PAPER Special Section on New Technologies and their Applications of the Internet III

Reduction Over Time to Facilitate Peer-to-Peer Barter Relationships

Kenji SAITO[†a)], ***Member***, **Eiichi MORINO**[††b)], ***Nonmember***, ***and*** **Jun MURAI**[†††c)], ***Member***

SUMMARY A peer-to-peer complementary currency can be a powerful tool for promoting exchanges and building relationships on the Internet. *i*-WAT [1] is a proposed such currency based on the WAT System [2], a polycentric complementary currency using *WAT tickets* as its media of exchange: participants spontaneously issue and circulate the tickets as needed, whose values are backed up by chains of trust. *i*-WAT implements the tickets electronically by exchanging messages signed in OpenPGP [3]. This paper investigates an extension to the design of *i*-WAT to facilitate mutual help among peers in need. In particular, we investigate additional "reduction" tickets whose values are reduced over time. By deferring redemption of such tickets, the participants can contribute to reduce the debts of the issuers, and the issuers help participants by providing exchange media that accelerate spending. This paper describes in detail how incentive-compatibility is achieved by this extended design; we predict that the following properties will hold, which resulted from a game-theoretical analysis.

1. *Rapid circulation*, or a reduction ticket will typically circulate at high speed until its effective value reaches the scheduled minimum, and
2. *Vanishment equilibrium*, or the system will be most stable if the values of tickets are to be reduced down to zero.

A reference implementation of *i*-WAT has been developed in the form of a plug-in for an XMPP [4], [5] instant messaging client. We have been putting the currency system into practical use, to which the proposed feature has been added.
key words: *P2P, trust, currency, community formation*

1. Introduction

1.1 Peer-to-Peer Complementary Currency

Peer-to-peer (P2P) computing is a new paradigm in distributed computing which can potentially harness the under-utilized computing power of the network of computers connected one another via the Internet.

To share and make use of under-utilized computing resources, proper exchanging is a necessity. Since the resources are distributed over autonomous entities, such exchanging needs to be performed in an *incentive-compatible* [6] way: the coordination must be accomplished by collection of selfish behaviors. A medium of exchange which represents a guaranteed value should take an important role in the design of peer-to-peer systems. For this reason, the study of P2P has recently been leaning closer toward economics, especially in the fields of game theory and mechanism design.

Money is a well-known medium of exchange, but its scarcity has caused a lot of problems. *Complementary currencies*, or alternative forms of monetary media, have been proposed and tested in real life to achieve an autonomous, sustainable local economy even in short of money. There have been successful cases, such as experiments in Wörgl in 1932 (stamp money [7]), in Comox Valley in 1983 (Local Exchange Trading System [8]) and in Ithaca since 1991 (Ithaca HOURs [9]).

Those complementary currencies, being generated closer to the places in need, are used to support values which are not readily circulated in today's economy, such as volunteer works, daily helps and enjoyments, or skills that are not regularly utilized. Translating them onto the Internet would benefit the design of peer-to-peer systems, which are also intended to make use of under-utilized resources. But then, those currencies also need to be peer-to-peer.

We proposed *i*-WAT [1] in year 2003 as such a currency usable on the Internet, based on the WAT System [2]. The WAT System is a system of polycentric complementary currencies using *WAT tickets* as its media of exchange. A WAT ticket is like a bill of exchange, but without a specified redemption date or place. *i*-WAT implements the tickets electronically by exchanging messages signed in OpenPGP [3]. It has been put into practical use since June 2004.

1.2 Reduction Over Time to Accelerate Spending

We believe that there are many important lessons we can learn from the past, real-life experimental currencies, with which we can improve our currency system.

It is known among the practitioners of complementary currencies that reducing the value of the exchange medium over time accelerates spending. The stamp money experiment in Wörgl in 1932 is a well-known example. It was based on the idea of *stamp scrip* introduced by Sylvio Gesell in [10], who believed exchange media must also deteriorate as the exchanged goods do (for this reason, *Reduction Over Time* is dubbed *ROT*).

A user of stamp money needs to paste a stamp every week on the back of the note, or the note becomes invalid.

Manuscript received March 11, 2005.
Manuscript revised June 20, 2005.
[†]The author is with the Graduate School of Media and Governance, Keio University, Fujisawa-shi, 252–8520 Japan.
[††]The author is with the Gesell Research Society Japan, Yokohama-shi, 221–0021 Japan.
[†††]The author is with the Faculty of Environmental Information, Keio University, Fujisawa-shi, 252–8520 Japan.
a) E-mail: ks91@sfc.wide.ad.jp
b) E-mail: morino@grsj.org
c) E-mail: jun@wide.ad.jp
DOI: 10.1093/ietisy/e89–d.1.181

Users are motivated to spend the scrip before another stamp is required. The stamp is like a tax for withholding exchange media; this is a suitable way to implement ROT in a centralized currency system.

If ROT is to be implemented for decentralized currencies, a different approach needs to be taken. In [12], we have applied the notion of *calendar money* by Arthur Dahlberg [11], which has a schedule of reduction printed on the note, to achieve it in our currency system. We proposed the introduction of *reduction* tickets whose values are reduced over time.

1.3 Contributions of This Paper

We have realized that introducing ROT in our currency system has potential effects of not only promoting exchanges, but also providing participants with means to support peers by sharing debts among one another. While this was investigated casually in [12], this paper will discuss it in a more formal manner.

This paper begins by describing WAT/*i*-WAT concisely, as well as the proposed extension to the design of *i*-WAT to realize the above concept. It shows that the extended design is incentive-compatible by a game-theoretical analysis. In particular, we predict that the following properties will hold:

1. *Rapid circulation*
   A *reduction* ticket will typically circulate at high speed until its effective value reaches the scheduled minimum.
2. *Vanishment equilibrium*
   The system will be most stable if the values of tickets are to be reduced down to zero.

2. WAT/*i*-WAT Currency System

2.1 The WAT System

2.1.1 Overview

The WAT System [2] is a complementary currency designed by Eiichi Morino, a coauthor of this paper. It has been used broadly, especially in Japan, since its introduction in August 2000.

WAT tickets, physical sheets of paper resembling bills of exchange, are used as the media of exchange in the system. A lifecycle of a WAT ticket involves three stages of trading as illustrated in Fig. 1:

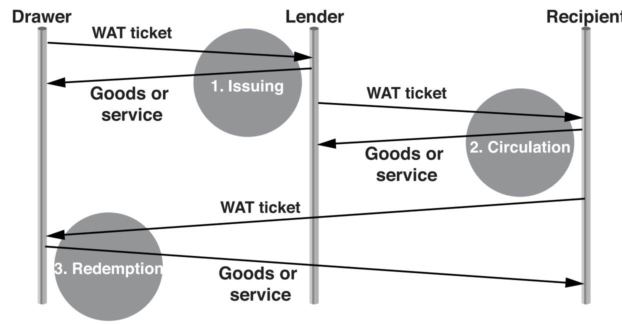


Fig. 1 Three stages of trading with a WAT ticket.

1. Issuing – the birth of a WAT ticket
   A *drawer* issues a WAT ticket by writing on an empty form the name of the provider (*lender*) of the goods or service, the amount of debt[†], the present date, and the drawer's signature. The drawer gives the ticket to the lender, and in return obtains some goods or service.
2. Circulation – ordinary exchange
   The person to whom the WAT ticket was given can become a *user*, and use it for another trading. To do so, the user writes the name of the recipient, as well as their own, on the reverse side of the ticket. The recipient will become a new user, repeating which the WAT ticket circulates among people.
3. Redemption – the return of the WAT ticket
   The WAT ticket is invalidated when it returns, as a result of a trade, to the drawer.

2.1.2 Distinctive Features of the WAT System

(1) Autonomy

Anyone can spontaneously become a member of the WAT System with a sheet of paper if they follow the above protocol.

(2) Compatibility

A WAT ticket is compatible with any other WAT tickets in the world, so that the currency system is operable globally, as long as the drawer can be credited.

(3) Extensibility

The protocol illustrated in Fig. 1 defines *the WAT Core*, the essence of the WAT System. An *extended part* can be defined for a new currency based on the WAT System, stating, for example, the region, group and duration in which the tickets are usable, as well as the unit in which the debt is quantified.

(4) Security

In case the drawer fails to meet their promise on the ticket, the lender assumes the responsibility for the debt. If the lender fails, the next user takes over. The responsibility follows the chain of endorsements. The longer the chain is, the more firmly backed up the ticket is. Therefore the length of the chain of endorsements represents the extent of trust the ticket has gained.

[†]Typically in the unit kWh, which represents cost of producing electricity from natural energy sources.

Table 1 *i*-WAT messages.

message	sender	receiver	function
<draw/>	drawer	recipient (lender)	draws an *i*-WAT ticket.
<use/>	user	recipient	uses an *i*-WAT ticket.
<accept/>	recipient	drawer and user	confirms readiness to accept the *i*-WAT ticket once it is validated.
<reject/>	recipient	drawer or user*	rejects an *i*-WAT ticket.
<approve/>	drawer	user and recipient	validates an *i*-WAT ticket, and approves the transaction.
<disapprove/>	drawer	user and recipient	denies an *i*-WAT transaction.

* depending on whether the ticket has just been issued or in circulation, respectively.

2.2 *i*-WAT: the Internet WAT System

2.2.1 Overview

i-WAT is a translation of the WAT Core onto the Internet. In *i*-WAT, messages signed in OpenPGP (*i-WAT messages*) are used to implement transfers of an electronically represented WAT ticket (*i-WAT ticket*).

An *i*-WAT ticket contains the identification number, amount of debt and public key user IDs of the drawer, users and recipients. Endorsements are realized by nesting PGP signatures.

Table 1 shows the types of *i*-WAT messages. All *i*-WAT messages are signed by the senders, and are formatted in the canonical form [13] of XML [14].

The messages cause state transfers of a ticket as illustrated in Fig. 2.

2.2.2 Changes from the WAT System

Upon translating the WAT Core onto the digital communication domain, we have made the following changes from the state machine of a WAT ticket:

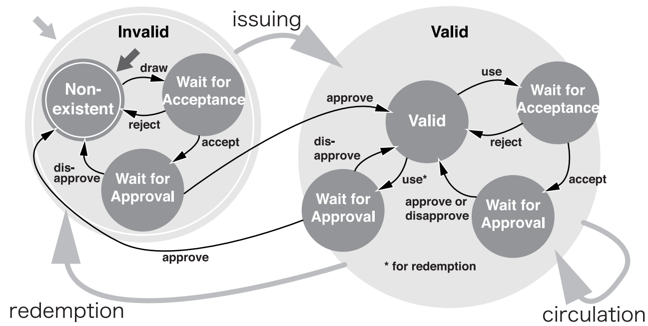
1. Trades need to be asynchronously performed. Intermediate states, such as waiting for acceptance or approval, are introduced.
2. Double-spending needs to be prohibited. The drawer is made responsible for guaranteeing that the circulating ticket is not a fraud. This means that every trade has to be approved by the drawer of the involved ticket.

The semantics of this design and the trust model of *i*-WAT are discussed in detail in [15].

2.2.3 Protocol

(1) Issuing – the birth of an *i*-WAT ticket

1. The drawer sends a <draw/> message which contains the public key user IDs of the drawer and lender, identification number and amount of debt. This message becomes the original *i*-WAT ticket after the protocol is completed.
2. The lender sends back the content of the message as an <accept/> message.
3. The drawer sends an <approve/> message to the lender.



* Gray arrows represent WAT state-transfer.
* Black arrows represent *i*-WAT state-transfer.

Fig. 2 State machine of a WAT/*i*-WAT ticket.

(2) Circulation – ordinary exchange

1. The user adds to the *i*-WAT ticket the public key user ID of the recipient, and sends it to the recipient as a <use/> message. This message becomes a valid *i*-WAT ticket after the protocol is completed.
2. The recipient forwards the content of the message to the drawer and user as an <accept/> message.
3. The drawer verifies the ticket, and sends an <approve/> message to the user and recipient.

(3) Redemption – the return of the *i*-WAT ticket

1. The user sends a <use/> message to the recipient, who equals the drawer.
2. The drawer verifies the ticket, and invalidates it as the debt is now redeemed. The drawer sends an <approve/> message to the user.

3. ROT: Reduction Over Time

3.1 Concept

We make a generalization to the value of a WAT/*i*-WAT ticket.

Definition 1 (Generalized value): The value of a WAT/*i*-WAT ticket is expressed as a triad $\langle V_0, V_m, f \rangle$ presented by the drawer, where V_0 is the face value (initial value) of the ticket, V_m is the minimum value, and $f(t)$ is the differentiation (derivative) of a function of time $F(t)$ such that $f(t) \leq 0$

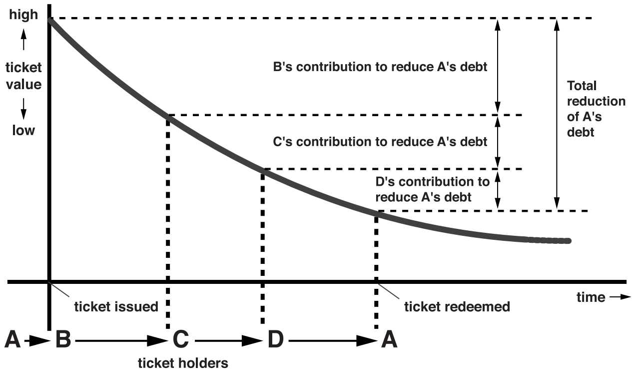


Fig. 3 Meaning of a *reduction* ticket.

for all $t^{\dagger}$. The effective value V_t of a ticket at time t is given by the following equation:

$$V_t = \max(\int_0^t f(t)dt + V_0, V_m)$$

Definition 2 (Reduction ticket): A WAT/*i*-WAT ticket is a reduction ticket iff $f(t) < 0$ for all t.

Intuitively, the value of a *reduction* ticket is reduced over time, limited by its minimum value.

Definition 3 (Regular ticket): A WAT/*i*-WAT ticket is a regular ticket iff $f(t) = 0$ for all t.

Reduction of the value of a ticket means that the drawer's debt is reduced. The cost of reduction is first admitted by the lender who credits the drawer, and then shared among the endorsers as illustrated in Fig. 3. The amount of the total reduction is manifested to the drawer upon redemption. By deferring redemption, participants can help easing the burden of the drawer. At the same time, they are helped by the utility of the ticket the dawer has issued (*mutual help among peers*).

3.2 Incentive-Compatibility of the Design

We show that the design of *reduction* tickets is incentive-compatible by modeling the series of transactions with such a ticket as a sequential game with incomplete information.

3.2.1 Prediction

Our analysis resulted in a prediction that the following properties will hold.

Property 1 (Rapid circulation): Unless $V_t = V_m$, participants are incentivized to minimize the duration of holding a *reduction* ticket, and they are disincentivized to use it against the drawer.

Property 2 (Vanishment equilibrium): If $V_m = 0$, a special case of *perfect Bayesian Nash equilibrium* is achieved; under the belief that no one defaults (because *rapid circulation* suggests that the value at redemption will be zero), all participants have no incentive to refuse the *reduction* ticket.

3.2.2 Notations and Preconditions

(1) Participants

The participants are denoted as W (for WAT friends) indexed by the order of their appearance: drawer = W_0, lender = $W_1, \ldots,$ current recipient = W_n.

(2) Probability of failure

Probability of W_i's failing to redeem a ticket is p_i. Note that in WAT/*i*-WAT, the responsibility follows the chain of endorsements if the drawer fails to redeem.

(3) Timing of usage

The time at which W_i uses the ticket is regarded i to simplify reasoning. This means that the time is not evenly distributed in the model. Still, by the definition of a *reduction* ticket, it holds that $V_n < V_{n-1}$ where $n > 0$.

Redemption takes place at time r.

(4) Cost of trust

Cost to rebuild trust relationships for W_i is CT_i. The cost includes that of *whitewashing*, or that one disappears and assumes a new identity. It is assumed that this cost does not vary in a large extent among participants, and is generally worth more than a value of a ticket. These assumptions should be justified by the fact that the *i*-WAT trust model requires construction of a *web of trust* [15], which requires that a new participant must know someone in the circle of friends around the *i*-WAT ticket in person.

(5) Transactional cost and benefit

No transactional cost or benefit is explicitly modeled except for the losses/gains measured by the values of exchanged tickets.

There assumed an implicit utility of having an exchange medium instead of having specific goods or unused services.

Transactional cost is negligible for *i*-WAT, which is the very reason why the WAT System had to be electronized and made usable on the Internet.

(6) Incentives and rationality

Existence of the following set of incentives is assumed as the common knowledge among participants.

1. The drawer is interested in maximizing their own benefit.
2. Other participants are interested in minimizing their losses and at the same time participating in maximizing the drawer's benefit. In other words, they are willing to help but unsure about the extent they want to sacrifice their own benefits.

It is assumed that all participants are rational.

†A further extension to allow $f(t) > 0$ is conceivable, which has been discussed elsewhere.

3.2.3 Game Trees

It is often useful to draw *game trees* when analyzing transactions as games. A game tree is a graph consisting of players' decision points as nodes, which are connected in the order of their occurrences. Each player has an *information set*, or a set of decision points from which they can choose an action. In the end of the graph, the gains of all players are drawn as leaves.

(1) Payoffs for issuing

Figuer 4 shows a game tree for issuing a *reduction* ticket.

The first player is the nature who chooses between two types of W_0 as the drawer: *successful* or *failing* to redeem the ticket. These types appear by probabilities of $(1-p_0)$ and p_0, respectively, for reasons either situational of strategic which are not distinguishable by other participants.

The lender W_1 has an information set in which the player is uncertain about W_0's type. Depending on the player's belief, W_1 chooses to either accept or refuse the ticket presented by W_0.

Inside parentheses are the gains of W_1 and W_0 in each combination of W_0's type and W_1's action.

1. If W_1 chooses to accept the ticket
   If W_0's type is successful, W_1 gains $V_1 - V_0$ which is negative, and W_0 gains $V_0 - V_r$ which is positive. Otherwise W_1 gains $V_1 - V_0 - C_1$, which is still negative, where C_1 is the cost of default for W_1 expressed as follows:

   $$C_1 : V_r \times (1 - p_1) + CT_1 \times p_1$$

   which intuitively states that the player has either to pay equivalent of V_r or to lose their tust, depending on the probability of his or her failure p_1. W_0 gains $V_0 - CT_0$ if the player's type is failing, which is assumed to be negative.
2. If W_1 chooses to refuse the ticket
   Both W_0 and W_1 gain or lose nothing.

(2) Payoffs for circulation

Figure 5 shows a game tree for circulating a *reduction* ticket, which is an extension to Fig. 4.

1. If W_n chooses to accept the ticket
   If W_0's type is successful, W_n gains $V_n - V_{n-1}$ which is negative. Otherwise the player gains $V_n - V_{n-1} - C_n$, which is also negative, where C_n is the cost of default for W_n expressed as follows:

   $$C_n : (V_r \times (1 - p_n) + CT_n \times p_n) \times \prod_{i=1}^{n-1} p_i$$
2. If W_n chooses to refuse the ticket
   W_n gains or loses nothing.

3.2.4 Analysis

First, we would like to know whether it is rational or not for the lender W_1 to accept a *reduction* ticket. Since no one would want to receive an exchange medium which cannot be used for an exchange, we begin by investigating if W_n would accept the ticket in circulation.

(1) Rational behaviors of W_n

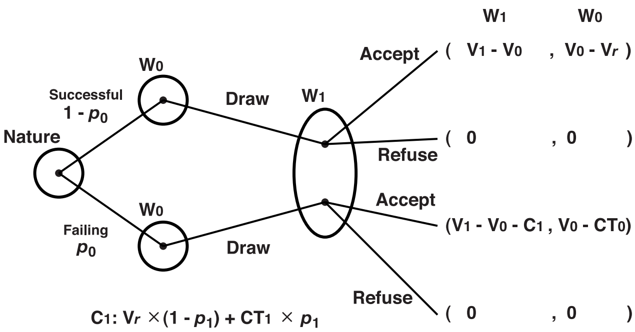
The expectation of the gain if W_n chooses to accept the ticket is as follows:

$$(V_n - V_{n-1}) \times (1 - p_0) + (V_n - V_{n-1} - C_n) \times p_0$$

$$= V_n - V_{n-1} - C_n p_0$$

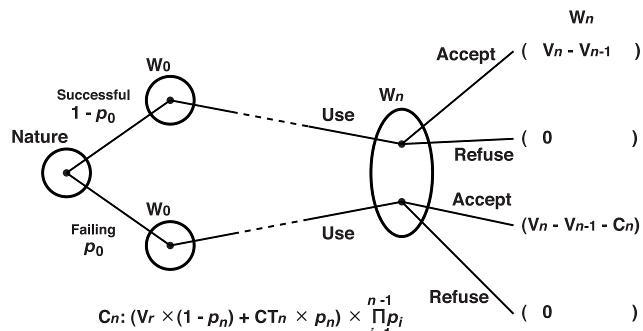
It is inevitable that this value is negative, but W_n wants to take part in maximizing W_0's benefit. Thus W_n seeks a possibility of making the value very close to zero so that the loss is negligible (and the implicit utility of the currency exceeds the loss).

$\prod_{i=1}^{n-1} p_i$ approaches zero as n increases, which makes the cost C_n negligible if n is sufficiently large. W_n can control the value V_n and minimize $V_{n-1} - V_n$ by spending the ticket as soon as possible. To do so, there must be someone willing to accept the ticket.



* $V_r = V_1$ and $p_1 = 0$ if W_1 is the last user

Fig. 4 Game tree for issuing a *reduction* ticket.



* $V_r = V_n$ and $p_n = 0$ if W_n is the last user

Fig. 5 Game tree for circulating a *reduction* ticket.

There are two candidates against whom W_n can use the ticket: the drawer W_0 and the prospective participant W_{n+1}. Since W_n is incentivized to maximize the benefit of W_0, the player decides to refrain from using the ticket against W_0 unless $V_n = V_r = V_m$, at which time W_0's gain $V_0 - V_r$ is maximized.

By applying the same reasoning as their own, W_n can infer that W_{n+1} will try to minimize their loss, only that C_{n+1} is even smaller than C_n. Apparently, W_{n+1} is in a better position than W_n with respect to the cost of default, so that W_n infers that W_{n+1} will accept the ticket if W_n chooses to accept it.

Therefore, there is no strategic reason for W_n not to accept the ticket if n is sufficiently large.

(2) Rational behaviors of W_1

The expectation of the gain if W_1 chooses to accept the ticket is as follows:

$$V_1 - V_0 - C_1 p_0$$

which is also inevitably negative, but W_1 wants to take part in maximizing W_0's benefit as others do.

W_1 can control the value V_1 and minimize $V_0 - V_1$ by spending the ticket as soon as possible. As W_n reasoned, W_1 can infer that it is likely that $C_1 > C_2$, or W_2 is in a better position than W_1 with respect to the cost of default (unless W_1's type is failing and CT_1 is small). The question is how W_1 can minimize C_1.

It is assumed that $V_r < CT_1$, so that W_1 would like both V_r and p_1 as small as possible. Since the incentives support that V_r is ultimately V_m, ease of acceptance for W_1 increases as presented value of V_m becomes small, whose lowest possible value is zero.

Therefore W_1 is most likely to choose to accept the ticket if $V_m = 0$.

(3) Rational behaviors of W_0

We would like to know if W_0 would agree to issue a *reduction* ticket whose value is to be reduced down to zero. Intuitively, the answer is yes, as this would maximize W_0's gain $V_0 - V_r$. In fact, it is the only equilibrium we can reach if the ticket is accepted.

Note that CT_0 is applied just once after an incident of default. If we consider existence of other tickets issued by W_0, the cost of default for W_0 shoulde be more precisely expressed as $V_0 - \frac{CT_0}{N}$, where N is the number of W_0's tickets in circulation. It is possible that $V_r > \frac{CT_0}{N}$ if N is sufficiently large. To eliminate the risk of default, V_r needs to be zero.

Therefore, desires of W_0 and W_1 match, and $V_m = 0$ results in an equilibrium where everyone believes that no one defaults (it is impossible to do so), and no one has incentive to refuse the ticket.

3.2.5 Hazards

We consider two probable hazards caused by the design: moral and timing hazards (the problems of colluding will be discussed elsewhere).

(1) Moral hazard

The prediction that the most stable value for V_m is zero implies no risk for W_0 to issue new *reduction* tickets.

To prevent W_0 from excessively issuing tickets, the group of lenders who take the role of W_1 must share information among one another about the face values of W_0's tickets in circulation. Since it must be a common knowledge that W_0 is in need to begin with, this should not be difficult to achieve.

(2) Timing hazard

There is a risk that circulation may be stalled by negligence of W_0 in their role for approving transactions. However, we can show that it is to W_0's own benefit to maintain the liveness of their tickets.

If W_0 is late to respond to the request for approval, the prospective transaction is delayed. It is the recipient W_{n+1}'s interest that transaction is performed as quickly as possible, otherwise their loss $V_n - V_{n+1}$ cannot be minimized. Meanwhile, W_0 is not affected by their own laziness because the effective value will not decrease further after redemption as the ticket itself will disappear. When likelihood of acceptance is in question, if W_n needs to choose from the two, their natural choise is to ask W_0 for redemption, which is against W_0's interest.

Therefore, being lazy is to risk early redemptions, and W_0 is incentivized to respond quickly.

4. Design and Implementation

4.1 Protocol

Reduction tickets can be incorporated to the system with minimal changes to the message format of the existing *i*-WAT protocol.

In the existing message format, an *i*-WAT ticket is represented by an XML data in which the value is expressed in the following element:

```
<sum ns="name-space-URL">value</sum>
```

where *name-space-URL* distinguishes the unit in which the debt is quantified. The ROT feature is implemented by adding the following set of elements to the XML data:

```
<min>minimum-value</min>
<var per="time-unit">reduction-rate</var>
```

Currently, constant value only is supported as an expression in place for a *reduction-rate*:

```
<constant value="constant-value"/>
```

For compatibility reasons, *name-space-URL* is accompanied by a trailing `#var` in case of a *reduction* ticket. This way, older implementations of *i*-WAT can assume that the ticket is of unknown unit, avoiding situations where the effective value of a ticket is wrongfully presented to the users.

Semantically, since it is unrealistic to assume that the clocks of all participating computers are synchronized with precision, the time is ultimately measured by the computer of the drawer.

The timestamp of the drawer's or user's signature (depending on whether the trade is issuing or circulation) defines the effective value of a *reduction* ticket, to which the recipient either agrees or disagrees. The drawer (or their software agent) is responsible to check that the timestamp belongs to the past for them when they approve a transaction.

4.2 Implementation

We have been developing a reference implementation of *i*-WAT as a plug-in for *wija*, an XMPP (Extensible Messaging and Presence Protocol) [4], [5] messaging client. Implementation of the proposed ROT feature has already been included in the bundled plug-in for the version of *wija* which was released in April 2005. *wija* is available at the following URL:

- http://www.media-art-online.org/wija/

5. Applications

The ROT feature will be most effective in situations where it is known among all participants of a P2P system that prospective drawers are in need. Such situations include recovery from loss of data or collecting resources for providing common services.

As a more concrete example, let us think about a case of an internal service in a P2P system which is commonly used among participants, such as indexing. Let us assume that in a given partial overlay network of a P2P system, one node is elected and made responsible for such a service, and that such a node requires cooperation from other nodes to realize the service.

Figure 6 shows a simulated result of how such services can be made stable using the ROT feature of *i*-WAT.

In this simulation, 100 nodes participate in a partial network in a P2P system. Each nodes starts with their initial amount of resource, 100. The sevice-providable amount of resource, 1,000, is required to achieve the commonly-used service, which the elected node must obtain from other helping nodes. Three types of the elected node is prepared, who are different in the medium of exchange they use to obtain the resources from others: one uses *regular* tickets, one uses *reduction* tickets with rate -0.1 whose minimum value is the half of the initial value, and one uses *reduction* tickets with rate -0.1 whose minimum value is zero. Time is interleaved in the simulation, and there can be atmost one transaction within a time unit.

To be compatible with the result of the analysis made earlier in this paper, the following rules are set:

1. A ticket holder, whenever they have a chance, tries to have their tickets redeemed unless one of the following conditions hold:

   a. The drawer does not have enough resource to pay back, or
   b. The effective value of the ticket has not reached its minimum.

2. The drawer is only allowed to issue a ticket when their debt is less than the difference between the initial and service-providable resources.

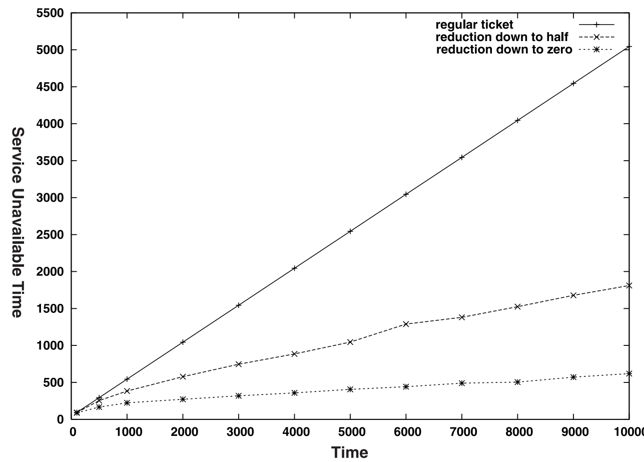


Fig. 6 Service unavailable time within a P2P system.

The simulation shows an unfair result for a *regular* ticket, which tends to be redeemed by the iteration following the drawing according to the above rule. However, such rules can be made implicit for *reduction* tickets, which we believe is the proof that those tickets are more self-regulatory.

6. Future Work

We will experiment on actual usage of the ROT feature to verify our prediction.

There are number of reasons why the ROT feature might not work in reality: we cannot always expect people to act rationally, there may be elaborate attacks of which we are unaware, etc. By putting the feature into practical use, we will investigate those possibilities, and seek for solutions.

7. Related Work

As described in Sect. 1.2, the ROT feature of *i*-WAT is an application of a concept experimented by past real-life complementary currencies. More examples of such experiments can be found in [16].

There seems no electronic counterpart of *i*-WAT with the ROT feature yet, especially among a few number of decentralized currency systems.

8. Conclusions

This paper investigated an extension to the design of *i*-WAT to implement ROT (Reduction Over Time), which has potential effects of both promoting exchanges and providing participants with means to mutually support peers by sharing debts among one another as a form of currency. The extended design is shown to be incentive-compatible by a game-theoretical analysis. In particular, we predicted that the following properties will hold:

1. *Rapid circulation*, or a reduction ticket will typically circulate at high speed until its effective value reaches the scheduled minimum, and
2. *Vanishment equilibrium*, or the system will be most stable if the values of tickets are to be reduced down to zero.

We will verify this prediction as the implementation has just become available to the public.

Acknowledgments

We would like to thank members of Gesell Research Society Japan and the WIDE Project for valuable advices and discussions on the content of this paper, as well as feedback on *wija* software.

References

[1] K. Saito, "Peer-to-peer money: Free currency over the Internet," Proc. Second International Conference on Human.Society@Internet (HSI 2003), Lecture Notes in Computer Science 2713, Springer-Verlag, June 2003.
[2] watsystems.net, "WATSystems home page," Hypertext document, Available electronically at http://www.watsystems.net/
[3] J. Callas, L. Donnerhacke, H. Finney, and R. Thayer, "OpenPGP message format," RFC 2440, Nov. 1998.
[4] P. Saint-Andre (ed.), "Extensible messaging and presence protocol (XMPP): Core," RFC 3920, Oct. 2004.
[5] P. Saint-Andre (ed.), "Extensible messaging and presence protocol (XMPP): Instant messaging and presence," RFC 3921, Nov. 2004.
[6] J. Feigenbaum and S. Shenker, "Distributed algorithmic mechanism design: Recent results and future directions," Proc. 6th International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communication (DIALM '02), Sept. 2002.
[7] F. Schwarz, "Das experiment von Wörgl," 1951, Hypertext document, Available electronically at http://userpage.fu-berlin.de/˜roehrigw/woergl/, *(Shortened English translation by Hans Eisenkolb is available at http://www.sunshinecable.com/~eisehan/woergl.htm)*.
[8] S. Seron, "Local exchange trading systems 1 — Creation and Growth of Lets," Hypertext document, Available electronically at http://www.gmlets.u-net.com/resources/sidonie/home.html
[9] P. Glover, "Ithaca HOURs Online," Hypertext document, Available electronically at http://www.ithacahours.com/
[10] S. Gesell, The Natural Economic Order, The Free Economy Publishing, 1934. Translated from the sixth German edition (originally published in 1913). Also available as a hypertext document in English, translated by Phillip Pye, at http://www.systemfehler.de/en/neo/
[11] A. Dahlberg, When Capital Goes On Strike, Harper & Brothers Publishers, 1938.
[12] K. Saito, E. Morino, and J. Murai, "Reduction over time: Easing the burden of peer-to-peer barter relationships to facilitate mutual help," Proc. Second International Workshop on Computer Supported Activity Coordination (CSAC 2005), pp.28–37, May 2005.
[13] J. Boyer, Canonical XML Version 1.0, March 2001, W3C Recommendation, Available electronically at http://www.w3.org/TR/xml-c14n.
[14] T. Bray, J. Paoli, C.M. Sperberg-McQueen, and E. Maler, Extensible Markup Language (XML) 1.0, second ed., Oct. 2000, W3C Recommendation, Available electronically at http://www.w3.org/TR/REC-xml
[15] K. Saito, "WOT for WAT: Spinning the web of trust for peer-to-peer barter relationships," IEICE Trans. Commun., vol.E88-B, no.4, pp.1503–1510, April 2005.
[16] H. Godschalk, "Aufschwung durch lokales Nebengeld?," Zeitschrift für Sozialökonomie 129, pp.11–16, June 2001.

Kenji Saito was born in 1964. He received M.Eng in Computer Science from Cornell University in 1993. Areas of his interest include real-time systems and distributed autonomous systems.

Eiichi Morino was born in 1949. He graduated from Graduate School of Economics, Kokugakuin University, in 1979. Areas of his interest include monetary economic theory. He founded Gesell Research Society Japan in 1995.

Jun Murai was born in 1955. He graduated from Department of Mathematics, Faculty of Science and Technology, Keio University, in 1979. He received MS and Ph.D. in Computer Science both from Keio University, in 1981 and 1987 respectively. Areas of his interest include computer network and operating systems.