Formalizing a Grammar for Reputation in Peer-to-Peer Communication

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Abstract

Trust between communicating peers is increasingly catching the attention of the research community. Several methods have been proposed to assist the task of establishing trust between communicating peers; all of which make use of reputation mechanisms.

We find that in present literature, reputation is incorrectly defined, as some chief aspects of reputation are not considered while defining it. We propose a definition of reputation and substantiate it.

Additionally, we find that in present literature, a classification of reputation does not exist. In this paper, we present a three dimensional classification of reputation for peer-to-peer communication. We validate our classification for reputation by drawing from the existing proposed trust models. We also show that the different types of reputation along the three dimensions are interrelated and cannot be treated in isolation. Finally, we propose a grammar for representing reputation along with its syntax.

1.0 Introduction

If two interacting peers, who have to make a trust-based decision of whether or not to interact with the other have previously interacted, then they know the trustworthiness of each other.

Based on this previous knowledge of each others' trustworthiness, the interacting peers can decide whether to interact with each other in the future.

However, the interacting peers may not have previously interacted and, hence; they do not know the trustworthiness of each other. In this case, reputation plays a pivotal role in the process of establishing trust between communicating peers. Reputation mechanisms help in filling this gap by:

- Providing the trusted peer with an idea of the trustworthiness of the trusting peer; and
- Providing the trusting peer with an idea of the trustworthiness of the trusted peer.

Based on the level of trustworthiness determined by the interacting peers of their counterparts, with the help of reputation mechanisms, the interacting peers (the trusting peer and the trusted peer) can decide whether or not to interact with each other. Thus, reputation mechanisms can be seen as mechanisms that aid an entity in making a trust-based decision of whether or not to interact with another entity when it has no knowledge of the other entity's trustworthiness.

All the existing proposed trust models [1, 4, 6, 12, 13 and 17] make use of reputation mechanisms. However, in present literature on reputation regarding peer-to-peer communication, reputation is incorrectly defined as explained in Section 2. Additionally, a classification of reputation does not exist in present literature.

Since peer-to-peer communication has great future potential and given the role of reputation in establishing trust between the interacting peers, we propose a definition of reputation that encompasses all the aspects of reputation and substantiate it. We compare our proposed definition of reputation with the definitions of reputation from existing literature. Additionally, we identify the different types of reputation in peer-to-peer communication.

The research questions that we address in this paper are as mentioned below. They also form the contribution of this paper to existing literature on reputation in peer-to-peer communication.
- What is meant by reputation (or) how do you define reputation?
- What are the different types of reputation in P2P communication?
- Is it possible to catalogue the different types of reputation into certain classes?
- How do we validate the proposed classification of reputation?
- Based on the above classification of reputation, is it possible to present a grammar for representing reputation?

This paper is organized as follows; in Section 2 we propose a definition of reputation and substantiate it. Additionally, we compare our definition of reputation with those in existing literature. In Section 3, we identify the different types of reputation in peer-to-peer communication and propose a three dimensional classification of reputation for peer-to-peer communication and validate it. In Section 4, we propose a grammar for representing reputation along with its syntax. Section 5 is the summary of this paper.

2.0 Definition of Reputation

In this section, we propose a definition of reputation and substantiate it. We define the reputation of a peer as 'the trustworthiness of a reputation queried peer, advised by the witness peers, in a given context and at a given point in time'.

The terms 'trustworthiness', 'reputation queried peer', 'witness peer', 'advised', 'context', 'given point in time' are essential when defining reputation, as will be explained later in this section. These six terms can be regarded as the building blocks of reputation. In the following sub-sections, we elucidate and explain the six building blocks of reputation.

2.1 'Trustworthiness' as Defined for Reputation

The authors defined trustworthiness in previous work [20] as *a numeric value that depicts the level of trust between two peers at a given time period in a given context and depends upon the intrinsic type of peers in a trusted relationship.*

The trustworthiness value assigned to a trusted peer by a trusting peer, once the interaction between them is over, quantifies the behavior of the trusted peer in the interaction [20].

2.2 'Witness Peer' and 'Advised' as Defined for Reputation

We define a witness peer as *a peer who knows about the trustworthiness of the reputation queried peer based on its previous direct interaction with the reputation queried peer.*

The basic premise in propagating the trustworthiness value of a given peer is that its future behavior will be a reflection of its past behavior. By propagating the trustworthiness value of a given peer (specifically termed as reputation queried peer), the witness peers help the other peers to determine how the reputation queried peer (the peer whose reputation is being queried) will behave in future interactions, based on its past behavior.

When soliciting recommendations from other peers, the reputation querying peer (a peer who is soliciting the reputation of another peer) will solicit recommendations from only those peers who have previously interacted with the reputation queried peer and hence, possess an idea of how the reputation queried peer has behaved previously. Other peers who have not previously interacted with the reputation queried peer will have no idea of how the reputation queried peer has behaved and hence, will not be able to either recommend or oppose it

The basic premise in propagating the trustworthiness value of the reputation queried peer is that the future behavior of a peer will be a reflection of its past behavior. By propagating the trustworthiness value of a peer, the witness peers help the others to determine how the reputation queried peer will behave in future interactions.

Since trust in another peer is acquired by experience/s with that peer and not simply by notions about that peer, we believe that only peers who have interacted previously with the reputation

queried peer and have trust in them, (by the term trust we mean they have an idea of how the reputation queried peer will behave) are eligible to recommend or not recommend them. The term 'witness peer', with reference to defining reputation, is used to denote a peer who has previously interacted with the reputation queried peer and is qualified to pass a judgment about the trustworthiness of the reputation queried peer.

The witness peer/s communicate or express the trustworthiness of the reputation queried peer to the reputation querying peer in order to help them to ascertain how the reputation queried peer will behave. The term 'advised', in reference to defining reputation, indicates that the witness peer communicates to the reputation querying peer about the trustworthiness of the reputation queried peer.

2.3   'Context' as Defined for Reputation

The authors stated in previous work [18] that the trust a trusting peer has in the trusted peer, in a given context may or may not be applicable to other contexts. As discussed above, the amount of trust that the trusting peer has in the trusted peer becomes the reputation of the trusted peer when the trusting peer communicates it to other peers and, given that trust is context dependent; reputation is inherently context dependent as well. The context in which reputation of a reputation queried peer is being considered by a reputation querying peer should be identical to the context in which trust exists between the witness peer and the reputation queried peer.

2.4   'Given Point in Time' as defined for Reputation

The authors identified in previous work [18] that the trust a trusting peer has in a trusted peer is not static and may vary with time. We pointed out three reasons why the trust that a trusting peer has in the trusted peer, in a given context, may vary with time [18].

As discussed above, the amount of trust that the trusting peer has in the trusted peer, becomes the reputation of the trusted peer when the trusting peer communicates it to other peers and, given that trust is dynamic; reputation is inherently dynamic. The reputation of a reputation queried peer will change when the trust that the witness peer has in it changes. Hence, we believe that the time factor needs to be explicitly specified when considering the reputation of a peer.

2.5   'Reputation Queried Peer' and 'Reputation Querying Peer' as Defined   for Reputation

We define a reputation queried peer as *a peer whose reputation is being queried by another peer.* The peer who is making an enquiry about the reputation of a given peer is termed as the *reputation querying peer.*
Reputation is always associated with the reputation queried peer. We believe that the relationship between trust and reputation of a given peer can be summarized as follows.

The trust that the trusting peer has in the trusted peer, in a given context and at a given point in time, becomes the reputation of the trusted peer, for the same context and over the same

period of time, when the trusting peer communicates its trust in the trusted peer, to other peers who want to make a trust based decision of whether or not to interact with the trusted peer.

2.6   Definition of Reputation in Literature

Reputation has been an area of focus in different disciplines like sociology, economics and psychology. In Computer Science, reputation has been a major focus area in the field of Multi-Agent Systems [10].   Recently, reputation has attracted the attention in peer-to-peer communications [6, 12, 13, 14, and 15, 17]. In this section, we review some of the definitions of reputations as given by other people and we discuss why these definitions are not appropriate for peer-to-peer communication.

Sabater [10] defines reputation as *'opinion or view of one about some thing'*. We believe that this is a simplistic view of reputation. This definition does not consider the time factor and the context in which reputation is being considered, which we believe is very important when defining reputation. Additionally, it does not mention who can vouch for the reputation of a peer and it does not specifically specify whose reputation is being considered.

Abdul-Rahman [1] defines reputation as *'an expectation about an agent's behavior based on information about it or it's past behavior'*. Similar to the definition of reputation proposed by Sabater [6], this definition too does not consider the time factor and the context factor while defining reputation.   Moreover, it does not mention who can vouch for the reputation of a peer and it does not specify whose reputation is being considered. As we mentioned before, all these factors should be made explicit when considering the reputation of a given peer.

Mui [14] defines reputation as 'perception that an agent creates through past actions about its intentions and norms'. This definition is similar to that given by Abdul-Rahman [1] who does not take into account the time factor and the context factor while defining reputation. Additionally, it does not mention who is eligible to vouch for an agent's reputation.

Miztal [2] defines reputation as 'Reputation helps us to manage the complexity of social life by singling out trustworthy people-in whose interest it is to meet promises'. This definition of reputation focuses on defining reputation as a means of finding trustworthy people. Although this is perfectly correct, it does not mention whose reputation is under consideration, at what given point in time and in what context and, more importantly, who is eligible to vouch for the reputation of an agent.

2.7   Characteristics of Reputation

In this section, we discuss the characteristics of reputation. We propose the following six characteristics of reputation:
- Context specific
- Time dependent
- Associated with a specific peer
- Reflects past behavior
- May not necessarily be correct(and)

- Personalized

In the following discussion of characteristics, we omit the discussion of the first three characteristics (context specific, time dependent, associated with a specific peer) as they have been addressed and explained above, while defining reputation. We now discuss the last three characteristics of reputation.

- *Personalized*: In previous works [18], the authors identified that trust is personalized. Depending on the psychological type of the trusting peer, the tendency to trust another peer and, more importantly, the amount of trust (trustworthiness) that the trusting peer has in the trusted peer may vary.
  As discussed above, trustworthiness that the trusting peer has in the trusted peer becomes the reputation of the trusted peer when the trusting peer communicates it to other peers and, given that trust and trustworthiness are personalized, reputation too is inherently personalized.

- *Reflects past behavior*: We discussed in Section 1 that the motivation behind gathering the reputation of given peer is to gather information about the past behavior of a peer so that the future behavior of a peer can be determined. In order to do so, the witness peers communicate the trustworthiness of the reputation queried peer. The communicated trustworthiness, in other words reputation of the reputation queried peer, reflects the past behavior of the reputation queried peer.

- *May not necessarily be correct*: We believe that the reputation of the reputation queried peer, conveyed by the witness peer/s to the reputation querying peer, may or may not be correct. The correctness of the reputation queried peer depends on how honest the witness peer is in communicating recommendations. The witness peers may or may not convey the actual reputation of the reputation queried peer to the reputation querying peer.

3.0 Classification of Reputation in Peer-to-Peer Communication

In this section, we present a three dimensional classification of reputation for peer-to-peer communication. Each dimension contains different types of reputation and we explain the different types of reputation along each dimension with examples to elucidate them. Additionally, we relate how the presently proposed trust models make use of the types of reputation that we present in this paper in order to validate our proposed classification of reputation. The dimensions for the classification of reputation are:
- The method by which the reputation of a given peer is gathered;
- The extent to which the reputation querying peer trusts the witness peer to communicate correct recommendations; and
- The suggested degree of trust as advised by the witness peer to the reputation querying peer.

Catalogue 1: The method by which the reputation of a given peer is gathered

The first dimension for classification of reputation signifies whether the reputation of a reputation queried peer is obtained by the reputation querying peer by querying the witness

peer directly or indirectly. A reputation querying peer can obtain the reputation of a given reputation queried peer either directly or indirectly (both of them are gathered by distinct ways, as explained later in this section). The basis of classification of reputation along this dimension is the method by which the reputation querying peer gathers the reputation about the reputation queried peer.

Based on whether the reputation is obtained directly or indirectly from the witness peer by the reputation querying peer, we identify two types of reputation along this dimension:
- Direct Reputation
- Indirect Reputation

We define **direct reputation** as *the reputation of a reputation queried peer, obtained from a witness peer who had been posed a query about the reputation of the reputation queried peer directly by the reputation querying peer.*

We define the method by which direct reputation of a peer can be obtained as ***direct reputation gathering method***. In the direct reputation gathering method, a reputation querying peer contacts the witness peer/s directly for the reputation of the reputation queried peer/s.

We define an **indirect reputation** as *the reputation of a reputation queried peer, obtained from a witness peer who has been posed a query about reputation of the reputation queried peer by an intermediate peer and not directly by the reputation querying peer.*

We define the method by which indirect reputation of a peer can be obtained as ***indirect reputation gathering method***. In direct reputation gathering method, a reputation querying peer does **not** contact the witness peer/s directly. The reputation querying peer issues a reputation query to an intermediate peer. The intermediate peer, in turn, passes the reputation query directly to the other peers who it feels could be the witness peer for the reputation queried peer or to those peers who it trusts to give accurate recommendations. This cycle goes on for a given number of iterations or until a witness peer is found.

Let us assume that Peer E wishes to know about the reputation of Peer C because it has to make a trust based decision of whether or not to interact with Peer C and has not previously interacted with Peer C. Peer E asks both Peer A and Peer B about the reputation of Peer C. Here, we wish to point out that Peer B and Peer A have been directly issued the request about the reputation of Peer C by the reputation querying peer (Peer E in this case).

Peer B had previously interacted with Peer C and Peer A had not interacted with Peer C previously in the same context and over the same duration of time over which Peer E wants to make a trust based decision about Peer C. We identify two scenarios that can take place.

Scenario 1:

Since Peer B had previously interacted with Peer C, Peer B advises Peer E about its perceived trustworthiness of Peer C. We term this reputation information of Peer C that is passed by Peer B (witness peer) to Peer E as **Direct Reputation**, since the reputation query was posed by the reputation querying peer directly to the witness peer and the reputation information was

communicated by the witness peer to the reputation querying peer (Peer E) without any help from intermediate peer/s.

Scenario 2:

Peer A, since it does not know the trustworthiness of Peer C, as they have not previously interacted, may pass on this reputation query from Peer E to other peers whom it feels may know about Peer C's trustworthiness. Peer A becomes an intermediate peer. Let us assume that Peer A passes the reputation query about Peer C, to Peer B.

For elucidation purposes we assume that Peer B, since it knows the trustworthiness of Peer C, on receipt of the reputation query from Peer A communicates the reputation of Peer C either to the reputation querying peer (Peer E) or to intermediate peer who had posed the reputation query (Peer A) depending method adopted in the trust model. We term this reputation obtained from Peer B about Peer C, as **Indirect or Transitive Reputation**, since the reputation query goes through one or more intermediate peer/s before it reaches the witness peer. We propose the use of the term indirect reputation or transitive reputation for such methods gathering information on reputations.

Note that in both the scenarios, Peer B is the witness peer. But the in the first scenario Peer B conveys the reputation of Peer C because it was directly issued the reputation query by the reputation querying peer (Peer E). On the contrary, in the second scenario, Peer B conveys the reputation of Peer C because it was queried by an intermediate peer and not by the reputation querying peer itself.

The reason for the distinction between indirect reputation and direct reputation is explained as follows. Once the reputation querying peer has gathered the reputation of the reputation queried peer, using indirect method and subsequently wants to make a trust based decision, s/he has to augment the indirect reputation appropriately as the reputation information is an opinion of the peers whom the intermediate peers trusts to give accurate recommendations. The opinion of an intermediate peer about a witness peer to communicate correct recommendations may or may not be the same as the opinion of the reputation querying peer about the witness peer. This process of augmentation the reputation obtained by indirect method may have to be repeated for each intermediate peer. The transitive nature of trust and modeling the transitive nature of comes plays a vital role when the reputation querying peer is making a trust based decision about a reputation queried peer, based on the indirect reputation.

However, when a reputation querying peer is making a trust based decision based on reputation obtained by direct method, s/he needs to augment the obtained reputation by the trust s/he has in the willingness and capability of the witness peer to give accurate recommendations. The process of augmentation will have to be carried out at most once, unlike the case of indirect reputation. The transitive nature of trust does not play any role and need not be explicitly modeled when the reputation querying peer is making a trust based decision about a reputation queried peer, based on the indirect reputation.

Validating the Reputation in Catalogue 1

In their proposed trust models, Yu [4], Lee [17], Aberer [12] and Xiong [13] make use of indirect reputation in order to uncover the reputation of the reputation queried peer from a witness peer. The common theme in their proposed trust models is that if an intermediate peer does not know about the trustworthiness of the reputation queried peer, it passes the reputation query on to other peers who it feels could be a witness peer. As mentioned before, we term this reputation of the reputation queried peer obtained from the witness peers with help from intermediate peers as Indirect Reputation. In their proposed trust models [4, 17, 12 and 13], due to indirect reputation, they model the transitive nature of trust in different ways.

In contrast, Abdul-Rahman [1] and Cornelli [6], in their proposed trust models, use a reputation querying peer who directly contacts the witness peers, in order to get the reputation of the reputation queried peer. As mentioned before, we term this reputation of the reputation queried peer obtained from the witness peers without any help from intermediate peers as Direct Reputation.

Catalogue 2: The extent to which the reputation querying peer trusts the witness peer to communicate correct recommendations

The second dimension for the classification of reputation is the extent to which the reputation querying peer trusts the witness peer to convey a correct or accurate recommendation.

As we mentioned before, the reputation querying peer, in order to find the reputation of the reputation queried peer, asks other accessible peers. Any peer can respond to the reputation query. Malicious peers can reply with a wrong trust value, increased trust value or decreased trust value, for reputation queried peer. Malicious peers can reply with a trust value for the reputation queried peer, even though they did not have any interactions with the trusted peer.

The recommendations obtained about the reputation queried peer can be broadly classified into the following three types:
- Reputation obtained from peers whom the reputation querying peer trusts to convey correct recommendations - **Trustworthy reputation**
- Reputation obtained from peers whom the reputation querying peer does not trust to convey correct recommendations - **Untrustworthy reputation**
- Reputation obtained from peers with whom the reputation querying peer has no previous experience of soliciting recommendations. In other words, the reputation querying peer does not know whether the recommendation/s by these peers can be trusted or not - **Unknown reputation**

The reputation querying peer, over a period of time, can come to know which witness peers report truthful and accurate trustworthiness values and which witness peers give misleading, deceitful or incorrect trust values.

The reputation querying peer may receive reputation values about the reputation queried peer from witness peers, with whom it had no previous experience of soliciting recommendations and, hence, the recommendations obtained from these witness peers cannot be classified as

being either trustworthy reputation or untrustworthy reputation. We propose that reputation values obtained from a witness peer with whom the reputation querying peer has had no previous experience of soliciting recommendations be known as an Unknown Reputation. Unlike the Untrustworthy Reputation which is fraudulent, Unknown Reputation could be fraudulent, truthful or both.

We define a trustworthy reputation as *reputation of a reputation queried peer, obtained from a witness peer, whom the reputation querying peer trusts to give an accurate recommendation.*

We define an untrustworthy reputation as *reputation of a reputation queried peer, obtained from a witness peer, whom the reputation querying peer does not trust to give an accurate recommendation.*

We define an unknown reputation as *reputation of a reputation queried peer, obtained from a witness peer, about whom the reputation querying peer does not have knowledge its ability and willingness to convey correct recommendation/s.*

Extending the above example, let us assume that Peer E issues a reputation query about Peer C to every accessible peer in the network at that point in time. Lets us further assume that, Peer E has previously solicited recommendations from Peer B. Based on this previous experience, it found that Peer B provides accurate recommendations. If Peer B responds with a reputation value for Peer C in response to reputation query by Peer E, Peer E can trust the reputation communicated by Peer C to be accurate. We propose the use of the term *Trustworthy Reputation* for such a reputation.

On the contrary, let us assume that Peer E, based on its past experiences with Peer B in soliciting recommendations had found that Peer B does not provide accurate recommendations. If we assume that if Peer E issues a reputation query about say Peer G and subsequently Peer B responds with a reputation value for Peer G in response to the reputation query by Peer E, Peer E cannot trust the reputation communicated by Peer B to be accurate, based on its past experience with Peer B. We propose the use of the term *Untrustworthy Reputation* for such a reputation.

Let us now assume, for elucidation purposes that Peer E has no previous interaction with Peer B in the context of soliciting recommendations and hence cannot judge the accuracy of the recommendations communicated by Peer B. If Peer B responds to the reputation query, then the recommendation communicated by Peer B can neither be classified as trustworthy reputation nor untrustworthy reputation. Since Peer E has no previous experience of soliciting recommendations from Peer B, it cannot judge the correctness of the recommendations communicated by Peer B. We proposed the use of the term *Unknown Reputation* for such a reputation.

Validating the Reputation in Catalogue 2

All the proposed trust models [1, 4, 6, 12, 13 and 17] categorize the reputation obtained from a witness peer into certain classes. The most common classes into which the existing proposed

trust models classify the reputation obtained from a witness peer is being from a trustworthy witness peer (trusted reputation) or from an untrustworthy witness peer (untrustworthy reputation) [4,12 and 17]. However, the basis for categorizing the reputation obtained from a witness peer into one of the classes differs from one model to another. Most of the existing trust models fail to notice that reputation obtained can be from an unknown witness peer as well. To the best of our knowledge only Rehman [1] considers that the reputation obtained from a given witness peer may be from an unknown peer.

Catalogue 3: The suggested degree of trust as advised by the witness peer to the reputation querying peer

The third dimension of classification of reputation is the degree of trust as advised by the witness peer to the reputation querying peer about the reputation queried peer. The witness peer may advise that the reputation queried peer may be trusted or be not trusted (distrusted) for that given context. Additionally, in the trust model that we proposed [20], a trusting peer can have neutral trust in another trusted peer. This neutral trust denotes that the peer is question is neither worthy of laying trust upon nor worthy of being distrusted. Additionally, a trusting peer may have neutral trust in a peer because it has not interacted with it before and hence cannot make a judgment.
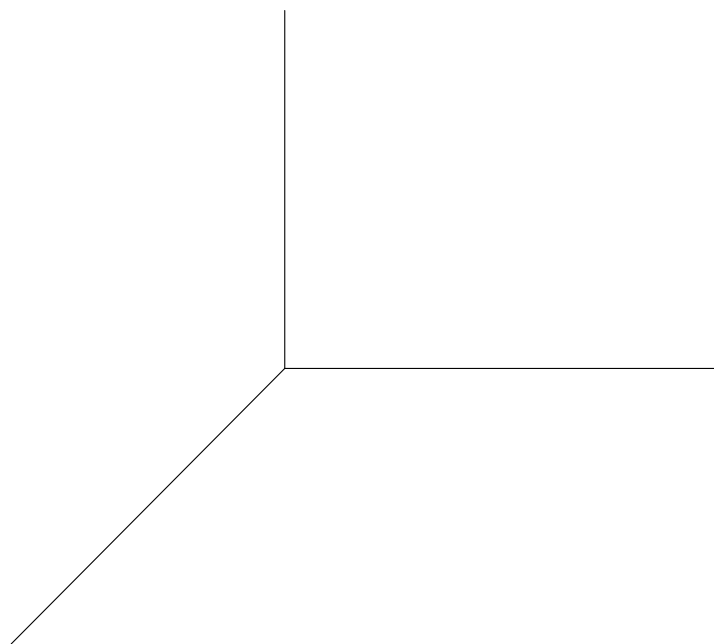
Figure 1. Classification of Reputation in Peer-to-Peer Communication

Based on different types of trust that a given peer has in another peer, we broadly identify three main types of reputation along this dimension:
- Positive Reputation
- Negative Reputation
- Neutral Reputation

We define positive reputation as *the reputation of a reputation queried peer obtained from a witness peer who advises that the reputation queried peer be trusted.*

Let us assume that Peer E asks Peer A about its perceived trustworthiness of Peer B in a given context at a given point in time. If Peer A responds to Peer E stating that Peer B can be trusted for that given context and over the same period of time as the time over which Peer A wants to make a trust based decision, then this reputation of Peer B obtained from Peer A is termed **Positive Reputation**.

We define negative reputation as *the reputation of a reputation queried peer obtained from a witness peer who advises that the reputation queried peer is not to be trusted.*

On the contrary if in the above case, if Peer A replies to Peer E stating that Peer B cannot be trusted for that given context and over the same period of time as the time over which Peer A wants to make a trust based decision, then this reputation of Peer B obtained from Peer A is termed as **Negative Reputation**.

We define neutral reputation as *the reputation of a reputation queried peer obtained from a witness peer which does not aid the reputation querying peer to make a trust based decision about the reputation queried peer.*

In the above example if Peer A responds to Peer E about Peer B stating that:
- It is not sure whether Peer B can be trusted or not for that given context and over the same period of time over which Peer A wants to make a trust based decision, because
  - It has not previously interacted with Peer B in the same context in which Peer E wants to make a trust based decision about Peer B. This reputation about Peer B communicated by the witness Peer A does not help the reputation querying peer, Peer E to make a trust based decision about Peer E and hence is termed as **Neutral reputation**; or
  - It has previously interacted with Peer B in the same context in which Peer E wants to make a trust based decision, but not over the same duration of time over which Peer E wants to make a trust based decision of whether or not to interact with Peer B.

This reputation information about Peer A does not fall in the same time duration over which Peer E wants to make a trust based decision and hence Peer E cannot this reputation information about Peer A which does not fall in the time period in which it wants to make a trust based decision about Peer A. This reputation about Peer B communicated by the witness Peer A is termed **Neutral reputation**, since is does not aid the reputation querying peer (Peer E) in making a trust based decision about Peer A.

4.0 Grammar for Representing Reputation

From the above discussion, we note that a reputation querying peer can obtain the reputation of the reputation queried peer by either of the two methods below,

- Issuing a reputation query about the reputation queried peer, to the witness peers directly. As mentioned in Section 3, this method is of obtained reputation of a given peer is termed as Direct Reputation.
- Issuing a reputation query about the reputation queried peer, to any peer. This peer(to whom the reputation query has been issued) if s/he does not about the trustworthiness of the reputation queried peer , it passes it to other peers who it feels knows the trustworthiness of the reputation queried peer or to other peers whom it trusts to give accurate recommendations. As mentioned in Section 3, this method is of obtained reputation of a given peer is termed as Indirect Reputation.

Reputation information about the reputation queried peer has to be obtained by either of the two methods listed above. Hence reputation information should be qualified by the method by which it has been obtained, in order to provide additional details to it.

Irrespective of the method adopted by the reputation querying peer to obtain the reputation information about the reputation queried peer, the reputation querying peer can trust, distrust or have no opinion of the witness peer to communicate or give correct referrals. Hence reputation information if it is qualified by the extent to which the reputation querying peer thinks that the reputation information in question is accurate, in addition to the method by which it has been obtained, it would provide more details about the reputation information in question.

For any reputation, irrespective of the method by which has been obtained by the reputation querying peer, the reputation querying peer will have an opinion about the obtained reputation, which denotes the extent to which it believes that the reputation obtained from a witness peer is accurate.

Irrespective of the method adopted by the reputation querying peer to obtain the reputation information and irrespective of the trust that the reputation querying peer has in the ability and willingness of the witness peer to convey correct recommendation, each recommendation has to convey the amount that the witness peer has in the reputation queried peer. In other words each reputation has to convey the opinion of the witness peer about the reputation queried peer. Any given recommendation can convey one of the following:
1. The witness peer recommends positive trust about the reputation querying peer
2. The witness peer recommends negative trust about the reputation querying peer
3. The witness peer recommends neutral trust about the reputation querying peer

Hence reputation information if it is qualified by what exactly it denotes or signifies, in addition to:
- The extent to which the reputation querying peer thinks that the reputation information in question is correct; and
- The method by which it has been obtained it would provide more details about the reputation information in question and would clarify all the aspects of the reputation in question.

Based on the above argument we propose a method for representing reputation. The format is shown below. We propose that reputation be represented as a tuple, which we term as

reputation tuple. By representing reputation in this we qualify and supply additional information about the reputation in question. The generic format of the reputation tuple is shown below:

[Method of Obtaining Reputation, the extent to which the reputation querying peer trusts the witness peer to communicate correct recommendations, Suggested degree of trust as advised by the witness peer]

We propose that reputation in peer-to-peer communication be always represented by a tuple as shown above. We propose the following grammar for the above tuple when it is used to represent reputation.
1) Any tuple should have all the three elements, shown above,
2) Any tuple must have the elements in the same order as specified above.
3) Any tuple, should start with an opening brace '[' and should end with a closing brace ']',
4) Each element of the reputation tuple should be separated from the next one by a comma.

We now explain the grammar for representing reputation with two examples. As an example let us assume that Peer C wants to know about the trustworthiness of Peer A. Let us assume that it passes the reputation query to all the peers. Let us furthermore assume that Peer B and Peer E reply to the reputation query. We identify two scenarios here .

Scenario 1:

Let us assume that since Peer E has previously interacted with Peer A, it passes a reputation value for Peer A. But Peer C has no previous experience of soliciting recommendations from Peer E as can be observed from Figure 1.Let us assume for arguments asks that Peer E recommends that Peer A be assigned a trustworthiness value of 6, which corresponds to Peer A being 'Very Trustworthy'. The reputation of Peer A communicated by Peer E can be represented as:

[Direct Reputation, Un-known Reputation, 6]

Scenario 2:

Since Peer B too had previously interacted with Peer A, let us assume that it communicates to Peer C that Peer A be assigned a trustworthiness value of 1, which corresponds to Peer A being Very Untrustworthy. Additionally let us assume that Peer C has previous experience of soliciting recommendations from Peer B and it trusts the recommendations given by Peer B. The reputation of Peer A communicated by Peer B can be represented as:

[Direct Reputation, Trusted Reputation, 1]

5.0 Summary

In this paper we presented a definition of reputation that encompasses all the aspects about reputation. We then defined the characteristics of reputation and presented a three dimensional

classification of reputation in peer-to-peer communication. Additionally we validated our classification of reputation by drawing from the existing proposed trust models. Finally, we presented a grammar for representing reputation and outlined the motivation and the need for a grammar for representing reputation.

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