PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE
ESCUELA DE INGENIERÍA

COLLABORATIVE SYSTEMS BASED ON REPUTATION

ANA EMILSE FERNÁNDEZ ONTIVEROS

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor:
JENS HARDINGS PERL

Santiago de Chile, September 2009

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"But seek first the kingdom of God
and his righteousness; and all these
things shall be added unto you."
(Mt 6:33)

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RESUMEN

Los sistemas de reputación han ganado una creciente importancia en los últimos años, pero sus aplicaciones han estado centradas en sitios de subastas comerciales. Este trabajo presenta dos aplicaciones para los sistemas de reputación en escenarios diferentes que han sido pobremente explorados por este concepto: redes móviles inalámbricas y participación ciudadana.

Este trabajo presenta un sistema de reputación genérico que calcula la reputación de sus participantes con una combinación de retroalimentación explícita e implícita, dando mayor importancia al comportamiento más reciente, para así representar la confianza de un nodo en el sistema.

El primer caso de aplicación es en redes móviles inalámbricas con la presentación de una heurística de ruteo que utiliza la reputación de los nodos que son parte de la comunidad. El segundo caso de aplicación incorpora un sistema de reputación para la participación ciudadana de manera de poder identificar los usuarios más calificados y así, las mejores ideas que surgen de la ciudadanía y que podrían ser usadas como políticas futuras.

Palabras Claves: Sistemas de reputación, confianza, redes inalámbricas, participación ciudadana.

ABSTRACT

Reputation systems have gained an increasing importance over the past years but its applications have been centered in commercial auction websites. This work presents two application cases for reputation systems in different scenarios that have been poorly explored areas by this concept: mobile ad hoc networks and citizen participation.

This work presents a generic reputation system that computes the reputation of its participants by a combination of explicit and implicit feedback giving more importance to the most recent behavior in order to represent the trustworthiness of a node in the system.

The first application case is in mobile ad hoc networks by the presentation of a routing heuristic that uses the reputation of the nodes that are part of the community. The second application case incorporates a reputation system for citizen participation in order to identify the most qualified users and therefore, the best ideas that arise from citizenship that could be used as part of future policies.

Keywords: Reputation systems, trust, wireless networks, citizen participation.

1. INTRODUCTION

Information technologies (IT) have advanced considerably in the past years, allowing significant changes in the way processes are being developed in areas as diverse as general-purpose Internet searches, personal communications and e-commerce.

Reputation systems are becoming very popular by the day and its uses have been multiple but mainly centered in online commercial transactions. The significance of this work is the application of a reputation system in two poorly explored areas by this concept: mobile ad hoc networks and public participation.

Due to the topography of most mobile ad hoc networks, in order to send a message between two nodes, multiple hops between nodes may be needed. The routing path for the message is crucial for its correct delivery; therefore the nodes involved in communication must be trustworthy nodes. The incorporation of the reputation of nodes can help solving the problem of the routing process by including only the nodes with higher level of trust which will lead to a more safety transmission process.

One of the purposes of this thesis is to present a protocol in order to increase the security of a mobile ad hoc network, understood as the reliability in the delivery of messages. The provided solution is a trust-based algorithm that identifies an appropriate routing path for the transmission of a package, based on the reputation of intermediate nodes. Such work was presented by the authors in (Fernández and Hardings, 2009).

Although IT already is being used in plenty areas of politics, there is still a gap in the usage of IT in terms of what it can provide to the world of politics, we are not yet taking enough advantages of these tools. Reputation systems are already being used in successful commercial online applications; nevertheless it has not yet been adequately implemented in the fields of politics and citizen participation. In particular, one of the most interesting issues regarding the use of IT in politics is still a promise: using IT to make a closer interaction between citizens and elected.

The second purpose of this work is to show how an information system based on the reputation of its users can be applied to citizen participation, democracy and politics, in order to solve the problem of making direct involvement of people in every political decision of interest to them. We present a reputation system that promotes trust among participants based on online social networks that targets the scale of a municipal government, in which the citizens have a more direct relationship with the elected authorities and the traditional media do not offer much help in the communication process between citizens and their representatives. By using this system, the objectives are the assessment of the authorities' performance and the proposition of innovations, discussions and ideas and, when they have merit, enable these to be used as part of future policies. Such work was also presented by the authors in (Fernández and Hardings, 2009) with the aim to promote participation and e-democracy between peers.

1.1 Objectives

The general objective of this thesis is to show that the usage of reputation systems can have an important impact in application areas beyond commercial auction websites and can be applied in at least two different scenarios.

The specific objectives for this work are the following:

- Identification of the design guidelines for the construction of a trust-based system by proposing an adequate reputation metric that appropriately represents the level of trustworthiness of a person or node in the system.
- Application in two different areas. In the first area, the objective is to identify a satisfactory routing algorithm using the reputation of the nodes that are part of the community in a wireless network. In the second area, the objective is the implementation of a reputation system prototype in politics to stimulate citizen participation.

1.2 Hypothesis

The first hypothesis of this work is that the simulation of a mobile ad hoc network becomes more efficient by the incorporation of the reputation of the nodes that are gathered in a community.

The second hypothesis is that it is possible to have a collaborative system based on reputation in order to be applied into citizen participation.

1.3 Methodology

To achieve the objectives stated for this work, there were three different steps that had to be taken into account: revision of the state of the art in reputation systems, definition of a generic reputation system and the implementation of a prototype.

After the research was on reputation metrics we finally came up with a novel metric that summarizes a user's past behavior, giving more importance to his recent performance in the system by the aggregation of two factors: past activity and ratings from others.

The implementations were made according to the respective scenario. For the wireless network environment, simulations over the routing protocol were performed. For the citizen participation scenario, we developed a prototype implemented in the student center of the engineering school at the local university.

1.4 Structure of This Thesis

The work developed for this thesis has been structured into five different chapters. Chapter 1 is the introduction of this work and includes the hypothesis, objectives and the methodology followed. Chapter 2 refers to the concept of trust between users and the challenges emerged by the new era of the Internet and how reputation systems can be applied in order to help solving this problem. Chapter 3 is about the existing reputation metrics, that are the models needed to calculate the reputation, and presents a novel reputation metric. Chapters 4 and 5 are two different application cases of the proposed metric. Chapter 4 presents a trust-based routing protocol to increase the security in wireless communications, more specifically in mobile ad hoc networks, some simulation results over a five-node community and a complexity comparison between the proposed routing algorithm and the main routing protocols. Chapter 5 presents a collaborative reputation system for public participation and an implementation case for such system in a local university environment. Finally the conclusions and the future steps of this work are included in Chapter 6.

2. TRUST AND REPUTATION SYSTEMS

2.1 Trust

2.1.1 Definition of Trust

The concept of trust has tried to be explained by many diverse fields such as anthropology, economics, organizational behavior, psychology, and sociology since very old times going back at least to Confucius who told his disciple Tsze-kung: 'Three things are needed for government – weapons, food and trust. If a ruler can't hold on to all three he should give up the weapons first and the food next. Trust should be guarded to the end. Without trust we cannot stand.' (Confucius).

In the last decades there has been an explosion of interest in the concept, partly because of evidence of its decline in western societies and partly because of the intense interest in theories of social capital (Newton, 1999).

An author that described trust in an integrated view was Mayer (Mayer et al., 1995) who defined the concept as 'the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to control that other party.'

(Newton, 1999) defines trust as the belief that others will not deliberately or knowingly do us harm, if they can avoid it, and will look after our interest, if this is possible.

(Rousseau et al., 1998) defined trust as a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another. An important attribute of trust is vulnerability (McKnight et al., 2002), (Pavlou and Gefen, 2005) because trust always exists in uncertain environments.

An outstanding point is that we do not either trust or distrust, but do so to varying degrees (Newton, 1999), that is to say that trust is a variable that ranges along a continuum.

2.1.2 Trust and Relationships

The simplest type of trust is the one particularized in small communities which share characteristics such as the fact that they are relatively reduced in size, clearly bounded and strongly bonded communities consisting of similar kinds of people who are dependent upon each other and who interact closely together. The members of such communities are socialized into a comparatively homogeneous culture in which social sanctions are very powerful and difficult to escape because the community is clearly bounded (Newton, 1999). The great merit of this kind of specific trust is that it binds the community strongly but it also carries the disadvantage that out-groups and strangers are likely to be distrusted (Gambetta, 1988).

In real world we do have long-time identities and most interactions are between well-known partners, therefore trust builds naturally in long-term relationships. According to (Resnick et al., 2002) this is due to two different causes. First, when you interact with someone over time, the history of past interactions informs you about the other party's abilities and disposition. And secondly, the expectation of reciprocity or retaliation in future interactions creates an incentive for good behavior. Axelrod refers to this as the ‘shadow of the future’ (Axelrod, 1984), an expectation that people will consider each other’s past in future interactions which means that shadow constrains behavior in the present.

In modern large-scale societies the concept of trust is far more generalized involving strangers. In these societies much social interaction is between people who neither know one another nor share a common social background therefore trust is much harder to build between strangers.

Strangers do not have known past histories or the prospect of future interactions, and they are not subject to a network of informed individuals who will punish bad and reward good behavior toward any of them. If we do not know our partner ourselves, when we want to know about someone else we often ask others for a reference, hence trust is often based on rumors or on experiences a friend made. As a result of this, future interactions with an entity can be influenced by past interactions. We tend to call this the reputation of the partner.

We can refer to trust as a personal and subjective phenomenon that is based on several factors or evidence, and that some of those carry more weight than others. Personal experience typically carries more weight than second hand trust referrals or reputation, but in the absence of a personal experience, trust often has to be based on referrals from other users (Josang, 2007).

2.2 Internet Today

The Internet is the latest in a series of technological breakthroughs in interpersonal communication, following the telegraph, telephone, radio, and television. It combines innovative features of its predecessors, it is interactive, people can overcome great distances to communicate with others almost instantaneously such as bridging great distances and it is a mass medium, content and advertising can reach millions of people at the same time (Bargh and McKenna, 2004).

2.2.1 Evolution of the Internet

The Internet has been growing at an exponential rate in since its creation. For many years computer users have used the Internet to share data, collaborate on their work, and exchange messages. Recently, millions of computer users worldwide have begun to explore the Internet and engage in commercial online activities (Hagel and Amstrong, 2007), (Lee et al., 2006). Internet today has changed the way we perform most of our daily activities. Between its main effects we can find: globalization, crescent popularity of virtual communities and interaction with unknown people.

The Internet has unique, even transformational qualities as a communication channel, including relative anonymity and the ability to easily link with others who have similar interests, values, and beliefs (Bargh and McKenna, 2004). Internet has facilitated communication and thus closes ties between family and friends, especially those too far away to visit in person on a regular basis. The Internet can be fertile territory for the formation of new relationships as well, especially those based on shared values and interests as opposed to attractiveness and physical appearance as is in the off-line world (Hatfield and Sprecher, 1986).

2.2.2 Virtual Communities

Virtual communities have gained importance over time as a new business model for online collaboration, as demonstrated by the proliferation of trading and educational communities. In an increasingly networked society, with ever more need for global and flexible ways of professional interactions, virtual communities are natural candidates to fill collaborative gaps in traditional, hierarchical organizations (De Moor and Weigand, 2007).

A community has been defined as a group of people who share social interactions, social ties, and a common space (Kozinets, 1992); as a social network of relationships that provide sociability support, information, and a sense of belonging (Wellman, 2001), and as a set of relationships where people interact socially for mutual benefit (Smith, 2002). The key seems to be strong and lasting interactions that bind community members and that take place in some form of common space (Wenger et al., 2002). A virtual community differs from other communities only in that its common space is the cyberspace. Virtual communities therefore describe the union between individuals or organizations who share common values and interests using electronic media to communicate within a shared semantic space on a regular basis (Bannon, 1996).

2.2.3 Interaction with Strangers

With the enormous growth of the Internet and e-commerce, online trust has become an increasingly important issue. The Internet has created vast new opportunities to interact with strangers. The interactions can be fun, informative, and even profitable. But they also involve risks (Resnick et al, 2000). Deciding whether to trust something or somebody nowadays is not an easy task because people and organizations are not always well intentioned, as they used to be in the beginnings of the Internet community era, mainly motivated by personal gain and financial profit.

Over the Internet, players have to cope with much higher amount of uncertainty from quality of products and trustworthiness of participants. Between the causes of this phenomenon are the fact that there is an enormous amount of people from different cultures and the anonymity given by the possibility to change one's identity. Online service provision commonly takes place between parties who have never transacted with each other before, in an environment where the service consumer often has insufficient information about the service provider and about the goods and services offered (Josang, 2007).

In most cases the consumer is forced to accept the risk of prior performance, i.e. to pay for services and goods before receiving them, which can leave him in a vulnerable position. The consumer generally has no opportunity to see and try products before he buys. The service provider, on the other hand, knows exactly what he gets, as long as he is paid in money.

One way to address this uncertainty problem is to use feedback ratings about past behavior to help make recommendation and judgment on decision about who to trust. The inefficiencies resulting from this information asymmetry can be mitigated through trust and reputation. The purpose is that consumer will feel confident in advance about the product or service he will receive as long as he trusts the seller.

2.3 Reputation Systems

2.3.1 Definition of Reputation Systems

The concept of reputation has been used in many fields such as, economy, sociology, and computer science, but only recently, the literature has been emphasizing the advantages of using reputation systems for the establishment of trust relationships in large scale networks (Boukerche et al., 2004), (Buchegger and Boudec, 2002), (Cahill et al., 2003), (Pirzada et al., 2004).

Reputation can be considered as a collective measure of trustworthiness, in the sense of reliability, based on the referrals or ratings from various members in a community (Josang, 2007). An individual's subjective trust can be derived from a combination of received referrals and personal experience.

Keeping that in mind we can build a system that collects information about the quality of interactions, processes this information and distributes them. Referring to (Zhou and Hwang, 2007), we call such a system ‘reputation system’. A reputation system collects, distributes, and aggregates feedback about participants’ past behavior. Such systems provide the mechanisms to capture and spread information about which users are more reliable than others, according to rates assigned by other users of the system. (Resnick et al., 2000) refers to these types of systems as systems help people decide who to trust, encourage trustworthy behavior, and deter participation by those who are unskilled or dishonest.

The basic idea is to let parties rate each other and use the aggregated ratings about a given party to derive a reputation score, which can assist other parties in deciding whether or not to transact with that party in the future (Josang and Haller, 2007). Based on the knowledge of past behavior it is up to each agent to form his opinion on his potential transaction partner.

2.3.2 Trust and Reputation Systems

Reputation systems are well suited for stimulating social control within online communities or markets and are an important building block for achieving trust within large distributed communities, especially when mutually unknown agents engage in ad-hoc transactions (Schlosser et al, 2004). Trust and reputation systems represent a significant trend in decision support for Internet mediated service provision. Reputation systems can be called 'collaborative sanctioning systems' to reflect their collaborative nature, and are related to collaborative filtering systems.

Reputation systems help establish mutual trust between different nodes by assigning each of them a reputation value. These systems use past transaction feedback over the assumption that past behavior will be an indicator of future behavior. Reputation systems seek to restore the shadow of the future to each transaction by creating an expectation that other people will look back upon it (Resnick et al. 2000). According to the previous definition we will refer to a trustworthy agent when such agent has a high reputation value in its community.

2.3.3 Characteristics of Reputation Systems

(Resnick et al. 2000) identified three minimum properties that any reputation system should have, which are:

- **Entities should be long-lived.** The longevity of agents means that there has to be an expectation of future interaction. It should be impossible or very difficult for an agent to change identity or pseudonym for the purpose of erasing the connection to its past behavior.
- **Feedback about current interactions is captured and distributed.** Such information must be visible in the future. In the offline world, capturing and distributing feedback is costly and most reputations travel haphazardly by word of mouth, through rumors, or through the mass media. The Internet can vastly accelerate and add structure to the process of capturing and distributing information.
- **Past feedback guides future decisions.** People must pay attention to reputations.

In order to have a quality reputation system, (Dingledine et al., 2000) have proposed the following set of basic criteria for judging the system:

- **Accuracy for long-term performance.** The system must reflect the confidence of a given score. It must also have the capability to distinguish between a new entity of unknown quality and an entity with poor long-term performance.
- **Weighting toward current behavior.** The system must recognize and reflect recent trends in entity performance. For example, an entity that has

behaved well for a long time but suddenly goes downhill should be quickly recognized as untrustworthy.

- **Robustness against attacks.** The system should resist attempts of entities to manipulate reputation scores.
- **Smoothness.** Adding any single rating should not influence the score significantly.

2.3.4 Architecture of Reputation Systems

The network architecture determines how ratings and reputation scores are communicated between participants in a reputation system. There are two main types of reputation systems which are centralized and distributed architectures.

a) Centralized Reputation Systems

In centralized reputation systems, information about the performance of a given participant is collected as ratings from other members in the community who have had direct experience with that participant. There is a reputation center that functions as a central authority which collects all the ratings, typically derives a reputation score for every participant and makes all the scores publicly available. The main idea is that a particular participant can decide whether or not to transact with a particular party. The idea is that transactions with reputable participants are likely to result in more favorable outcomes than transactions with disreputable participants (Josang et al., 2007). Within a global centralized reputation system, there is only a single reputation value per agent at a time which could possibly be a multidimensional value.

The main components and actors of a centralized reputation system are shown in Figure 2-1. After each transaction, the agents provide ratings about each other's performance in the transaction. The target of a rating is called ratee. The collector gathers ratings from agents called raters. This information is processed and aggregated by the processor. The algorithm used by the processor to calculate an aggregated representation of an agent’s reputation is the metric of the reputation system. The emitter makes the results available to other requesting agents so updated reputation scores are provided online for all the agents to see, and can be used by the agents to decide whether or not to transact with a particular agent. For example if agent A wants to transact with agent B, he will first retrieve the current reputation of B in order to know the trustworthiness of such agent. If the interaction is executed A becomes a rater and will rate agent B. Such rating is then collected and processed in order to update the reputation.

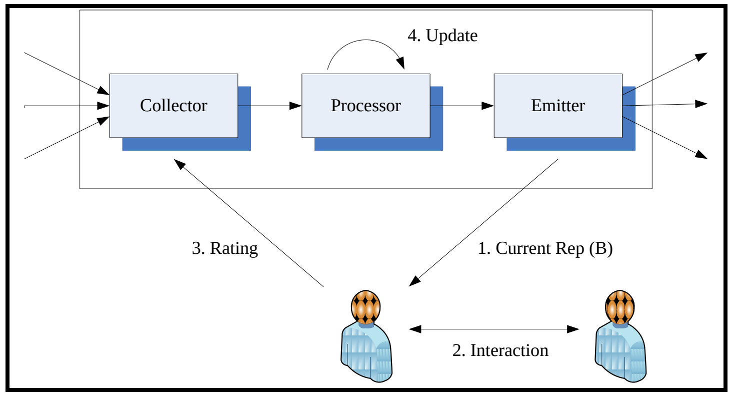

Figure 2-1: Architecture of a reputation system

Bellow, Figure 2-2 shows a typical centralized reputation framework, where A and B denote transaction partners with a history of transactions in the past, and who consider transacting with each other in the present. The ratings post transactions go to the reputation center which is in charge of gathering them and making them available for potential transactions, as shown in Figure 2-3.

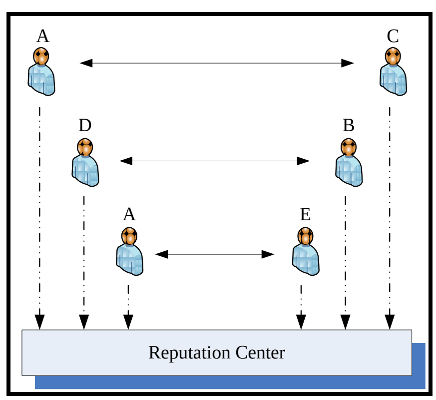

Figure 2-2: Centralized reputation systems in past transactions

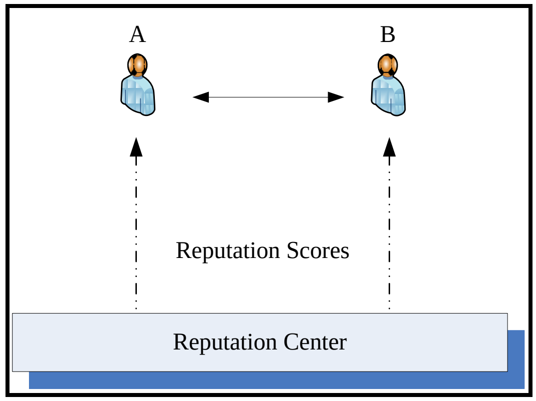

Figure 2-3: Centralized reputation systems in potential transactions

b) Distributed Reputation Systems

The second types of systems are the distributed reputation systems. In a distributed system there is no central location for submitting ratings or obtaining reputation scores of other participants. Instead, there can be distributed stores where ratings can be submitted, or each participant simply records the opinion about each experience with other parties, and provides this information on request from relying parties (Josang et al, 2007). A relying party, who considers transacting with a given target party, must try to obtain ratings from as many community members as possible who have had direct experience with that target party. This is illustrated in Figure 2-4 and Figure 2-5 below.

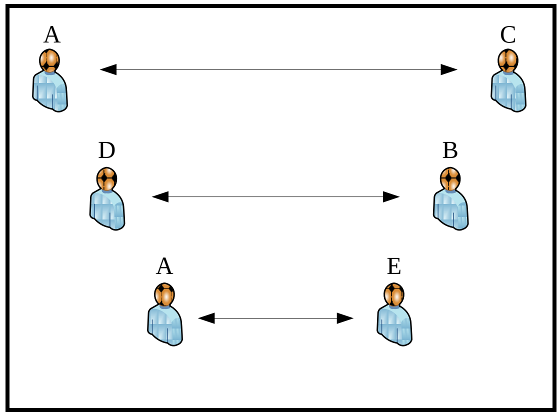

Figure 2-4: Distributed reputation systems in past transactions

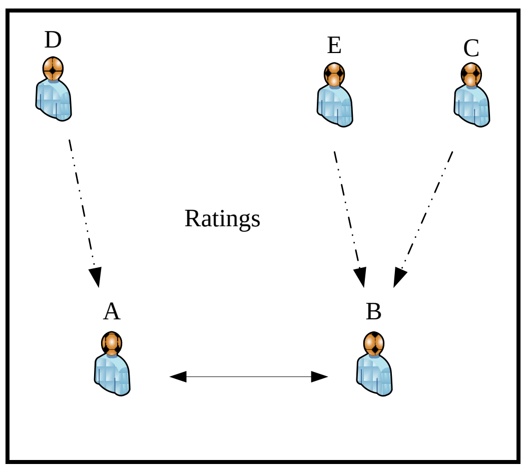

Figure 2-5: Distributed reputation systems in potential transactions

The relying party computes the reputation score based on the received ratings. In case the relying party has had direct experience with the target party, the experience from that encounter can be taken into account as private information, possibly carrying a higher weight than the received ratings.

Reference (Josang et al, 2007) states the main differences between centralized and distributed systems, in regards with the degree of centralized protocols and a reputation computation engine used by the central authority. The main concern of distributed system is the existence of many copies of the tables in the front end processors which would introduce too much complexity for a simulation system according with this project. Therefore in order to reduce the complexity, for the present work we will focus only on centralized reputation systems for both application cases.

3. PROPOSED REPUTATION METRIC

Reputation systems need metrics in order to calculate the reputation of its participants, that is, a way to obtain a qualification for each individual, using information stored in the system. Many reputation models have been proposed for online environments systems throughout the past years, but no accepted common model of reputation exists yet.

In general, the reputation is meaningful only inside the particular system or model in which it is calculated but in spite of that the scope it can reach could be very wide. This allows variation of parameters used in the calculation that can be used to avoid abuses and adapt the system to changing conditions and improve the model constantly.

The reputation of users can be captured via either implicit or explicit user feedback. In the implicit approach the reputation of users is inferred by observing behavior patterns. This approach requires less intervention from users, captures short-term participation and continuous updates reputation of users. However modeling user reputation on the basis of implicit feedback has a major limitation: the underlying assumption is that the implicit contribution is directly proportional to how much they like it. Consequently, explicit feedback is the favored approach for gathering information about users (Amatriain et al, 2009). Although this approach adds a burden on the users and different users might respond differently to incentives (Harper et al., 2005), it is generally accepted that explicit data is more reliable in most situations.

On the other hand implicit feedback is the basis input of the concept of ‘Web 2.0’ which claims the opposite as remarked in (Joachims et al., 2007). Therefore we believe that the best approach would be to have a reputation metric that combines the explicit and implicit approaches.

3.1 Existing Reputation Metrics

The simplest form of computing reputation scores is simply to sum the number of positive ratings and negative ratings separately, and to keep a total score as the positive score minus the negative score. This is the principle used in eBay's reputation forum which is described in detail in (Resnick and Zeckhauser, 2002). The main advantage of this metric is that anyone can understand the principle behind the reputation score due to its simplicity, but at the same time has the disadvantage of being too primitive and therefore gives a poor picture of the participants' trustworthiness.

A slightly more advanced scheme proposed in (Schneider et al, 2000) is to compute the reputation score as the average of all ratings. Average systems compute the reputation of an agent as the average of all ratings the agent has received, making this average value the global reputation of this agent. The idea of this metric is that agents behave the same way most of their lifetime. Unusual ratings have only little weight in the computation of the final reputation. This principle is used in the reputation systems of numerous commercial web sites such as Epinions and Amazon.

Bayesian systems take binary ratings as input (i.e. positive or negative) and compute reputation scores by statistically updating the beta probability density functions. The updated reputation score is computed by combining a previous reputation score with the new rating (Josang and Ismail, 2002), (Withby, 2000). The advantage of Bayesian systems is that they provide a theoretically sound basis for computing reputation scores, but has the disadvantage that it might be too complex for average people to understand (Josang et al., 2007).

EigenTrust Systems combine the local reputation values of each agent iteratively to a global reputation (Kamvar, 2003). This is done by modifying a target agent's reputation values by the opinions of surrounding agents. These opinions are weighed according to the local reputation values a certain agent has about its neighbors. During this process the individual reputations are iteratively accumulated to one single global reputation for each agent.

Blurred Systems compute a weighted sum of all ratings. The older a rating is, the less it influences the current reputation. An approach in a peer-2-peer environment is described in (Selcuk et al., 2004). This metric is based on the observation that agents do change their behavior during their lifetime. The assumption is that they will behave more probably like they did in their most recent transactions than they did in transactions long ago in the past.

The Dirichlet probability distribution is a multinomial Bayesian probability distribution that represents a generalization of the binomial Beta reputation system. The multinomial aspect of Dirichlet reputation systems means that any set of discrete rating levels can be defined. This provides great flexibility and usability, as well as a sound basis for designing reputation systems (Josang et al., 2007). The mathematical representation of reputation systems based on the Dirichlet distribution allows graded ratings to be directly expressed and reflected in the derived reputation scores (Josang et al., 2007). Although the Dirichlet distribution might seem mathematically complicated, the computation of the distribution itself never actually has to be done to accumulate ratings or to compute reputation scores.

Systems that compute trust or reputation by transitive iteration through looped or arbitrarily long chains can be called flow models. Some flow models assume a constant reputation weight for the whole community, and this weight can be distributed among the members of the community. Participants can only increase their reputation at the cost of others. For example Google's PageRank (Page et al., 1998) belongs to this category. In general, a participant's reputation increases as a function of incoming flow, and decreases as a function of outgoing flow. In the case of Google, many hyperlinks to a web page contribute to increase the PageRank whereas many hyperlinks from a web page contribute to decrease the PageRank for that web page.

3.2 Proposed Reputation Metric

As we already mentioned, a reputation system requires a reputation metric to calculate the reputation of its participants. This reputation can be captured via implicit user feedback, by observing behavior patterns, or via explicit user feedback.

In our model we identified two main factors that should influence on the reputation of a user in the system which are:

- Implicit user feedback.
- Explicit user feedback.

Each type of feedback represents a multidimensional vector which will depend on the scenario where the system is being developed. The implicit approach will summarize the level of recent activity given for example, by the amount of answers in a certain debate. As for the explicit approach we could find the past ratings given by other users.

The chosen model is based in the one described in (Ren and Boukerche, 2008). The essential distinction between that metric and ours is that this novel metric considers explicit feedback as qualifications from other nodes, assigning more importance to the most recent ones.

The trust for user a will be calculated as described below in Equation (3.1) in which $R_Q(a)$ is the past qualifications from others of user a (explicit feedback) and $F(a)$ is the level of recent activity of user a (implicit feedback).

$$Trust(a) = \frac{R_Q(a)^{1+F(a)} - 1}{R_Q(a) - 1} \qquad (3.1)$$

Eventually the trust of users will be a value that represents their level of trustworthiness in the system.

3.2.1 Level of Recent Activity

We will define F as a function that determines the level of recent activity of a certain node. The level of recent activity for user a will be obtained from the Equation (3.2) where $R_P(a)$ is the participating reputation of user a, $R_L(a)$ is the leadership reputation of user a, $T(a)$ is the residential time of user a and k is a discount factor between 0 and 1 that will be chosen in order to decrease the level of participation when the time spent in the system is longer and increase it when the time is shorter.

$$F(a) = R_P(a) \cdot R_L(a) \cdot k^{T(a)} \tag{3.2}$$

a) Participating Reputation

Stimulating users to participate responding to reputation queries is a relevant issue because users in the open system have individual interests and are generally reluctant to serve others for free (Zhang et al., 2004). A way to solve the lack of interest problem is by a credit-based approach; in particular whenever a user participates in the system he should gain extra points.

Based on this approach we believe that users should be rewarded for their participation in the system. In other words, a user can increment his reputation score by participating actively in the system.

A good way to measure the participation is by the relative contribution factor which will be the amount of actions executed by a user over the amount of total actions. We will denote C_i^P as the relative contribution factor for participation which has been divided in m areas, where m represents the amount of participation dimensions measured by the system, and its values will satisfy $0 \le C_i^P \le 1$ for $i = \{1, ..., m\}$. Each contribution should have different importance in the system, for such reason we will identify β_i as the importance weight of C_i^P which values will go between 0 and 1. We then define the participating reputation R_P of user a as shown in Equation (3.3) below.

$$R_P(a) = \sum_{i=1}^{m} \beta_i C_i^P(a) \tag{3.3}$$

b) Leadership Reputation

Certain users have the ability to generate participation in others and such ability should be rewarded by the system. In a similar way to participating reputation, C_i^L represents the contribution factor for leadership which will be sorted out in n different areas, where n represents the amount of leadership dimensions and its values will satisfy $0 \le C_i^L \le 1$ for $i = \{1, ..., n\}$. We will define δ_i as the weight of C_i^L in the system which values will go between 0 and 1. Equation (3.4) presents the leadership reputation R_L of user a which is defined as:

$$R_L(a) = \sum_{i=1}^{n} \delta_i C_i^L(a) \tag{3.4}$$

3.2.2 Past Qualifications

Users in the system can be qualified by others for a performed activity. Agent a will be rated and given a qualification $q \in Q$ where $Q = \{1, 0\}$ which represent a positive or negative qualification respectively.

(Dellarocas, 2004) has shown that storing feedback information on the most recent time interval is enough; and that summarizing feedback information for more than one window of time interval does not improve the reputation system. For that reason each user a in the system will have a time-sorted list Q_a of his last h qualifications where $Q_a[1]$ is the oldest rate and $Q_a[h]$ is the most recent. When a new qualification $h+1$ arrives, the oldest one comes out of the list like a FIFO array.

Agents will behave more probably like they did in their most recent transactions. Therefore we chose a metric called BlurredSquared (Schlosser et al., 2004) which computes a weighted sum of all ratings. The older a rating is, the less it influences the current reputation. In our particular case the reputation will only be calculated with the last h qualifications. The peer reputation R_Q of user a will then be defined as described below in Equation (3.5).

$$R_Q(a) = \sum_{j=1}^{h} \frac{Q_a[j]}{(h - j + 1)^2} \tag{3.5}$$

4. TRUST-BASED REPUTATION SYSTEMS IN MANETS

(Rasmusson and Janssen, 1996) were the first to use the term ‘hard security’ for traditional mechanisms like authentication and access control, and ‘soft security’ for what they called social control mechanisms, like reputation systems which complement traditional information security mechanisms.

Reputation is an interdisciplinary concept that has been used in many different contexts from social to finance. (Schneider et al., 2000) explain how information about reputation assists in daily human interactions. They provide a solution to evaluate a user’s trustworthiness in a mobile and wearable community.

Finding reliable agents over the Internet is vital when referring to the exchange of packages. Nodes that have communicational problems due to the integrity of the signal or the distance between the two-point communication will tend to interrupt a transmission or deliver an inappropriate message, for such reason the proper identification of good nodes will certainly improve the global communication leaving aside the nodes that do not keep up with the desired requirements. This especially applies to wireless networks which need other trustworthy nodes for establishing a secure transmission.

4.1 Mobile Ad Hoc Networks

A mobile ad hoc network (MANET) is a multi-hop wireless network where all nodes cooperatively maintain network connectivity. Due to the limited transmission range of wireless nodes, as well as the rapid change in network topology, multiple hops may be needed for one node to exchange data with another across the network.

A typical example of a MANET network is shown in Figure 4-1, in this case with eleven nodes. Node *S* and *R* represents the sender and receiver nodes respectively and the information sent requires two intermediate nodes in order to cooperate for the transmission of the message.

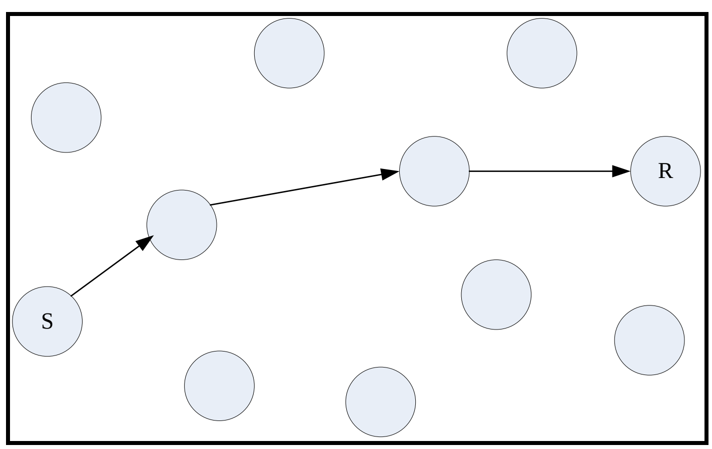

Figure 4-1: Typical transmission in a MANET

A rapid growth of research interests in mobile ad hoc networking (MANET) has emerged in the last decade by many different organizations and institutes. MANETs characterize for the diverse application of these networks in many different scenarios such as battlefield and disaster recovery together with the infrastructureless and the dynamic nature of these networks demands new set of networking strategies to be implemented in order to provide efficient end-to-end communication (Abolhasan et al., 2004).

MANETs employ the traditional TCP/IP structure to provide end-to-end communication between nodes. However, due to their mobility and the limited resource in wireless networks, each layer in the TCP/IP model requires redefinition or modifications to function efficiently in MANETs.

One interesting research area in mobile ad hoc networking is routing. The limited resources in MANETs have made designing of an efficient and reliable routing strategy a very challenging problem (Abolhasan et al., 2004) and for such reason has received a tremendous amount of attention from researchers. Not only the reduced amount of resources but also the requirement of being able to adapt to several changing network conditions such as: network size, traffic density and network partitioning, is that an efficient and intelligent routing strategy is essential in mobile ad-hoc networks. This has led to development of many different routing protocols for MANETs. (Abolhasan et al., 2004) classified these algorithms into three different groups:

- Global / Proactive Routing Protocols
- On Demand / Reactive Routing Protocols
- Hybrid Routing Protocols

Each group has a number of different routing strategies, which employ a flat or a hierarchical routing structure and diverse characteristic features explained in the following sections.

4.1.1 Proactive Routing Protocols

In the first category, called global or proactive routing protocols, the routes to all the destination (or parts of the network) are determined at the start up, and maintained by using a periodic route update process. Each node maintains routing information to every other node (or nodes located in a specific part) in the network. The routing information is usually kept in a number of different tables and such tables are periodically updated whenever the network topology changes.

All proactive routing protocols use the shortest path as their routing algorithm. The difference between these types of protocols exists in the way the routing information is updated, detected and the type of information kept at each routing table (Abolhasan et al., 2004). In addition, each routing protocol may maintain different number of tables.

One proactive routing protocol is the Destination-Sequenced Distance Vector (DSDV) algorithm (Perkins and Bhagwat, 1994) which is a modification of the Distributed Bellman-Ford (DBF) algorithm (Bellman, 1957), (Ford and Fulkerson, 1962) that guarantees routes free of loops. It provides a single path to a destination, which is selected using the distance vector shortest path routing algorithm. In order to reduce the amount of overhead transmitted through the network, two types of update packets are used that are referred to as a 'full dump' and 'incremental' packets. The full dump packet carries all the available routing information and the incremental packet carries only the information changed since the last full dump. The incremental update messages are sent more frequently than the full dump packets. The main problem of this algorithm is that DSDV still introduces large amounts of overhead to the network due to the requirement of the periodic update messages, and the overhead grows according to $O(n^2)$. This is the main reason why the protocol will not scale in large networks since a large portion of the network bandwidth is used in the updating procedures.

The Wireless Routing Protocol (WRP) (Murthy and Garcia-Luna-Aceves, 1995) also guarantees loops freedom and it avoids temporary routing loops by using the predecessor information. However, WRP requires each node to maintain four routing tables which introduces a significant amount of memory overhead at each node as the size of the network increases. Another disadvantage of WRP is that it ensures connectivity through the use of hello messages. Such messages are exchanged between neighboring nodes whenever there is no recent packet transmission as each node is required to stay active at all times. This will also consume a significant amount of bandwidth and power.

Another proactive protocol that improved the routing overhead of the previous two algorithms is the Distance Routing Effect Algorithm for Mobility (DREAM) (Basagni et al., 1998). In DREAM, each node knows its geographical coordinates through a GPS. These coordinates are periodically exchanged between each node and stored in a routing table called a location table. Exchanging location information presents the advantage of consuming significantly less bandwidth than exchanging complete distance vector information, which means that this algorithm is more scalable in mobile ad-hoc networks. Routing overhead is further reduced in DREAM by making the frequency at which update messages are disseminated proportional to mobility and to distance effect therefore stationary nodes do not need to send any update messages.

After a brief description of three of the most important proactive routing protocols we can summarize that most global routing algorithms utilize only the shortest path algorithm to determine the routing of a message. Besides the differences between them caused mainly by the way they update the routing tables that store the paths information, these types of protocols do not scale very well. This is because their updating procedure consumes a significant amount of network bandwidth (Albohasan et al., 2004).

4.1.2 Reactive Routing Protocols

In the second group, called on demand or reactive protocols, routes are determined when they are required by the source using a route discovery process. On-demand routing protocols were designed to reduce the overheads in proactive protocols by maintaining information for active routes only. This means that routes are determined and maintained for nodes that require sending data to a particular destination. Route discovery usually occurs by flooding a route request packets through the network.

Reactive protocols can be classified into two categories, as remarked by (Abolhasan et al., 2004), which are: source routing and hop-by-hop routing.

The first category of the reactive routing protocol is the source routed on-demand protocols (Toh, 1996), (Johnson and Maltz, 1996) in which each data packet carries the complete source to the destination address. Therefore, each intermediate node forwards the corresponding packets according to the information stored in the header of each packet. This means that the intermediate nodes do not need to maintain up-to-date routing information for each active route in order to forward the packet towards the destination. Moreover, nodes do not need to maintain connectivity with neighbors through periodic messages. The major drawback with source routing protocols is that in large networks they do not perform well. This is due to two main reasons; as the number of intermediate nodes grows, then so does the probability of route failure and the amount of overhead carried in every header of each data packet. Therefore, in large networks with significant levels of multi-hoping and high levels of mobility, these protocols may not scale well (Abolhasan et al., 2004).

The second category is the hop-by-hop routing or also known as point-to-point routing (Das et al., 2003), in which each data packet only carries the destination address and the next hop address. Every intermediate node uses its routing table to forward each data packet towards the destination. The main benefit of this strategy is that routes are adaptable to the dynamically changing environment of MANETs, since each node can update its routing table when they receive fresher topology information and hence forward the data packets over improved routes. Using fresher routes also means that fewer route recalculations are required during data transmission. The disadvantage of this strategy is that each intermediate node must store routing information for each active route and this may require the use of messages to be aware of a node's surrounding neighbors.

An example of a reactive routing protocol is the Ad Hoc On-Demand Distance Vector (AODV) proposed in (Das et al., 2003) that is based on Destination-Sequenced Distance-Vector routing (DSDV) and the Dynamic Source Routing (DSR) (Johnson and Maltz, 1996) algorithm. It uses the periodic beaconing and sequence numbering procedure of DSDV and a similar route discovery procedure as in DSR. In AODV the packets carry the destination address which means that AODV has potentially less routing overheads than DSR. The other difference is that the route replies in DSR carry the address of every node along the route, whereas in AODV the route replies only carry the destination IP address and the sequence number. The advantage of AODV is that it is adaptable to highly dynamic networks. However, node may experience large delays during route construction, and link failure may initiate another route discovery, which introduces extra delays and consumes more bandwidth as the size of the network increases (Albohasan et al., 2004).

The protocol Signal Stability Adaptive (SSA) (Dube et al., 1997) selects routes based on signal strength and location stability. The routes selected in SSA may not be the shortest path to the destination but on the other hand, they tend to live longer, which means that fewer route reconstructions are needed. One disadvantage of SSA when compared to DSR and AODV is that intermediate nodes can not reply to route requests sent toward a destination, which may potentially create long delays before a route can be discovered (Albohasan et al., 2004). Another disadvantage of SSA is that no attempt is made to repair routes at the point were the link failure occurs. In SSA the reconstruction occurs at the source which may introduce extra delays.

Location-Aided Routing (LAR) algorithm (Ko and Vaidya, 1998) is a flooding protocol that attempts to reduce the routing overheads present in the traditional flooding algorithms by using location information. The main principle LAR is that each node knows its location through a GPS. In (Ko and Vaidya, 1998) two different LAR schemes were presented. Both methods limit the control overhead transmitted through the network and hence conserve network bandwidth. In most cases, this algorithm can determine the shortest path to the final destination since the route request packets travel away from the source and towards the destination. The main disadvantage of this protocol is that each node is required to carry a GPS device which is not always available in all MANETs.

4.1.3 Hybrid Routing Protocols

Finally the third category is known as the hybrid routing protocols which combine the basic properties of the first two classes of protocols into one. That is, they are both reactive and proactive in nature. These protocols are designed to increase scalability by allowing nodes with close proximity to work together to form some sort of a backbone to reduce the route discovery overheads. This is mostly achieved by proactively maintaining routes to near nodes and determining routes to far away nodes using a route discovery strategy. Most hybrid protocols are zone-based, which means that the network is partitioned or seen as a number of zones by each node.

Zone Routing Protocol (ZRP) (Hass and Pearlman, 1999) is an example of a hybrid routing protocol. In ZRP the nodes have a routing zone, which defines a range (in hops) that each node is required to maintain network connectivity proactively. Therefore, for nodes within the routing zone, routes are immediately available. For nodes that lie outside the routing zone, routes are determined on-demand (i.e. reactively), and it can use any on-demand routing protocol to determine a route to the required destination.

Unlike ZRP, Zone-Based Hierarchical Link State routing protocol (ZHLS) (Joa-Ng and Lu, 1999) utilizes a hierarchical structure. The network is divided into non-overlapping zones, and each node has a node ID and a zone ID, which is calculated using a GPS. The hierarchical topology is made up of two levels: node level topology and zone level topology. This algorithm scales well to large networks because it is highly adaptable to dynamic topologies and it generates far less overhead than pure reactive protocols.

Other hybrid algorithms are for example the Distributed Spanning Trees (DST) routing protocol presented in (Radhakrishnan et al., 1999) and the Distributed Dynamic Routing (DDR) described in (Nikaein et al., 2000), both tree-based protocols.

Hybrid routing protocols have the ability to provide higher scalability than pure reactive or proactive protocols because they attempt to minimize the number of rebroadcast nodes by defining a structure that permit nodes to work together to organize the routing. By working together the best or the most suitable nodes can be used to perform route discovery. Hybrid routing protocols attempt to eradicate point of failures and to create bottleneck nodes in the network which is achieved by allowing any number of nodes to perform routing or data forwarding when the preferred path is not available.

4.1.4 Summary of the Main Routing Protocols

The algorithms presented in the previous sections are summarized in Table 4-1 below according to their type and the reputing algorithm they employ to transmit a package to its final destination.

Table 4-1: Routing algorithms of existing protocols

Protocol	**Type**	**Routing Algorithm**
DSDV	Proactive	Shortest path
WRP	Proactive	Shortest path
DREAM	Proactive	Shortest path
AODV	Reactive	Shortest path
SSA	Reactive	Signal strength and location stability
LAR	Reactive	Shortest path
ZRP	Hybrid	Fewest number of hops
ZHLS	Hybrid	Shortest path

The existing routing protocols consider basically three types of routing algorithms: shortest path, signal strength and location stability, and the fewest number of hops. The behavior of nodes in past transactions is not taken into account therefore valuable information about the reliability of the nodes is not being considered. In this work we present an approach to a routing algorithm based on the level of trustworthiness of the nodes in a community.

4.2 Proposed Trust-Based Routing Heuristic

A trust-based reputation system in a mobile ad-hoc network helps establish trust between different nodes by the allocation of reputation values to every node. Such system uses past transaction feedback as an indicator of future behavior of nodes. When a node that is part of a MANET has a high trust value, it means that such node is a trustworthy node in the network and therefore should be part of future communications. In a MANET network based on trust, nodes will use their community partners to communicate between each other and the nodes chosen will depend on their level of trust.

In section 4.1 we discussed over the existing routing protocols for mobile ad hoc networks. In general, flat routing algorithms, which mean non hierarchical algorithms, can be simple to implement, however it may not scale very well for large networks (Iwata et al., 1999). In order to make flat addressing more efficient, the number of routing overheads introduced in the networks must be reduced. One way to do this is to use a device such a GPS (Albohasan et al., 2004).

The network model proposed in this work makes the following assumptions for the trust-based system:

- The geographic position of each node is known all the time. This can be easily implemented by having a GPS device in every node.
- Nodes can communicate with each other using a multi-hop architecture.
- The reputation of nodes is managed centralized and all nodes have access to the central trust system at all times.
- The network must be equipped with an infrastructure of authorities for the assignment of authentication certificates.

A node to be part of a network has to be properly authenticated by an association between its identity and its public key. Public key certificates are usually used for this purpose. Certificates will be associated with an identifier of the node such as IP address or MAC address. Thus we propose a mechanism of assignment of a unique certificate for each node by a certifying authority.

Nowadays, key management schemes based on public key cryptography are not suitable for MANET networks because of its computation inefficiency and nodes resources constraints. Hence we propose to use a symmetric key distribution scheme between mobile nodes like the one proposed in (Dahshan and Irvine, 2008). Such scheme distributes symmetric keys between mobile nodes in two steps: the distribution of certificates during the route request process and the dissemination of symmetric keys during the route reply process.

In our model we identified two reputation factors that are directly correlated with the trust of a node in a MANET: activity level and past behavior. The activity level of a node is directly correlated with his level of participation in the transmission of messages. The past behavior of a node reflects his performance in the exchange of packages that the node was involved in. Considering these two factors we can apply the reputation metric proposed in Section 3.2, in this case to improve the security of a mobile ad hoc network.

To send a package between two peers it is necessary to find the appropriate path for the message in order to reach its goal with the highest probability of success. Once the path is selected, the message is sent. The algorithm proposed in this paper identifies the best path for a message based in three factors: reputation of nodes, distance between them and integrity of the wireless connection.

The strength of the wireless connection between two nodes A and B is expressed by the signal-to-noise ratio (SNR). The connection between these two nodes has a score $Score_{AB}$ which is calculated as a weighted sum of the distance between them d_{AB} and the strength of the signal SNR_{AB}, with $\lambda \in [0,1]$ a scalar between zero and one. Such score is then obtained according to Equation (4.1).

$$Score_{AB} = \lambda \cdot SNR_{AB} + (1-\lambda)d_{AB} \tag{4.1}$$

In this work we present a novel routing heuristic named Trust-Based Routing Algorithm (TRA) which is used for the transmission of a package from an initial node to a final node in a MANET network. This protocol returns the path with the highest level of trust for such message according to the reputation of each node and their participation in previous communications.

In the beginning an initialization of the path and current node is performed. After that an iterative instruction is performed while the current node is different from the final node. Inside that loop we identify the good neighbors of the current node using the connection score and for all selected nodes we choose the one with the highest trust. By 'neighbors' of a node we mean all nodes in the network that are one-hop distance from the node. After that selection we include the chosen node into the path and then jump to the node with highest credibility. Finally the function returns the path with the highest level of trust. This algorithm is shown next.

```
path [ ] ← insert (initial_node);
current_node ← initial_node;
while (current_node ≠ final_node) do
  selected_nodes[ ]← good_neighbours (current_node);
  max_trust ← selected_ nodes[0];
  for j = 0…size (selected_ nodes[] do
    if (selected_ nodes[j] = final_node) then
      max_trust ← selected_ nodes[j];
    else
      if (trust (selected_ nodes[j]) > trust (max_trust)) then
        max_trust ← selected_nodes[j];
  path [ ] ← insert (max_trust);
  current_node ← max_trust;
return path[];
```

Every received message is checked to verify its integrity. In a real-world implementation this could be done by a checksum. According to the integrity of the message received a qualification will be given to all nodes that are part of the selected path. Figure 4-2 shows a transmission between nodes A and B which involves two other nodes as part of the path. Node B after receiving the message rates the three nodes involved in the communication.

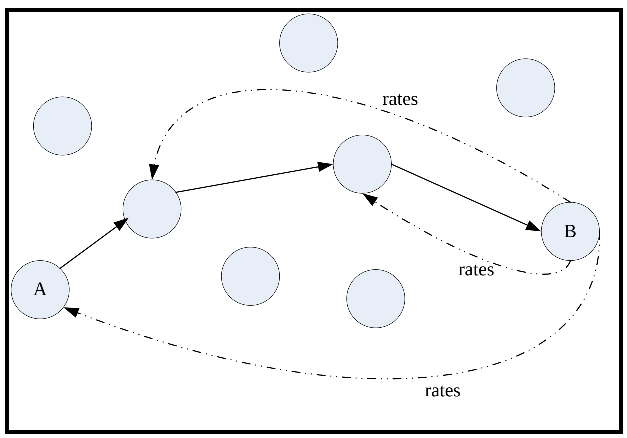

Figure 4-2: Transmission and ratings between nodes

The reputation of nodes will change depending on their level of participation in the number of messages exchanged as well as the integrity of the messages they send to other nodes. Eventually the reputation of peers will tend to represent their level of trustworthiness in the community. The higher the reputation is the better node for communication. A high reputation means that such node is a secure node to transmit messages in comparison with other nodes in the network with lower reputation.

4.3 Simulation Results for a Five-Node Community

Each node was given a random position in a two dimension map between $(0,0)$ and $(10,10)$. The SNR of connections between every two nodes was also assigned randomly because it is not necessarily related to distance since obstacles could be placed in the way and oscillated between 0 and 20. Every connection between any two nodes has a particular score as is shown in Table 4-2. For simulation we used $\lambda = 0{,}5$ for the score formula described in Equation (4.1).

Table 4-2: Connection scores for a five-node community

Connection	SNR	Distance	Score
N_1 - N_2	13,24	6,25	3,50
N_1 - N_3	3,38	4,44	-0,53
N_1 - N_4	15,83	4,14	5,84
N_1 - N_5	5,65	6,54	-0,45
N_2 - N_3	12,46	6,42	3,02
N_2 - N_4	15,46	6,29	4,58
N_2 - N_5	5,92	4,87	0,53
N_3 - N_4	18,15	8,13	5,01
N_3 - N_5	3,34	9,39	-3,02
N_4 - N_5	2,60	3,39	-0,39

For this five-node community we simulated an event between two nodes (in this case N_2 sends a message to N_5). The algorithm identified the best path as: $N_2 - N_4 - N_1 - N_5$. In Figure 4-3 we show the average bit error ratio (BER) for all paths between those two peers. We can see that any alternative path has a higher average bit error ratio than the one selected by the algorithm which is colored differently from the rest.

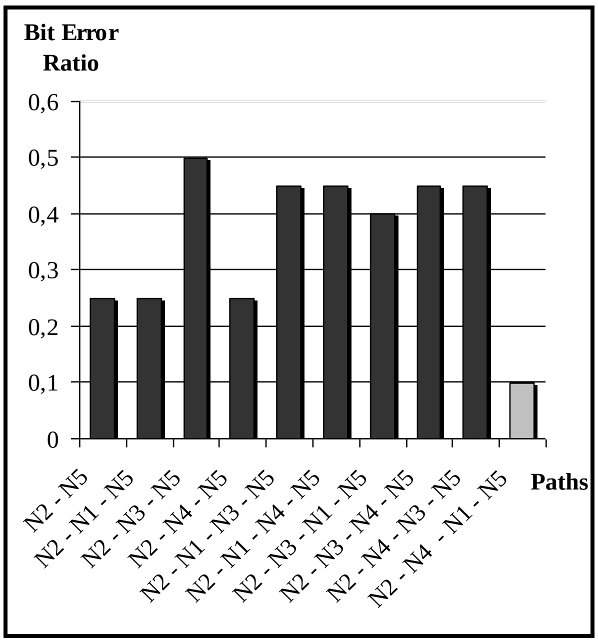

Figure 4-3: Average BER for path between two nodes

To simulate the final BER, each link has a convolutional code with a rate of ½. The mobile channel was set with a frequency of 900 Hz and a velocity of 500 meters per hour. The BER for each path is calculated between the message sent by the initial node and the message received by the final node.

4.4 Complexity Studies

Two well-known complexity parameters are the Time Complexity (TC), defined as the number of steps required to perform a protocol operation, and the Communication Complexity (CC), defined as the number of messages exchanged in performing the operation. Below Table 4-3 shows a comparison between tha main existing routing algorithms and TRA, the novel protocol proposed in this thesis. These complexity computations are supported by (Park and Corson, 1997) and (Albohasan et al., 2004) to which the reader is referred for details.

Table 4-3: Complexity comparison

Protocol	**TC**	**CC**
AODV	$O(2\mathrm{d})$	$O(2x)$
DSDV (link failure)	$O(x)$	$O(Dx)$
DSDV (periodic update)	$O(l)$	$O(\|L\|)$
DUAL (link addition, cost decrease)	$O(d)$	$O(\|L\|)$
DUAL (link failure, cost increase)	$O(x)$	$O(6Dx)$
GB (connected, postfailure)	$O(2l)$	$O(lDx)$
GB (disconnected, postfailure)	∞	∞
ILS	$O(d)$	$O(2\|L\|)$
LAR	$O(2d)$	$O(2\mathrm{x})$
LMR (connected, postfailure)	$O(2l)$	$O(2Dx)$

LMR (disconnected, postfailure)	$< \infty$	$< \infty$
SSA	$O(2d)$	$O(2\mathrm{x})$
TRA	$O(d)$	$O(2\|L\|)$
WRP (link addition, cost decrease)	$O(d)$	$O(\|L\|)$
WRP (link failure, cost increase)	$O(h)$	$O(Dx)$

The complexity parameters mentioned previously are the number of network links $|L|$, the network diameter d, the number of nodes in a network x, the length of the longest directed path in the affected network segment l, the height of the routing tree h, and the maximum nodal degree D.

The routing protocol proposed in this paper has a similar complexity to ILS for it presents a time complexity of $O(d)$ and a communication complexity of $O(2|L|)$. This last value is due to the need of a past-transaction feedback about the reputation of a node in a package transmission. Although the complexity of algorithms such as DUAL is lower, the increase in complexity is minor compared to the enormous benefits reported by the use of ratings over past transactions. The proposed algorithm presents a low complexity accompanied by the identification of reliable nodes in the network which is very valuable for the general security in a wireless network.

4.5 Discussion

The proposed algorithm is somehow similar to the SSA protocol. Both algorithms use signal strength and location stability as part of their routing algorithm, but in our case, the signal strength is more implicit due to the whole concept of reputation. Most routing protocols only consider physical attributes of the current connection but this approach combines this view with the use of reputation of the nodes involved as part of complementary information which gives information about past transactions.

Comparing the presented protocol with existing ones we can tell that the complexity of this algorithm is rather low. Indeed the main contribution is not in the reduction of the complexity of a routing protocol for MANETs, but in the incorporation of reputation systems in wireless communications.

For the theory we proposed a centralized reputation system in order to simplify the model and to reduce complexity, but for a further step we should consider to extend the proposed model into a decentralized reputation system because of the distributed nature of mobile ad hoc networks.

If a node that is part of a MANET sends false information to another peer, this problem is not yet being identified nor solved by our routing protocol. For further steps we consider necessary to include some way to address the intentionality of a node in order to provide protection against malicious parties. In this way reputation systems can help the traditional approaches.

5 REPUTATION SYSTEMS IN PUBLIC PARTICIPATION

The usage of information technologies (IT) can provide a wide range of services to political activities. Among the services are coordination of interest groups, administration of working groups and committees, management of registered voters and members of political parties, among others. We can see a huge interest in using IT for voting processes, with varying degrees of success, and specially acceptance, because of privacy, accuracy and accountability issues (Mercuri, 2002). A strong evidence of the utility posed by IT in the USA in the election of the presidential candidate Obama in processes like aligning advocates and raising funds is found in (Dutta and Fraser, 2008). Despite the unsuccessful results of the candidate, the usage the campaign managers made of the Internet was later replicated in other campaigns with great success. However, one of the most interesting issues regarding the use of IT in politics is still a promise: using IT to make the interaction between citizens and elected representatives scalable.

The promise of IT in the political arena is to allow every citizen to express his or her will regarding every issue that is relevant to them. This is not a new issue since it has been around for over ten years (Grossman, 1996), (Hague, 1999), (Wilhelm, 2000) without much impact. A notable exception was the organization of the crowds that finally ended the scandal-ridden presidency of Joseph Estrada in

Philippines, in which the people coordinated efforts using cell phones and their short messaging system to avoid police anticipation (Rheingold, 2002).

Cyberoptimists hold that information technology (IT) will appreciably reduce political ignorance and apathy and enable citizens to provide substantial input into government decision making (Aikens, 1996), (Carlitz and Gunn, 2005), (Rheingold, 2000). Researchers and enthusiasts express the hope of benefits from using electronic technologies for more deliberative input into government decision processes that involves discussion between citizens (Noveck, 2004), (Shulman et al., 2003).

The theory and findings in (Muhlberger, 2006) strongly indicate that government should design for citizen participation; in particular indicate that e-government deliberative initiatives would be worthwhile. An interesting work on the use of IT to democratic processes, in particular to representative democracy (Pino, 1998) cites the representative (parliamentarian) as someone who must listen to the positions of the citizenship. These findings indicate among others that online discussions can be as useful as face-to-face discussions.

If we are able to vote from the comfort of our homes and the results can be available almost instantly after receiving every electronic ballot, the possibility of voting on every single decision is tempting. However, such a mechanism is not scalable and has one big limitation: the mechanism to define what is to be voted, and what the options are, has to be defined somehow, leaving us with the same problem. Therefore, it is necessary to use IT in a way that every person could raise his own issues, and this way treat every relevant topic, not just the ones massive enough as it is now. Currently, in order to raise an issue a person needs huge resources in order to mobilize media and get to enough citizens and decision makers in order to just make their case known.

The expansion of new platforms of digital democracy does not necessarily entail an increase in citizen participation. In (Pérez et al., 2006) a sociological analysis was made to determine the causes of this apparent failure, reaching the conclusion that users are demanding capabilities that are not available in present systems.

The Internet and mobile phones have lowered the barriers to participation and increased opportunities for many-to-many communication (Goldstein and Rotichm 2008). Clay Shirky gets to the heart of the matter: “The current change, in one sentence, is this: most of the barriers to group action have collapsed, and without those barriers, we are free to explore new ways of gathering together and getting things done.” (Shirkey, 2008)

In this work we propose a trust-based approach by the use of a reputation system in order to promote participation between citizens.

5.1 Reputation Systems and Democracy

Reputation systems have been used in many fields, but there are hardly any real-world applications in politics and citizen participation and if there exists any, the reputation of peers does not represent a good metric of qualification. Such is the case of (Cruz et al., 2007) in which a proposal for the use of reputation systems in Communities of Practice (CoPs) was presented in order to assist users in creating relationships for honest and useful participation based on trust, for the benefit of an entire community. The main weakness of this system is the fact that it uses a very simple reputation calculation based only on the median of past reputations. As we discussed in previous sections, a metric like this is not a good enough representation of the trustworthiness of its participants.

According to (Picci, 2007), reputation effects have tree main positive effects on governance. First, at a given moment in time they help discriminating between providers of different quality – at least when a choice is possible. Secondly, they allow selection forces to weed out the least fit, which means that bad nodes eventually go out of business or at least become less relevant. Thirdly, they provide incentive to invest in quality.

A good scenario for a start could be a municipality because they manage a wide range of resources, and the citizens living in their jurisdiction generally include experts in every one of the aspects inside that range. Thus, the ‘customers’ of a municipality almost always include experts that are as qualified as the people in charge of the particular issues. This is a perfect example of what von Hippel states in ‘Democratizing Innovation’ (Hippel, 2005), in that the customers are the most capable of suggesting innovations to their providers, and the latter should work together with their customers to seize that opportunity.

The proposed system in this section pretends to promote participation and trust between users as well as become a reference for citizens who are interested in participating, based over a reputation system. The general objective of this application case is to design a reputation-based information system that improves the current state of citizen participation in a municipality government level, where citizens have a more direct relationship with the elected authorities and where traditional media do not offer much help in the communication between citizens and their representative authorities.

The system will allow people to pose their suggestions, complains and doubts in specific areas. The relevant topics and opinions will then stand out and be addressed by the elected representatives and the municipal workers. By using this system, the objective is to enable citizens to present their concerns and, when they have merit, enable them to be used as part of future policies. This principle has been termed ‘Emergent Democracy’ and we can find some examples of it in (Surowiecki, 2004) in which crowds tend to act smarter than individuals.

Citizens must be given the necessary tools to assess the work of their elected representatives. When their concerns are taken care of efficiently, they would want them to be reelected. The purpose is to enable citizen to participate actively in the decisions and tasks that affect the community, view the result of their effort and thus feel motivated to become more active in the community.

5.2 Social Background and Requirements

The classical theory of social influence states that people that belong to a group, when they are required to make a decision or judgment, or to build a theory about some phenomenon, they take into consideration all the available information mainly social information coming from other relevant members of the group.

People actively seek information about the opinions of others in order to evaluate how they compare and to correctly form their own attitudes and behavior. Social comparison most often occur when people lack objective means for evaluation, being in a state of uncertainty about what they should be thinking or doing. In addition the effects of social comparison are especially evident if people compare themselves to individuals who can be considered somehow similar to them. As a consequence, people who are new to a certain context or are not an expert of certain domain should be interested in topics which reflect the opinions of other individuals in the network, since such opinions represent useful information for them to form their own point of view.

Social facilitation occurs when people are encouraged in performing a certain target behavior as a consequence of the physical or virtual company of other people. Social facilitation dynamics can influence the level of motivation, involvement, frequency and effectiveness. As a consequence, people who are interested in a certain topic but lack strong motivation should appreciate information showing that other people in their network share their interest, since this encourages and motivates them.

There are certain requirements that need to be considered for a system that wants to achieve strong acceptance among citizens. According to (Pérez et al., 2006) the characteristics all citizen participation systems should hold are the following.

- **Digital stratification must be confronted:** Though there are fresh government initiatives daily backing the introduction of computers across demographics, there still exists a high percentage of the population which is information technology (IT) illiterate. Particularly for these people, it is essential that citizen participation systems are simple and easy to use.

- **The issues under discussion must be close to the participants' concerns:** On this point, participation systems orientated to local issues have proved very attractive for local communities.
- **Commitment by the relevant authorities:** There must be a commitment that the conclusions arising from a debate are taken into account in a final decision. It has been found that one of the most negative aspects affecting the success of a given forum is that opinions offered hold merely testimonial value or that mechanisms have not been clearly defined to transmit these opinions to the pertinent bodies. The promises and expectations generated by the process must be respected and fulfilled if citizen participation is intended to grow.
- **Open to the community:** The system should enable citizens to share their point of view and give arguments about it, therefore it has to be a simple way to communicate between users just by sharing intangible social capital such as intelligence, information or culture. It should ensure freedom of speech, whereby all users of the platform can express themselves with no fear of reprisals in the present or in the future.
- **Equal opportunities for every participant:** It is a reality that not every person has equal access to online communities; the digital divide is a serious barrier. It is necessary to avoid this situation and improve the current opportunities for every participant.

5.3 Deployment of the System

The system proposed in this project would allow citizens to participate directly in a community that constantly evaluates every contribution and emphasizes the important issues and those that represent the agreement of a majority of the participants. To do so, the system will make use of several characteristics of what has been identified as ‘Web 2.0’ The most important characteristics are the ones related to social software, that is, software that enables people to interact, form online communities and collaborate using computer-mediated communication.

The popularity of social networking sites can be partly attributed to the human desire to identify with a larger group and the need to be connected to people (Nail and MacDonald, 2000). People conform within a group because of a desire to be socially accepted, a desire to align with similar individuals, and a desire to avoid rejection and conflict.

The recent proliferation of online social networking systems such as Facebook, Dodgeball and MySpace, has made significant changes in the way people relate. This expansion has even reached many political figures. A clear example is the fact that many of them are already part of massive social networks. If this new phenomenon is getting stronger by the day, it seems like information technology could enable citizens to provide substantial input into government decision through an active collaboration of the citizens of a determined community.

Using a well-known social network will bring the advantage of a quick mass distribution due to the already existing billions of connections between its users. So instead of creating a new site that would allow friends and acquaintances to collaborate in politics and citizen participation issues, which would have difficulty attracting initial users, we chose to build our system into the popular social network Facebook.com.

The application will have access to social information making an application more engaging by using social information and by taking social actions, all available through the APIs provided by the Facebook social network.

Facebook applications work as described in Figure 5-1. A user of the system adds the application and makes a request through the virtual address of the application on Facebook's server. Facebook.com receives the request and then looks up to into the URL of our local server. Our server will receive the request and process it like any normal request and returns it back to the Facebook server. Facebook finally builds a response that is made of a markup language understood by the social network, in this case Facebook Markup Language (FBML). Facebook then incorporates FBML onto the content of our application and returns the result back to the user. This is how Facebook keeps a consistent look and feel and makes things simple for application users.

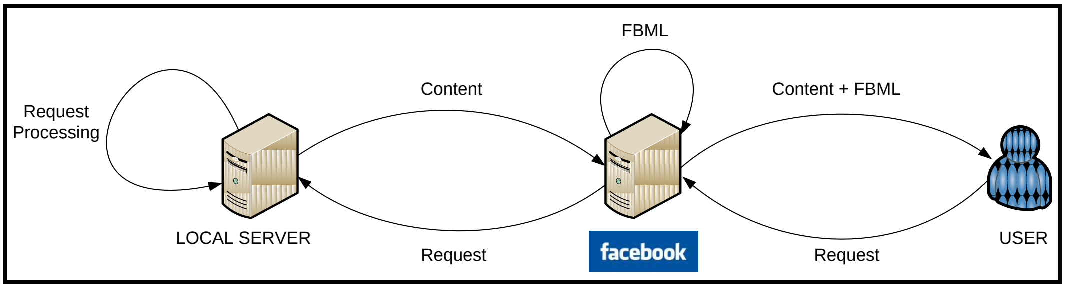

Figure 5-1: Diagram of the functioning of Facebook applications

The proposed system was implemented in the Student Center of the Faculty of Engineering of Universidad Católica de Chile using the well-known social network Facebook. Such implementation offers a participation platform for students as it permits them to express their concerns and ideas and allows others to vote or comment about them. The previously described model was applied in order to determine the improvement of trust among peers.

In the existing application developed for the student center CAI named Participa CAI (http://apps.facebook.com/participacai), the possible actions for a user to do in the system are the following:

- **Comment:** Used to calculate the contribution percentage for the participating reputation.
    - Comment an idea
    - Comment in the forum

- **Vote:** Used to calculate the contribution percentage for the participating reputation.
    - Vote for an Idea
    - Vote for a comment of an idea

- **Propose:** Used to calculate the contribution percentage for the leadership reputation.
    - Propose an idea
    - Propose a topic in the forum

- **Visit the application:** Used to obtain the residential time to calculate the activity level.

To calculate the global reputation of a user, also denoted as trust level, we have used the proposed metric with the parameters we were able to gather from the application in the following way:

- Participating Reputation:

$$R_P(a) = \beta_{CI} C_{CI}^P(a) + \beta_{CF} C_{CF}^P(a) + \beta_{VI} C_{VI}^P(a) + \beta_{VC} C_{VC}^P(a) \qquad (2.7)$$

Where $C_{CI}^P(a)$ is the participating reputation for commenting ideas

$C_{CF}^P(a)$ is the participating reputation for commenting in the forum

$C_{VI}^P(a)$ is the participating reputation for voting for ideas

$C_{VC}^P(a)$ is the participating reputation for voting for comments of ideas

- Leadership Reputation:

$$R_L(a) = \delta_{PI} C_{PI}^L(a) + \delta_{PT} C_{PT}^L(a) \qquad (2.8)$$

Where $C_{PI}^L(a)$ is the leadership reputation for proposing ideas

$C_{PT}^L(a)$ is the leadership reputation for proposing topics

- Past Qualifications:

A user can qualify another user in two ways, both stored in the same way according to the previous description, by:

  - Rating his/her ideas
  - Rating his/her comments.

The idea of this early version of a trust-based information system was to provide feedback for a future expansion to a larger scale. In global terms, the scale being targeted is a municipality level, but ideally such a system should work considering the whole world population.

Figure 5-2 shows the evolution of trust for several users. Initially all users begin with the same trust value. Their behavior in the system and the qualifications assigned by others determines the progress of their trust. User 1 has an increasing participation and leadership reputation as well as a good reputation among other peers; therefore his level of trust increases significantly over time. User 2 presents a decreasing participating reputation but an incremental leadership and a high reputation. Finally User 3 has a poor participation in the system and is not well qualified by others for that reason it presents a decreasing trust value as time passes by.

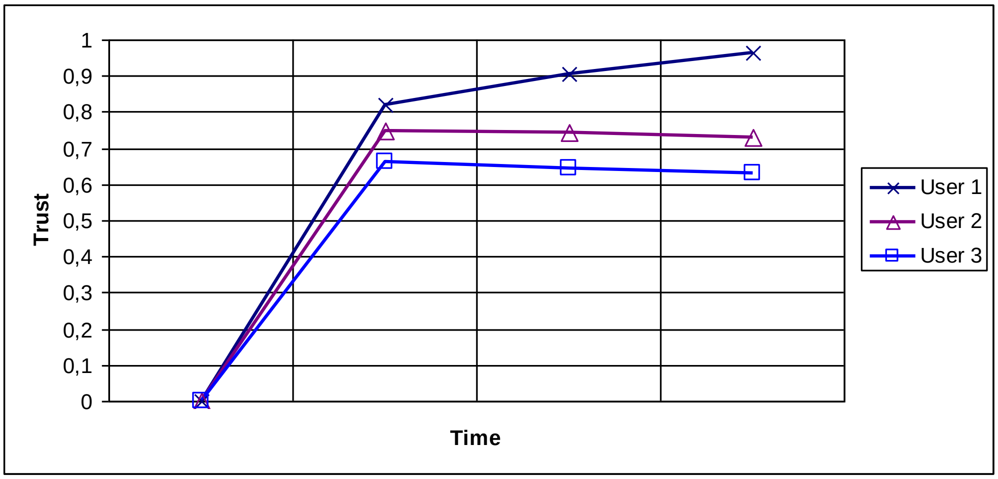

Figure 5-2: Evolution of trust for different users

The level of trust was finally normalized to keep the values between zero and one in order to simplify the visualization of the data.

5.4 Analysis and Future Work

For a collaborative system based on reputation for wide-scale public participation to work it has to face the barrier of digital divide. The goal of using IT in politics is to enable a better democracy, to improve current situations and avoid opening the door to new problems that play against that goal. Current situations that make the system unfair is that the more resources a person has, the more she can influence the political system to follow her agenda. The same can and does happen in systems that are based on IT if we take no precautions to avoid it.

One of the propositions of a system like this is to improve the democratic system in some way. This means to provide better opportunities for everybody to participate, and their opinions or suggestions to be heard when they have merit. But when we limit this system to participation among people that have access to the Internet, this would also restrict the opportunities and worsen the situation rather than improving it (Zuckerman, 2006).

We have to make sure that the access to participation does not get worse by introducing changes, and specially in a country like Chile, with very pronounced income inequalities, this is a very sensible area. This reflects a problem that is difficult to overcome, and it has to be considered when evaluating the importance of a system that needs internet access in order to participate.

Municipal government is precisely an area that could reduce the problem of digital divide. Many municipalities are well concerned on stimulating the participation of its habitants.

As this work aims to improve the current situation and allow a fair access to every interested citizen in participating in the relevant topics, the access to the information has to be addressed. Therefore, this work considers the future preparation of several instances that promote active participation using several channels. The preparation of access to participate using the proposed system needs an infrastructure that can be provided through several possible ways, mainly through *infocentros* that are nationwide coordinated public access community internet centers.

However, the infrastructure alone might not be enough to assure active participation. It is necessary to provide some assistance to ignite the active use of the system, especially among people that do not use Internet technology on a daily base. The effort on behalf of this project is to prepare the instructors that will provide support to the end users. They need to understand the system, how it works and what is expected on behalf of the users so that their participation is as long-term as possible. It is necessary that the users understand that they can use the system not only to send suggestions and reports, but also to obtain feedback on what happens with their participation.

An information system like the one proposed has to face several security challenges, because of people trying to manipulate the results in their favor using fraudulent means. As any other system where strong personal interests can conflict, there will be incentives to commit fraud that would benefit some of the participants. The system should be able to avoid the negative impact of those attempts and therefore one of the fundamental tasks early on in the implementation is to detect and avoid the possible mechanisms that could be used to commit fraud. Digital signatures have already been discussed as a way to provide not only transparency, but tamper-proof transparency, so that nobody can undetectably modify data or software after it has been released. The system has to be robust enough to avoid the manipulation of results on behalf of a reduced set of interests.

Systems of digital democracy are still in a period of maturation, both from the technological point of view and from a functional, social one. In this first phase, digital democracy must be brought to the citizens through the design of attractive systems that are easy to use and which arouse their interest. Moreover, public authorities must lose their suspicion of systems of digital democracy, for these constitute the most direct form of control by citizens over decisions affecting them, and instead lend full support to their use in decision-making processes.

As for future work it would be very interesting to extend the model with a common syntax for the participative budget environment such as Democracy Interaction Language (DemIL) syntax (Maciel and Garcia, 2006), which establishes the primitive of communication among a participative process by allowing a structured dialog between citizen and government. The main advantage of using this type of model is that it maps all contents provided by a government into a simple language accepted by citizens.

6 CONCLUSIONS

Trust and reputation systems represent a significant trend in decision support for Internet mediated service provision. The basic idea is to let parties rate each other in order to assist them in deciding whether or not to transact with that party in the future. Reputation systems can be called collaborative sanctioning systems to reflect their collaborative nature because they help to deal with the problem of knowing who to trust over the Internet.

Reputation systems are already being used in successful commercial online applications nevertheless it has not been adequately implemented in the two scenarios proposed in this work: improving the routing protocol of a mobile ad hoc network and a framework used for politics in order to assist citizen participation.

This work reflects the behavior of a node in two particular systems and the way this behavior contributes in its trust value. Existing reputation metrics only consider the qualifications from other users but our proposal includes a weighting of the rates as well as the recent level of participation of the node. The evolution of trust for different users was analyzed according to the proposed metric and from simulation we can conclude that the recent activity level of a node and the use of ratings from other participants about past transactions is a high-quality reputation metric. A direct result from both systems is the fact that nodes with high level of trust are comparatively better nodes.

In the described proposal we have aimed to reach the desired characteristics for reputation systems described in section 2.3.3. Entities are long-lived in both application cases conceived by the use of a unique identifier for the nodes, using a IP or MAC for the wireless scenario and by a login access in the citizen participation application. The feedback of current interactions is being captured and distributed by the reputation system and such information becomes available to be used as guidelines for future interactions.

The first application case is the use of a reputation system for wireless networks, more specifically for mobile ad hoc networks. In this work we presented a secure reputation-based protocol that selects paths along nodes with a higher reliability expressed by its reputation and higher signal integrity using the connection score and the reputation of the nodes. The model presented uses a symmetric key distribution scheme between nodes easily implemented due to its low complexity in comparison with other algorithms. The proposed algorithm identifies an appropriate routing path including nodes with high reliability in the system; therefore nodes with lower trustworthiness are not selected in the routing path and eventually will be segregated from network operations. This leads to smaller error ratios in the transmission of messages as well as an improved reliability of the chosen paths depending in the characteristic of the channel. A direct consequence is an increased security and effectively in the network in the exchange of packages.

In the second application case we presented another use for reputation systems, in this case for citizen participation. The purpose of this system was to identify the users with high level of trust because they will eventually come up with good ideas that could be used as part of future policies in the world of politics.

When referring to citizen participation a trust-based system built over a well-known social network brings a great opportunity to participate for all interested users as well as an opportunity to identify high-quality users whom may become the leaders for tomorrow. A prototype of the idea was developed in the student center of the Engineering School at Pontificia Universidad Católica de Chile over the popular social network Facebook with very successful results in terms of the acceptance among the students and the representation of the user's trustworthiness through the proposed reputation metric. In this application case the trust of a user depends on his level of participation, his leadership ability and also on ratings from others.

As a conclusion we can say that it is feasible to have collaborative systems based on the concept of trust and reputation that can help improving the trustworthiness and reliability of its users, as proven through the two presented application cases.

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APPENDIXES

APPENDIX A : SCREENSHOT OF APPLICATION

APPENDIX B : GLOSSARY

BER	**Bit Error Ratio.** The number of erroneous bits received divided by the total number of bits transmitted.
FBML	**Facebook Markup Language.** A variant-evolved subset of HTML that allows Facebook application developers to customize their applications so that Facebook's servers can read and publish it.
IP	**Internet Protocol.** A protocol used for communicating data across the Internet using the Internet Protocol Suite, also referred to as TCP/IP.
MAC	**Media Access Control address** (MAC address). A unique identifier assigned to most network adapters or network interface cards by the manufacturer for identification.
MANET	M**obile Ad Hoc Network.** A self-configuring network of mobile devices connected by wireless links.
SNR	**Signal-To-Noise Ratio.** A measurement defined as the ratio of a signal power to the noise power corrupting the signal. The higher the ratio, the less obtrusive the background noise is.

APPENDIX C : ACCEPTANCE EMAIL

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asunto	JCIS090949 Manuscript Submission (Acknowledgement)

Dear Dr. Ana Fernandez Ontiveros,

Thank you for submitting your manuscript JCIS090949 entitled "A New Collaborative Strategy Based on Trust and Reputation" to the *Journal of Computer Information Systems (JCIS)*. Please be advised to print this acknowledgement as a back-up hard copy.

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