed description here and refer to the previous discussion.

IV. QUALITY OF INTERACTION REVIEW ONTOLOGY FOR E-BUSINESS

A second building block to ensure successful and autonomous interactions between agents is the monitoring and review of the quality of service (QoS) and contract adherence according to the mutually agreed contract or service level agreement. This monitoring process takes place during the contract execution or service delivery and is of specific importance for the adjustment of QoS information. This QoS data is continuously updated and used to adjust reputation and credibility values for the business partner during long term business relationships or long running contracts. For example, a consumer agent may monitor the QoS of an internet connection and compare its results with the service level agreement promised by telecommunications service provider. Another example is where a consumer agent constantly monitors the performance of a financial advisor who is responsible for investing superannuation funds in a profitable manner. In both cases the service providers may also monitor the adherence to the contract by the consumer who agreed to pay monthly fees.

In other cases constant monitoring of the contract adherence may not be required since its execution is expected to be completed within a very short period of time. One example for this is the previously discussed example where a consumer agent has purchased a stack of printer paper. The delivery and payment conditions to which both parties agreed, in this case, are, that the paper must be delivered within one week by the supplier and the price must be paid by bank transfer within two weeks by the consumer. Another example may be the order of a custom built computer. The consumer agent will not only review the timely delivery but also check whether the computer is built according to the order.

The results of the QoS monitoring or review process are used to update trustworthiness data for future reference if the business interaction is completed. If the business interaction is still ongoing the constant update of the trustworthiness value with contract monitoring information may prove important to detect and solve problems or even terminate the contract prematurely. Furthermore, the QoS data can be used to provide opinions about the trusted agent to other

agents. In case of an extended trust relationship, the review or monitoring information is furthermore used to assess the quality of opinions delivered by recommending agents about the recommendation queried agent. If an opinion received from a recommending agent differs significantly from the actual performance of the trusted agent, the credibility value for these recommending agents will be adjusted accordingly [12].

Public reputation values are also adjusted as a result of the QoS monitoring and review process. For example, the reputation of a supplier agent is increased if it performs better than expected, that is, it conforms to all contract conditions despite having a mediocre previous reputation value. Furthermore, the reputation of a service or product may be adjusted according to their quality, which may affect the overall reputation of all products or services that are categorized in the same context (alliance). Moreover, significant changes to trustworthiness, reputation or credibility values will affect the trend values that indicate the most recent developments of these social ratings. For example, if a reputation value changes from 4.6 (very good reputation) to 3.6 (good reputation) than the trend value is adjusted to 'decreasing' [6] which indicates the negative development of the reputation value. On the other hand, a reputation value may increase from 2.9 (some reputation) to 3.6 along with a new trend value of 'increasing'. Despite matching reputation values of, both, agents or entities, their trend values differ significantly and, thus, give the evaluating agent an indication about the future development of both reputation values.

In order to achieve a flexible, consistent, and efficient QoS review we employ the CCCI (Correlation, Commitment, Clarity, and Influence) metrics introduced by Chang et al. [16]. The central objective of the CCCI metrics is the measurement of the correlation between the service contract both agents agreed to before their business interaction (expected behaviour) and the actually delivered services or products during or after the completion of the business interaction (actual behaviour). The overall correlation measurement is performed through the assessment of three variables which play an important role in the review process of the business interaction; commitment, clarity and influence.

The commitment measures the fulfilment of individual criteria to which both parties mutually agreed upon in the contract. For example, if a one of the criteria defined in the contract is a policy which specifies delivery conditions then it is easy for the service consumer to rate the commitment to this criterion by comparing the expected delivery with the actual delivery. Another important value is the clarity of individual contract criteria, which need to be clearly specified, commonly understood and mutually agreed upon between both business partners. This is not always as straight forward as one would expect, for example, if a criterion specifies the delivery time as 'autumn' there are two problems; first, the delivery date is not quite clear; and second even the year of delivery is unclear, it might be this year or in five years. The third and last central value which is measured as part of the CCCI metrics is influence. The influence value allows both parties to denote specific contract criteria

as more important than others. The more important contract criteria are crucial for the QoS measurement during or after the completion of the contract.

V. CONCLUSION

In this paper we have proposed a number of ontologies to formalize and facilitate autonomous interactions between intelligent agents in centralized and decentralized e-business environments. These ontologies focus on the integration of social factors such as trustworthiness, reputation and credibility concepts during the formation and stabilization of unsupervised virtual communities. We provided detailed descriptions of concepts and their relationships with regards to essential problems such as business discovery, business selection (with and without recommendations from third party peers) and the review of the quality of service during and/or after the business interaction. These ontologies offer a common set of concepts and their relationships and reflect the complex nature of social network with specific focus on e-business. The adherence to such ontological concepts will improve interoperability between the various platforms and frameworks and, therefore, improve transparency, accessibility and increased confidence for all involved parties.

In future work we will present a prototypical implementation of our proposed *Deco Arch* framework and ontologies.

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