Virtual Currency and Reputation-Based Cooperation Incentives in User-Centric Networks

A. Bogliolo, P. Polidori, A. Aldini
University of Urbino - Italy

W. Moreira, P. Mendes
SITI, University Lusofona
Lisboa - Portugal

M. Yildiz
Technical University of Berlin - Germany

C. Ballester, J.-M. Seigneur
University of Geneva - Switzerland

Abstract—Cooperation incentives are essential in user-centric networks to motivate users to share services and resources (including bandwidth, computational power, and storage space) and to avoid selfish nodes to hinder the functioning of the entire system. Virtual currency and reputation mechanisms are commonly adopted in online communities to boost participation, but their joint application has not been deeply explored, especially in the context of wireless communities, where not only the services, but even the enabling infrastructure is opportunistically built by community members. This paper investigates the combined use of virtual currency and reputation-based incentives in the specific context of a community of users with Wi-Fi enabled devices capable of establishing ad-hoc connections.

Keywords – User-centric network; Virtual currency, Trust; Reputation; Reward; Cooperation incentive.

I. INTRODUCTION

User centricity has become one of the main driving factors of the Internet value chain. Users are more and more involved in the provision of contents, applications, and services, rather than just being the recipients of those made available by established providers. The success of the Internet would not be the same without user-generated contents and user-provided services. As a matter of fact, individuals increasingly rely on other individuals’ willingness to cooperate. In spite of the widespread cooperative attitude that has determined the success of online social networks, content sharing systems, and peer-to-peer applications, the willingness to cooperate cannot be taken for granted in terms of sharing network functionality. In fact, nodes are usually constrained in terms of bandwidth, energy, and computation, and they may incur into operational costs that might keep them from sharing potentially limited resources. Since the presence of selfish nodes, which refuse to be cooperative, might impair the functioning of the entire network, cooperation incentives play a key role in user-centric architectures.

For instance, the lack of a mass deployment of ad-hoc networks may possibly be due to the fact that entities managing different networks lack clear incentives to participate in the creation of ad-hoc wireless networks. The result of this is actually the rise of simpler and more autonomic wireless architectures, mesh networks, in which all devices are static and normally belong to the same administrative entity.

In despite of the aforementioned aspects, a recent trend related to autonomic wireless architectures is giving rise to wireless community initiatives with the purpose to provide broader connectivity. In this type of architectures, called user-centric networks (UCNs), users, individuals or communities, share subscribed Internet access and network resources in exchange of specific incentives from a social, economic, and also technical viewpoint [1,2].

Individuals’ motivation to be cooperative can be broadly classified into intrinsic and extrinsic [3]. The first category includes fairness [4], sense of community, synergy, and personal interests matching public interests. Whenever intrinsic motivation is not enough, cooperation incentives are required to provide additional extrinsic motivation, which can be viewed as a reward capable of realigning individuals’ utility to public utility. There are three forms of rewards that can be considered: reputation, which enhances the status of a cooperative individual in a group; reciprocity, describing the evolution of cooperative behaviors influenced by the probability of future mutual interactions; and monetization, which entails the quantification of the value of pro-social decisions. Virtual currency is often adopted in online communities both to support monetization, and to provide a guarantee of reciprocity (reducing the risk of betrayal which could keep people from taking pro-social decisions). As for reputation, it is the result of social evaluation that affects trust in community members. Reputation can either emerge spontaneously from social interactions, or be formally defined and managed according to specific community rules. This latter is the case of wireless communities implementing trust-management mechanisms.

This paper presents a cooperation incentives framework for UCNs, which is based on the joint application of trust-management and virtual currency mechanisms. The proposed framework is currently under consideration for being adopted within the ULOOP project [5].

The rest of the paper is organized as follows: Section II provides a survey of background concepts and previous work on reputation-based cooperation incentives and virtual currency; Section III outlines the proposed cooperation incentives framework; Section IV discusses implementation issues and draws conclusions.

II. BACKGROUND AND PREVIOUS WORK

A. Trust and Reputation

The trust value computed by an entity (truster) referring to
another entity (trustee) provides a digital representation of the trustworthiness of the trustee for the truster, which is, in other words, the level of trust of the truster on the trustee. Trust is affected by direct observations, recommendations, and reputation.

Whereas trust can be seen as a private value that the truster might not want to share with the rest of the community, reputation can be seen as the “public trustworthiness” of a community member and it usually encompasses the aggregation of individual trust values computed by many trusters for the same trustee.

A computational model of trust was first proposed by Marsh [6]. In social research there are three main types of trust: interpersonal trust, based on past interactions with the trustee; dispositional trust, which accounts for truster’s general disposition towards trust, independently of the trustee; and system trust, provided by external means such as insurance or law.

Computational trust and reputation systems can be either centralized or distributed. In centralized mechanisms, ratings from direct interactions are provided to a central node which acts as a trusted authority who stores the computed trust values and derives a global reputation metric for each of the participants in the system, making it publicly available. In distributed mechanisms there are no central authorities to collect ratings or compute reputation levels, so that ratings are either stored in distributed storage systems or privately kept by each participating node as a result of its direct experience. Reputation values are then individually computed at each node based only on the previous experience of that particular node, on the data possibly available from distributed storage systems, and on the recommendations coming from other nodes.

Both centralized and distributed systems can be affected by many issues [7], including: little motivation of community members to provide the feedback required to compute trust and reputation metrics, biased/unfair ratings, identity-related vulnerabilities, variation of metrics over time, and discrimination. Trust management is particularly challenging in distributed and mobile environments, the dynamic nature of which results in uncertainty and incompleteness of the trust evidence [8].

Reputation can act as an incentive in UCNs as long as it represents an enabling condition for taking part in some kind of group activity, for providing some kind of service, or for taking advantage of some others. Although reputation cannot be traded for money, a trusted community node is more likely to be involved in remunerative tasks. On the other hand, associating tangible effects to reputation can motivate community members to take part in the trust-management system and provide their feedback.

B. Virtual currency

Virtual currency was first introduced in online games and social networks as a mean to buy and sell virtual goods without making use of real money, thus avoiding security issues, taxation, and mistrust. With the pervasive success of social media and the loss of clear boundaries between real and virtual worlds, virtual currency has become one of the key revenue driver of the Internet [9].

Virtual currency systems are subject to many requirements (including transferability, anonymity, usability, and scalability) and exposed to many issues (including forgery, double spending, cheating, and speculation) which make them hard to implement.

Existing solutions can be broadly classified into centralized and distributed systems. Centralized systems rely on a trusted third party (TTP) which acts as a bank. In online systems, the TTP is directly involved in any transaction and it provides a real-time guarantee to the merchant. In offline systems, on the contrary, the merchant accepts payments from the user without interacting with the bank and deposits them later on. Offline systems work as long as the merchant is guaranteed that the TTP will either accept the deposit or be able to identify and punish the cheating user. Distributed systems, on the contrary, do without centralized TTP and rely on peers to protect merchants from cheating. Regardless of their nature, all virtual currency systems exploit to some extent cryptography, which is used to avoid forgery, to identify cheating users, to guarantee anonymity, or to enable traceability (see, e.g., [10] and the references therein).

In the last decade virtual currency has been often adopted as a cooperation incentive framework in ad-hoc networks [11]. Distributed and offline virtual currency systems are the most suited to be applied to UCNs and peer-to-peer networks. Bitcoin [12], Nuglets [11], and WhoPay [13] are representative examples.

C. Hybrid incentive mechanisms

Combining economical and trust-based incentive mechanisms is an attractive perspective in that, in principle, it provides the opportunity of exploiting their complementary strengths to overcome their weaknesses. Although no general frameworks have been proposed encompassing both mechanisms, several pioneering approaches are worth being mentioned.

In 2002 Seigneur et al. [14] proposed to use trust directly as a digital money, called Trustos, to be managed by a ubiquitous brokering system in charge of determining the value of each service/resource. Yang et al. [15] used a trust-management system to give priority and premium services to users with high reputation, while Fernandes et al. [16] introduced economical incentives to motivate users to provide the feedback needed to set up the trust infrastructure. Such incentives are given in terms of rewards that can be spent to get a discount on future service requests, while there is no way to cash them. Finally, Zhang et al. [17] presented a collaborative system merging trust and economical incentive mechanisms. Peers providing the same type of service are grouped into a club, within which the price for the service is first determined by the club on the basis of classical competition models, and then adjusted on the basis of the trust of the club on the peer requesting the service.

In this paper we propose a general framework which combines full-fledged trust-management mechanisms and
virtual currency systems to build a comprehensive incentive mechanism specifically tailored to UCNs.

III. COOPERATION INCENTIVE FRAMEWORK

Reputation, reciprocity, and monetization are the pillars of the proposed cooperation infrastructure, in that they act as cooperation incentives and motivate community members to adopt pro-social behavior.

In the proposed framework the three pillars are implemented by means of two complementary and orthogonal mechanisms: trust-management and virtual currency. In particular, trust-management provides indirect rewards by enabling a rigorous definition of reputation as a metric positively affected by pro-social behaviors and positively affecting the opportunity of benefiting from the community, while virtual currency provides a direct reward mechanism which can be used to motivate cooperation even in absence of reciprocity, possibly enabling monetization of pro-social behavior.

The application of the cooperation framework to UCNs raises specific challenges coming from the fact that: i) even the communication infrastructure depends on cooperation among community members, ii) UCNs can be used to extend third-party services, including Internet access, iii) local community islands can sprout at any time possibly involving people without previous/stable relationships.

Four main driving principles have been adopted to combine direct and indirect rewards: i) trust can affect individual decisions and opportunities; ii) trust cannot be traded for virtual currency or money; iii) virtual currency is a commodity money mainly used to facilitate cooperation among community members; iv) virtual currency can be traded for fiat money at the only purpose of allowing the community to benefit from third-party services and to provide services to non-member end-users.

In the following we refer to a four-phase cooperation process which can be outlined as follows:

1. **Discovery and request.** In this phase a user, hereafter called *requester*, looks for a member sharing/providing the required service/resource, hereafter called *requestee*. Then, the requester issues a request, which is processed by the requestee who can either refuse the request because of the lack of resources or willingness to cooperate, or enter the negotiation phase.

2. **Negotiation.** The negotiation phase is aimed at finding an agreement between requester and requestee in terms of service level and reward, possibly taking into account the trust of the requestee on the requester.

3. **Transaction.** This phase encompasses both the provision/sharing of the service/resource and the payment of the reward in terms of virtual currency (where applicable).

4. **Evaluation and feedback.** In this phase the requester compares the negotiated quality of service with the perceived quality of experience and (possibly) provides a feedback affecting the reputation of the requestee. Similarly, the requestee provides a feedback on the behavior of the requester.

In case of a cooperation process involving more than two peers because of the lack of a direct link between the requester and the provider of a given service/resource, request and negotiation phases need to be applied at each hop.

Two different approaches can be envisioned to implement such a multi-hop cooperation process. In the first case, which is *iterative* in nature, relaying is explicitly considered as a service which is negotiated in its turn. The requester who does not find any provider in his/her neighborhood asks for a relaying node. Once relaying services have been negotiated, they are used to extend the region where to search for a provider and to conduct service negotiation. In the second case, which is *recursive* in nature, requests are transparently forwarded by each node until an available provider is found or a timeout elapses. The requester always interacts with the first hop as if it was the provider of the service, but negotiation takes into account all the conditions (in terms of trust and rewards) imposed by the relaying nodes and by the actual provider.

Discussing the technical issues related to multi-hop transactions is beyond the scope of the paper. Without loss of generality, in the following we focus on the cooperation incentives to be applied at each step.

A. Indirect rewards based on trust management

The success of any cooperative infrastructure depends on the willingness of users to share resources, which represents a key factor for the success of UCNs. While it is commonly recognized that in order to encourage resource sharing a reputation system is needed, here we emphasize that cooperation incentives based on trust represent a reward capable of building a reliable reputation system. In particular, in this subsection we discuss indirect incentives referring to the four phases of the cooperation process. We point out that the proposed incentives work independently of the underlying reputation infrastructure, which either can be based on centralized public repositories collecting all the information needed to estimate each node reputation, or can be completely distributed among the nodes, who compute reputation on the basis of direct observations and of recommendations from their neighbouring nodes.

Within the first phase, reputation (of the requestee) can represent an incentive whenever the topological organization of the network structure assigns a more important position to nodes with higher reputation. In particular, the list of potential requestees available to negotiate a request should be provided/considered in descending order with respect to the related reputation and the choice of the requester can be driven by his/her trust on the candidate requestees. Hence, high reputation helps to achieve more preferences and, possibly, to increase the reputation itself. This strategy is effective especially whenever combined with direct incentives that allow the requestee to receive a reward for the delivered service: the higher the reputation the higher the earning opportunities.

On the other hand, trust on the requester is a key factor
during the second and third phases. Firstly, the quality of service that is negotiated (e.g., amount of bandwidth, CPU, storage) could be parameterized to be proportional to requester's reputation. In its simplest version, trust thresholds can be applied to ensure access to the requested service in a binary way, i.e., a given service is available only for trust metrics higher than a certain threshold. In a more complex setting where services have a cost, the level of trust could represent a variable contributing to the calculation of such a cost, as discussed more in detail in the following subsections. Secondly, multiple transactions (that are negotiated by different peers with the same requestee) competing for the same resource should be queued based on a priority that depends on peer's reputation. In these cases, high reputation represents an enabling condition to access better services within stricter deadlines.

Finally, the fourth phase is fundamental to make the whole reputation system reliable. In fact, explicit and/or implicit mechanisms for evaluation of services have an impact over the quality of the information used to estimate the reputation gain/loss after a transaction. Explicit mechanisms involve the direct participation of the requestor who might be asked to vote explicitly the quality of the received service. Implicit mechanisms are based on transparent evaluation systems that compare the result of the transaction with the negotiated parameters. In any case, the result of the application of such mechanisms represents a feedback that affects both future local recommendations provided by the requester and the global reputation of the requestee stored in public repositories. Note that whenever such repositories are available, the provision of (honest) feedback is worth receiving a reward in its turn (e.g., in terms of reputation), as shown in literature [15,16]. The same benefits can be obtained in a distributed reputation system by rewarding (honest) recommendations in terms of reputation gain that the requester locally assigns to the recommender. The lack of feedback could also affect reputation.

**B. Direct rewards based on virtual currency**

Sometimes, UCNs and the kind of services they provide are such that reputation is not perceived as a sufficient motivating incentive. As an example, this is the case whenever the reputation infrastructure is distributed and nodes do not have a long-term presence in the system, which is highly dynamic in such a way that the frequent renewal of the nodes set does not allow a stable and reliable distributed reputation infrastructure to be established. Such a scenario encourages cheating and selfish behaviors, which could be profitable in a single, isolated transaction, while typically they are not convenient in continuous trading relations strengthened by an effective reputation infrastructure.

Direct rewards are the instrument adopted to overcome the weaknesses of reputation-based incentives by leveraging the "propensity to truck, barter and exchange one thing for another" which Adam Smith recognized to be peculiar of human beings [18]. Individual's propensity to barter is a cooperation incentive by itself, but it assumes that the services/resources are easily exchangeable, that their values are well recognized, and that there are community members with complementary needs. Such a perfect reciprocity is hard to find in practice.

Historically, the lack of reciprocity prompted for the introduction of a widespread intermediate commodity to be used as a store-of-value. The so-called commodity money overcame the limitations of barter, making the market of any other commodity more liquid. Nowadays fiat money retains the key features of commodity money, but raises additional issues (including security, mistrust, taxation, speculation) which make it unsuitable to be directly used to provide cooperation incentives in UCNs.

The virtual currency system outlined in this section provides a framework for handling credits which play the role of commodity money to provide direct rewards without making use of real money.

A given amount of credits is assigned to each new member as soon as he/she joins the UCN community. To avoid inflation, in our framework the amount of credits awarded to each new member conventionally corresponds to the incremental value brought to the community by any member because of positive externalities and network effects.

Referring to our 4-phase cooperation process, credits are directly involved in negotiation and transaction. During negotiation, credits are used by the requestee to express the cost of the service/resource he/she provides. The negotiation phase is positively concluded if and only if an agreement is found both in terms of service level and in terms of credits between requester and requestee, taking into account mutual trust as outlined in previous subsection and further discussed in the following one.

During transaction, the requestee provides the negotiated service/resource, while the requester pays the negotiated amount of credits. Notice that, in this phase, payment and service provision are not conditioned to each other. Rather, both the requester and the requestee are bound to the negotiated terms. The non-observance of the agreement possibly made by one of the peers does not authorize the other to do as much. This lack of control facilitates transactions, while the risk of abuses is mitigated both by the final evaluation, which will affect reputation in case of misbehavior, and by the small granularity of atomic transactions, which makes the risk of each of them almost negligible for the parties.

The virtual currency system described so far is closed, in that credits are not exchangeable with fiat money. Moreover, credits cannot be purchased, but they need to be earned by providing services/resources to other community members. This closure avoids speculation and motivates cooperation.

Exchangeable credits are needed, however, in order to make it possible for a UCN to become part of the Internet value chain by taking advantage of third-party services and by providing services to non-member end-users. Consider, for instance, the typical case of a wireless community which extends the Wi-Fi coverage of the Internet access infrastructure provided by an established operator. Consider an external end-user (hereafter called End-user) which exploits the relaying service made available by community members to reach the Internet gateway of the operator (hereafter called Provider).
Assuming that credits are used at each hop to reward the players involved, the credits corresponding to the overall cost of the multi-hop transaction have to be paid by the End-user, while part of them have to be transferred to the Provider. If neither the End-user nor the Provider are community members, there is no way for the End-user to get the required amount of credits, while credits have no value for the Provider. This motivates the introduction of a credit-exchange mechanism to be used at the boundaries of the UCN to allow the Provider to sell the credits he/she earned, and to allow the End-user to buy the credits he/she wants to use. In both cases, credits are traded for fiat money. We call this process monetization.

Once a credit exchange system is introduced, it cannot be restricted to non-members for two main reasons: first, because the monetization perspective could encourage UCN members to leave the community as soon as they have been awarded with the starting amount of credits; second, because the amount of credits offered by external Providers would be insufficient to satisfy End-users’ demand due to the overhead of the relaying services provided by UCN members. Referring to the above example, in fact, the amount of credits spent by End-user is larger than the amount of credits earned by Provider.

To solve these issues, the credit exchange system is open to anybody, regardless of the membership. To avoid speculation and to encourage cooperation in spite of the monetization perspective, credits need to be used to buy services/resources before being offered in the credit exchange market. This makes it impossible for anybody to speculate by buying credits at the only purpose of selling them at a higher price. The credits bought on the market are unmonetizable, and they become monetizable only after the first transaction. Monetizable credits are converted into unmonetizable ones whenever they are traded on the exchange market.

C. Combining direct and indirect rewards

Intertwining direct and indirect incentives entails including trust as a parameter affecting the cost of the negotiated service (see phase 2) and, vice versa, considering such a cost as an aspect that contributes to the final evaluation (see phase 4).

Previous approaches to hybrid cooperation incentives proposed to adjust the cost by taking into account trust as an additional parameter, as shown, for instance, by the following equation [17]:

\[
\text{Cost} = \alpha \cdot \text{bid} + (1 - \alpha) \cdot \text{trust}
\]

where \(\alpha\) in [0,1] is a risk factor, \(\text{bid}\) represents the cost established by following usual marketplace policies based on bidding, and \(\text{trust}\) is the cost associated with the trust level.

More in general, we assume that the trust level is a variable \((T)\) to be put in relation with the cost variable \((C)\). Such a relation is described by a curve which can be adapted to each category of services by tuning the following parameters: \(C_{\min}\), which is the minimum reward (cost) asked by the requestee regardless of his/her trust on the requester, \(C_{\max}\), which is the maximum reward asked to serve untrusted users, and \(T_{th}\), which is the trust threshold above which the minimum cost is applied to the requester. In the proposed framework, both the behavior of the cost-trust curve and the value of \(T_{th}\) are imposed to all community members, in order to be used as tuning parameters to adjust the behavior of the community as a whole, while \(C_{\max}\) and \(C_{\min}\) can be set by any member and for each category of service (e.g., relaying, information sharing, …). The simplest curve that can adopted is a piece-wise-linear function described by the following equation:

\[
C(T) = \begin{cases} 
C_{\min} + \frac{C_{\max} - C_{\min}}{T_{th}}(T - T_{th}) & \text{if } T < T_{th} \\
C_{\min} & \text{if } T \geq T_{th}
\end{cases}
\]

where \(C\) is the cost in terms of credits and \(T\) is the trust of the requestee on the requester. Notice however that this equation might induce an undesired effect, which is the unfair underestimation of trust due to the avidity of the requestee. In fact, the higher the trust the lower the direct reward obtained by the requestee. To avoid this effect, the value of \(T\) used as independent variable in the computation of \(C\) could be limited to the component of the trust metric which accounts for community-scale evidence of requester’s reputation.

Finally, direct rewards interact with indirect rewards in phase 4. In fact, the amount of credits paid by the requester inherently affects his/her evaluation of the transaction (which ultimately affects requestee’s reputation) because of the higher expectation that is always associated with a higher price, beyond the service level officially agreed during negotiation. Moreover, a higher price induces the requester to be less indulgent with the requestee in case of accidental service degradation.

IV. DISCUSSION AND CONCLUSIONS

The dynamic nature of UCNs makes them unsuitable to adopt centralized trust management and virtual currency systems relying on online trusted authorities. In fact, the cooperation incentive framework presented in this paper has to work in a distributed environment with intermittent connectivity. Although a thorough discussion of implementation issues and technical solutions goes beyond the scope of this introductory work, some of the issues raised by UCN (such as identity forgery and double spending) are worth being mentioned and briefly discussed.

Without loss of generality in the following we take as an example the UCN architecture which is under development within the ULOOP project [5]. ULOOP is aimed at building an open UCN environment providing seamless connectivity and allowing community members to share services and resources without threatening their own privacy.

In order to deal with the identity-related issues which affect trust-management mechanisms, rather than trying to forbid community members to create multiple virtual identities, a scenario can be envisioned which allows them to create many virtual identities based on crypto-ids [19] and makes use of attack-resistant trust metrics to mitigate the effects of identity forgery and Sybil attacks. In this scenario entities are identified by their crypto-ids, which are the hashes of the public keys of the asymmetric cryptography key-pairs self-generated by community members.
With respect to the reference cooperation process a computational trust management approach [6] can be adopted in phase 1 to allow the requestee to automatically compute a trust level for the virtual identity exposed by the requester. The trust level is based on different types of evidence, including direct observations, recommendations, reputation, and, possibly, data obtained by mining social networks.

If the requestee accepts to enter the negotiation phase, the requester can decide to trade privacy for trust by bringing into play more than one of his/her virtual identities. According to the policy outlined in Section III.c, the aggregate trust value of the identities disclosed by the requester can allow him/her to obtain higher priority, better services, or lower costs. The feedback provided by the requestee in the evaluation phase will then affect the reputation of all requester’s identities involved in the transaction.

As for virtual currency, one of the most common frauds in distributed systems is double spending, which occurs when the same credit is spent twice by the same user. Double-spending detection and prevention techniques are provided, e.g., by Bitcoin [12] and WhoPay [13]. The former is completely distributed, including the coin generation process. Protection against cheating users is provided by publicly announcing each transaction to the neighboring nodes and by involving them in the generation of long chains of digital signatures which grant traceability features to the coins. The latter also ensures anonymity by making transactions traceable only in case of cheating behaviors. Double spending detection is performed during the monetization process, but a form of real-time double spending detection is also performed by each peer on the basis of local information. The virtual currency system envisioned in this paper retains the key features of WhoPay, but it exploits the interoperating trust-management system, which acts as a deterrent for cheating users, to further reduce the computational burden while also improving robustness.

A. Conclusions
UCNs exploit the willingness of the members of a community to share their resources/services in order to increase collective welfare and to extend the reach of existing infrastructures. Wi-Fi communities providing wireless extensions to multi-access networks are a typical example. Cooperation incentives are essential in this context to avoid selfish free-riding nodes to impair the functioning of the entire system.

This paper has presented a cooperation incentive framework which combines direct rewards based on virtual currency with indirect rewards based on trust and reputation management. The benefits of the joint application of these complementary mechanisms have been discussed referring to a general 4-phase cooperation process.

The perspective provided in this paper is work in progress from the authors and is under consideration for being adopted by the ULOOP Consortium [5].

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