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Evaluating the Lightweight Currency System using the Probabilistic Model Checking PRISM

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Abstract

Electronic Commerce is one of the major factors in the evolution of the internet. It increases the possibility for private companies or individuals to trade with each other. Information plays a major role in such global economy. Immediate supply of information means improvement of the whole economy. The usual payment methods tend to be more unrealistic in such kind of commerce (information supply). Another kind of currencies is created to help in this point. They are called alternative currencies.

Probabilistic modeling becomes very important tool in analyzing and verifying many systems. It allows considering both quantitative and qualitative properties of the system. The extension of the Probabilistic modelling is the Probabilistic model Checking, it is a formal verification technique for the analysis of systems with stochastic behaviour.

In this paper we use the stochastic model-checker PRISM to address some of the useful properties of an alternative currency system.

1 Introduction

The marketplace is the location in which economic decisions, such as price, are determined by matching the sellers (suppliers) and the buyers (consumers). The sellers and the buyers are individuals, busnisses or companies. Their main desire is to maximize their profits. They exchange goods and services by using money.

In modern times, with the use of the computers and the internet, the marketplace has changed from being just a physical space to the virtual markets on the net, which is called electronic market or e-market. Electronic markets help in increasing the efficiency of the economy. It is a free market since buyers can choose better products with lower prices and sellers can charge different prices for the same product from different buyers. Examples of the e-markets include accepting credit cards for commercial sales online, i.e., e-Bay and selling books on a pay-per-download basis through a website of a book shop.

The increasing importance of electronic marketplace's emphasizes the need to develop a new kind of currencies to be created and used by the electronic marketplace users. These currencies are known as alternative currencies, or complementary, currencies [1],[2].

Alternative currencies are considered as agreements between indveduals other than national governments to issue another kind of payment method rather than legal tender. These currencies help the individuals to improve their economic situation by creating new trading relationships between them [3]. Alternative currencies work in parallel with the real-world currencies and they are not to be used instead of them, since alternative currencies are not considered as legal tender.

The users of alternative currencies are able to sell and buy commodities (resources or services) such as storage and bandwidth resources , CPU cycles, spam reduced email and video streaming. If the legal tender are used for such micro-payments the result will be high transaction costs. The alternative currencies can improve trading volumes as the legal tender can do. Any user has the right to issue a currency, which can then be owned by other users. The currencies issued by different users will compete with each other, providing economic efficiencies. In the long run, there may only be a small number of powerful currencies.

In recent years, there has been a huge growth in the number of such alternative currencies. In Japan, there are more than 600 alternative currency systems in operation. Some examples for the alternative currency systems are: LETSystem (Local Exchange Trading System), Time Dollars, and LCP (Lightweight Currency Protocol) [4], [5].

Probabilistic model checking is a formal method that enables representing real- life systems with random behaviour and analysis of the reliability, correctness and performance of such systems in an automatic way. In our paper we study and analyze the LCP using PRISM (Probabilistic Symbolic Model Checker). We establish some of the properties of the LCP system, such as the effect of the commission fees on the bank profits and the effect of the interest rate of the seller on its profits. Studying such properties helps the bank and the seller to make their right decision in order to increase their benefits. The paper is organized as follows: in the following section we describe LCP in more details. Section 3 is a brief introduction to the topic of model checking and probabilistic model checking, from which we choose PRISM as our application tool. Section 4 provides an overview of the system under study (LCP system). In Section 5 the analysis and results for the system are discussed. Finally, Section 6 gives conclusion and describes further work.

2 The Lightweight Currency Protocol (LCP)

The Lightweight currency protocol is a framework for creating currencies that is very easy to use by different users. It enables a direct peer-to-peer (p2p) transition between different currencies issued by different currency issuers. This feature makes LCP a very powerful medium for exchange of currencies. For example, a user who earns currency from selling bandwidth can use this currency to buy another application, such as download documents. The currency issuer could not restrict the holder of his currency from exchanging it with other ones.

In LCP, any user has a right to issue a currency. The currency issuer maintains accounts for its currency users; he can make debits and credits for the buyers and the seller, respectively, of his account. Any user that holds a given currency can ask the currency issuer to transfer some currency from his account to another user, for example if the first one is the buyer and the second is the seller. The currency issuer debits the buyer's account by the transfer amount and credits the seller's account by the same amount. Although the trading is between peer-to-peer, the users can rely on a trusted service like a bank (virtual bank) to manage their accounts and transactions on their behalf, and the bank can take some commission fees. This bank would provide a web interface for users to manage their accounts, check received payments and their balances, and so on. There are several research papers concerning the application of LCP in many fields. For more information about LCP see [6] and [7].

In [8], the authors defined a simple mechanism by which users can optionally manage their own currencies to be used generally in the cooperative; they also defined simple mechanisms to ensure reliability and privacy. In [7], the authors describe a resource market paradigm that has been designed to motivate peers to make their surplus resources available to p2p applications. In [9], the authors focus on the advantages of using the LCP to control Spam. To the best of our knowledge, the research papers on alternative currencies focus on security and availability, and in our research we focus on the performance of the system. In this paper we evaluate the performance of the system under different conditions.

3 Probabilistic Model Checking

Model checking [10] is a technique for verifying finite-state systems such as sequential circuit designs and communication protocols. The specification is often written as a temporal logic formula, and model checking establishes if the model satisfies the specification.

The model is usually expressed as a transition system, i.e. a directed graph consisting of nodes (states of the system) and edges (transition between states). A set of atomic propositions is associated with each node. The atomic propositions represent the basic properties that hold at a point of execution.

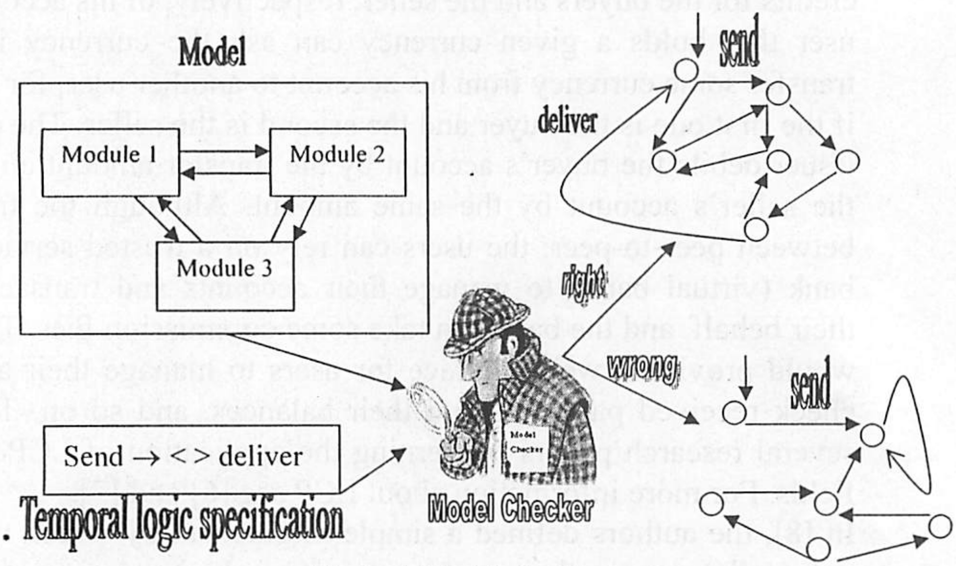


Figure 1:Model checking

Stochastic (probabilistic) model checking [11], [12] is an extension of the traditional model checking. It allows both the qualitative and the quantitative properties of the system to show for example, if the system is timely and reliable or not. As in the conventional model checking case, this model is usually a transition system but, in this case, a real-time delay before the transitions between states occurs, represented by a negative exponential distribution with parameter equal to the delay's rate. Exponentially distributed delays are often used for modeling inter-arrival times and component lifetimes.

Many models are used in probabilistic model checking, for example deterministic time Markov chains (DTMCs), Markov decision processes (MDPs) and continuous time Markov chains (CTMCs).

In many cases the system under study is complex, and therefore high-level specification techniques are used to automatically generate the models. There are several probabilistic model checking tools, such as ETMCC (Erlangen-Twente Markov Chain Checker), APMC (approximate probabilistic model checker), iLTL (A Model Checker for Discrete Time Markov Chains) and PRISM (Probabilistic Symbolic Model checker).

PRISM

PRISM (Probabilistic Symbolic Model Checker) is a probabilistic model checker developed at the University of Birmingham by Kwiatkowska et al. [13], [14], [15]. PRISM has a tool that supports the analysis of discrete time Markov chains, continuous-time Markov chains, and Markov decision processes. The tool uses the logic PCTL for properties of DTMCs and MDPs and the logic CSL for properties of CTMCs. PRISM tool allows verification and analysis of very large real-life systems, for example reliability properties of the thinkteam user interface, the correctness and performance of probabilistic contract signing and probabilistic fair exchange, and also the behaviour of biological processes such as molecular reactions. See [15] for further details about different case studies with PRISM.

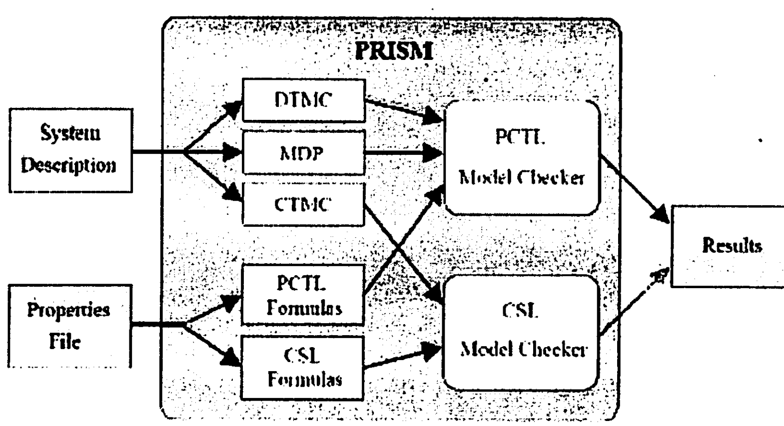


Figure 2: The structure of PRISM [15]

Probabilistic models to be analyzed in PRISM are specified in the PRISM modeling language, which is based on the Reactive Modules formalism of Alur and Henzinger [16]. PRISM also accepts the Performance Evaluation Process Algebra languge (known as PEPA language) [17] for system descriptions. The basic components of the PRISM language are modules and variables. Each component of the system is described as a module. The whole model is composed of a number of interacting modules. The state of a module is determined by the value of its local variables. The state of the whole model is determined by the states of all the modules together with the contents of the global variables.

The behavior of the module is described by commands, for example a command of a stochastic model takes the form:
[*action*] *guard* -> <*rate*$_1$>:<*update*$_1$> + <*rate*$_2$>:<*update*$_2$>+...

where *guard* is a predicate over all the variables in the whole model (not only the ones in the module itself), *action* represents the action that the guard will share (synchronize) with other modules; if there is no such synchronization then it is simply represented as []. Update describes the transition that can occur if the guard is true, and finally the rate is the rate of this transition.

The following simple example explains the basic concepts of the PRISM language.

Consider a system consists of two identical processes. Each process can be in one of two states: {0,1}. The first process: the initial state is 0, the process will move to state 1 in duration equals to $r_1 \in R$ and from state 1 it returns to state 0 in duration equals to $r_2 \in R$. The second process: It starts in state 1, it can not move to state 0, unless process 1 is not in state 0, also process 2 can move from state 0 to state 1 only when process 1 is not in state 1.
The PRISM code to describe this system can be as follows:

```
ctmc
const int r1;
const int r2;
const int r3;
const int r4;
module M1
x:[0..1] init 0;
[] x=0 -> r1:(x'=1);
[] x=1 -> r2:(x'=0);
endmodule
module M2
y:[0..1] init 1;
[]y=1 &x!=1 ->r3:(y'=0);
[] y=0 &x!=0 -> r4:(y'=1);
endmodule
```

Figure 3: The PRISM language: Simple example

The transition diagram representing the possible behaviour of the processes is shown in figure 4 below.

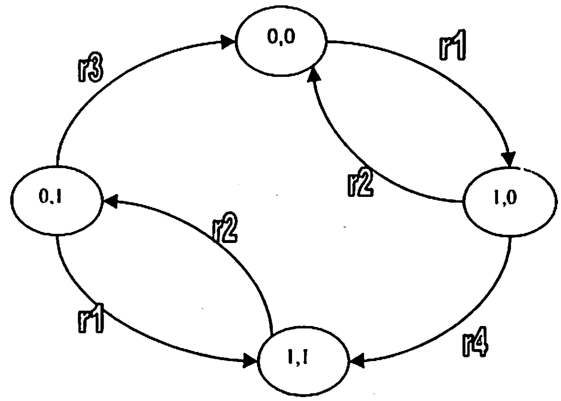


Figure 4: The state transition diagram of the model

The PRISM tool works as follows. First, it reads and parses a model description in the PRISM language. Then if constructs the corresponding DTMC, CTMC or MDP, computes the set of all reachable states, and identifies any deadlock states which can be allowed by PRISM. Properties of the system, which are to be verified, are then specified. PRISM checks the validity of some logic properties for the model and provides feedback on the calculated probabilities of such states where appropriate. These allow the specification of properties such as: "the algorithm eventually terminates successfully with probability 1", which is represented as follows:

- $P_{>=1}$ [true U terminate]

or "in the long run, the probability that the queue is more than 75% full is less than 0.05 ", which is represented as follows:

- $S_{<0.05}$ [queue size / max size >0.75]

The above properties give "yes" or "no" answer. In PRISM we can also directly ask "what is the probability of" and PRISM will calculate the numerical value. For the examples above they will be as follows:

- $P_{=?}$ [true U terminate]
- $S_{=?}$ [queue size / max size >0.75]

PRISM also includes support for the specification and analysis of properties based on costs and rewards. This gives PRISM the ability to reason about expectations, such as "expected time" and "expected number of given items".

Rewards are added to the PRISM models by using the following formula:

rewards
<guard> : *<reward>*;
<guard> : *<reward>*;
:
endrewards

where *<guard>* is a predicate over all the variables of the model and *<reward>* is an expression, which can contain any variables, constants, etc. from the model.

Rewards can also be assigned to transitions of a model as follows:

rewards
[*<action>*] *<guard>* : *<reward>*;
[*<action>*] *<guard>* : *<reward>*;
:
endrewards

This means that transitions from states, which are labelled with the action *<action>* and satisfy the guard *<guard>*, get the reward *<reward>*.

A single reward item can assign different rewards to different states, depending on the values of model variables in each one. The states that do not satisfy the guard of any reward item will not have rewards. For the states (transition) that satisfy multiple guards, the reward assigned to the state (transition) is the sum of the rewards for all the corresponding reward items.
A model description can specify rewards for both states and transitions, in a single *rewards ... endrewards* construct.

Furthermore, PRISM supports the notion of experiments, which is a way of automating multiple instances of model checking. This allows the user to easily obtain the outcome of one or more properties as functions of model and property parameters, using the same assignments of model states. For example with an experiment define the rate *alpha*= 10:10:100 means that *alph*a takes range of values 10,20...100 (step 10). The experiment runs automatically and returns with the result for each value. A table of results is created and can be viewed directly, or exported for use in an external application such as a spreadsheet, or plotted as a graph.

4 The System under Study

In this part we study Lightwieght currency protocol (LCP) based on [2] by modelling it using the PRISM approach.

In our scenario, three modules - the seller, the buyer and the bank - are working together in order to enable the users (the seller and the buyer) to trade currencies.

Consider that there is one seller and one buyer. For simplicity we consider there are only two types of currencies; Type1 Currency and Type2 Currency. Exchange is from Type1 Currency to Type2 Currency (this condition will be relaxed later by allowing exchange from any type to any other type).

The seller can involve in the following activities: open account, close account, post an offer, change his mind about the offer and make exchange.

The buyer can involve in the following activities: open account, close account, search for offer and make exchange.

The bank - which controls all the above businesses - involves in all the activities of both the seller and the buyer.

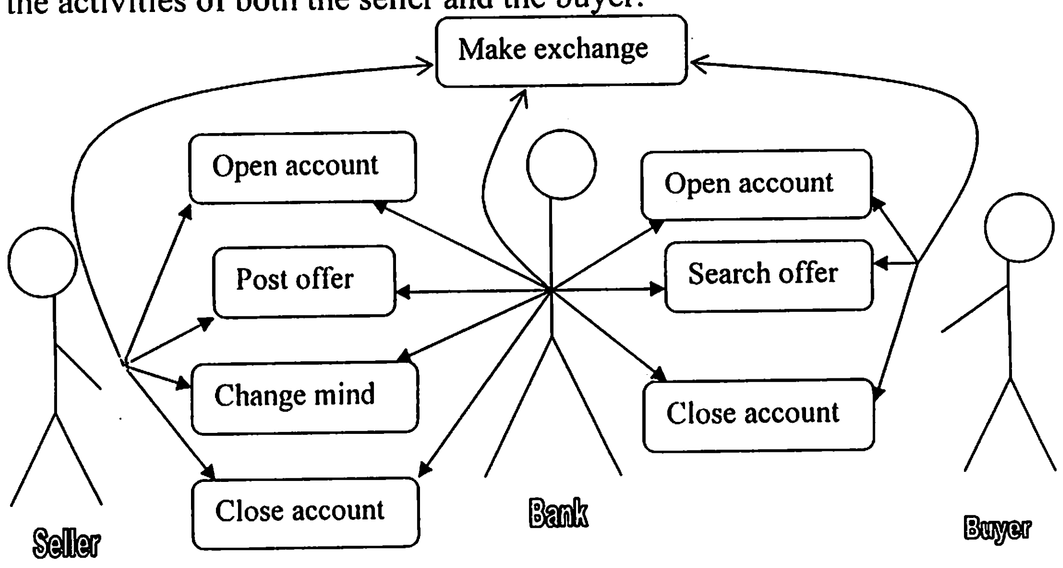
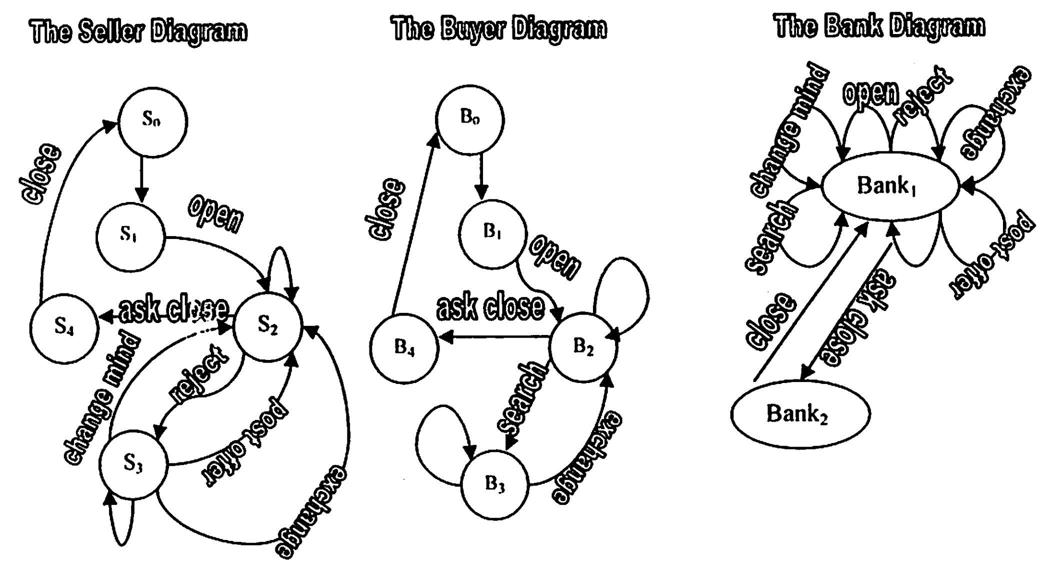


Figure 5: The basic activities of the three components

For simplicity, we do not add withdraw and deposit.

Suppose that the seller has a currency (issued by himself or someone else) called *Type1 Currency.* Suppose also that the buyer has a currency (issued by himself or someone else) called *Type 2 Currency.* If the seller wants to exchange some of his *Type 1 Currency* to *Type 2 Currency*, then the seller opens an account with the third trusted party "the bank" by depositing an amount K_1. The bank creates *sbalance1* (seller balance of Type 1 currency) and puts K_1 into it, and an empty *sbalance2* balance. Then the seller posts an offer to exchange S_1 amount of *Type 1 Currency* with an interest rate sm_1. The bank checks if the offer (plus the commission fees) is less than the balance and also checks the interest rate if it is in reasonable agreement with the market or not; if one of them is not true, it can reject putting the offer (thus controlling the transfer). The seller can change his mind for offering this money and the bank accepts that in the case where there is no buyer yet. The buyer who wants to exchange some of his *Type 2 Currency* to *Type 1 Currency* opens an account by depositing an amount equal to K_2 of *Type 2 Currency* to the bank. The bank creates *bbalance2* (buyer balance of Type 2 currency) and puts K_2 into it, and an empty *bbalance1* balance. The buyer can search for an offer B_1 (buyer search for *type 1 currency*) and if he agrees with the seller's offer, the exchange of the currencies will take place through the bank, which also will take its commission fees from the seller and the buyer. The bank reduces the seller's balance of *Type 1 Currency* by $S_1+C_1*S_1$, where C_1 is the commission fee for *Type 1 Currency.* The bank also increases the seller balance of *Type 2 Currency* by $S_1+sm_1*S_1$. The bank reduces the buyer's balance of *Type 2 Currency* by $S_1+sm_1*S_1+C_2$, where C_2 is the commission fees for *Type 2 Currency*, and increases the buyer's balance of *Type 1 Currency* by S_1. After this exchange the user (the seller or the buyer) can close his account or go for another exchange, or just continue with the account open.

The behaviour of each module is described on the following state-chart diagrams:



5 Evaluation of the model

PRISM allows us to study some interesting properties of the LCP such as the effect of different interest rates on the net profit of the bank from the exchange of currencies, the effect of different commission fees on the profit of the seller, and the effect of the rate of posting an offer by the bank on the cumulative total currencies on the bank.

First we consider the simple model, in which there is only one-way transition from type 1 currency to type 2 currency.
The PRISM program has 22849 states and 59418 transitions (for two currencies exchange the program has 1441084 states and 3926146 transitions), and for technical reasons, with PRISM we add to the program an integer variable L which decreases by 1 each time the exchange occurs and we run the program until l >=1.

We focus on total1 and how much it increases after the exchange happened, that is, the effect of the commission fees taken by the bank on type 1 currency. To do so we add a reward
rewards
(Bank=1&s=3&b=3): *Total1*;
endrewards
which returns the new value of Total1 in the state (Bank=1&s=3&b=3), that is, the state of the exchange.

We study the property R=? [S], which is: what is the expected reward in the long run.

Figure 6 shows the expected reward for different values of offers and with different commission fees.

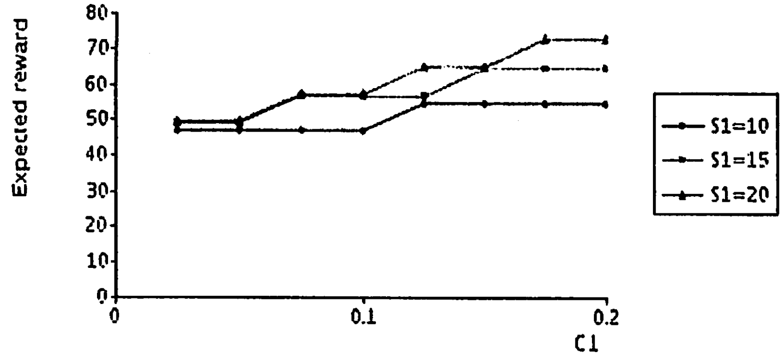


Figure 6

In Figure 6 the commission fees varied from 0.025 to 0.2 and the amount the seller offered S_1, takes the values 10, 15 and 20.
We notice that: with S_1 =10, Total1 increases when C1=0.125, with S_2 =15, Total1 increases when C1=0.075 and increases again when C1=0.15 and finally with S_3=20, Total1 increases when C1=0.075, increases again at C1=0.125 and again at C1=0.15.
According to this figure the bank can decide its policy for maximizing its units of currency as follows:
C1=0.125 with S_1 <=10,
C1=0.15 with 10<S_1<=15, and
C1=0.175 with S_1>20.
Alternatively it can set a policy, which can increase the number of users in the long run as follows:
C1= 0.125 with S1 <=15, and
C1= 0.15 with S1 > 15.
Also, by checking the total amount of a given currency the bank can increase or decrease its commission fees in order to control the transition between different currencies.

Now we study the effect of the change of the interest rate of the seller on (sm_1*S_1), i .e. the amount of net profit for the seller, with different values of S_1.
Then reward in this case is sm_1*S_1

Figure 7 shows the expected reward for different values of offers and with different interest rate.

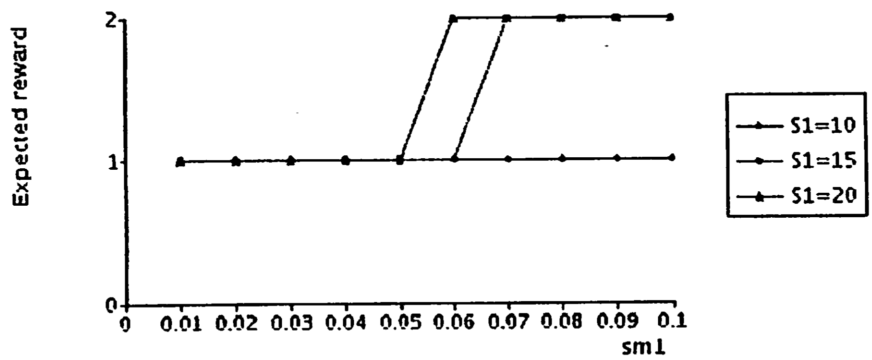


Figure 7

We notice that because the value of sm_l is very small and with a small value of S_l (S_l=10) the result of (sm_l*S_l) is a very small value and does not change with the change of sm_l. For S_l = 15 the effect starts when sm_l has the value 0.07, and for S_l = 20 the rewards increases with sm_l = 0.06.
From the above results the seller can increase his interest rate more than the values that we suppose, especially for the small offers.

The last property we study in our first group (one way transition) is the effect of the rate of posting an offer on the seller and the buyer balances and on both of Total1 and Total2.
Figure 8(a) and Figure 8(b) below show the results:

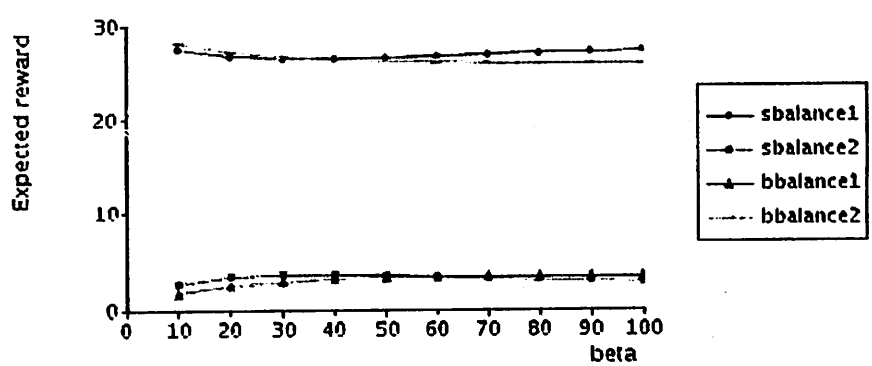


Figure 8(a)

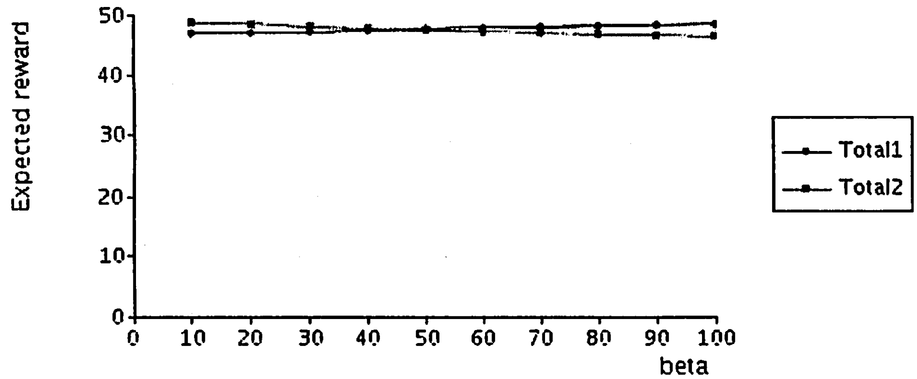


Figure 8(b)

As the system starts with sbalance1 = bbalance2 = K_l and sbalance2 = bbalance1 = 0 and with each occurrence of currency exchange bbalance2 decreases by B_l (=S_l), sbalance1 decreases by (S_l-sm_l*S_l). We notice that with the increase of the rate of posting an offer sbalance1 gains more. Also for bbalance1 and sbalance2 they increase by S_l and (B_l+sm_l*B_l) respectively.

For Total1 and Total2; we notice that Total1 increases by the amount C_l*S_l, while Total2 increases by the amount C_2*(S_l + sm_l*S_l), i.e., C_2*S_l(1+sm_l), then the choice of the values of the commission fees for both currencies and the interest rate of the seller are very effective on the total of the two currencies in the bank. As we can see from Figure 8(b) by taking beta =50 the bank gets Total1=Total2.

Now we study some properties for the model, which the seller sells two types of currencies and the buyer buys the two types of currencies.

Figure 9 and Figure 10 below show the cases of the effect of the change of the commission fees and the different offers on Total1 and the effect of the change of the interest rate and the different offers on sm_l*S_l (as in the case of one currency exchange).

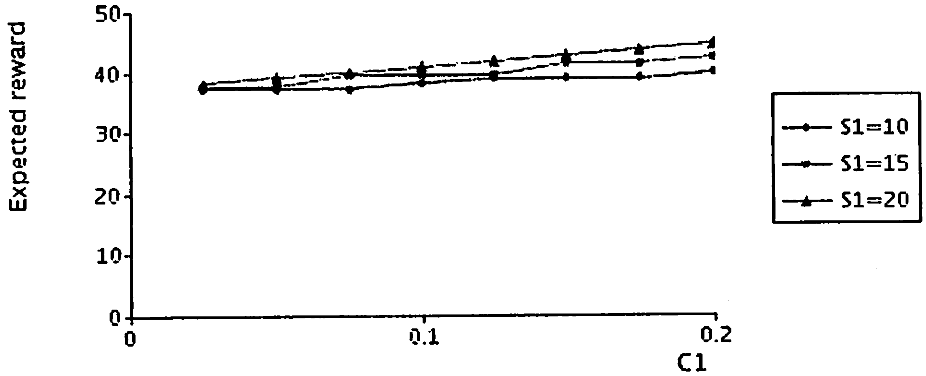


Figure 9

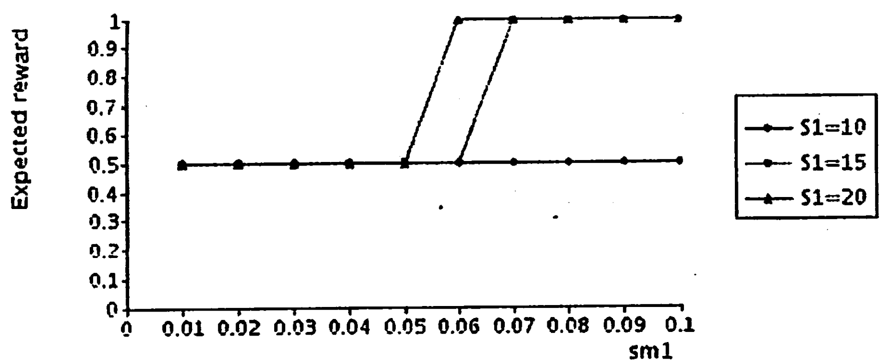


Figure 10

We notice that the expected rewards in Figure 9 increases more than in case of only one currency, and with the value of $S_1 = 20$ the increase of the rewards becomes sharp and the line becomes more smooth (not in steps shape).

The last property we study is the effect of the change of the rate of posting an offer on the balances of the seller and the buyer in their different currencies.

Figure 11(a) and Figure 11(b) below show the results.

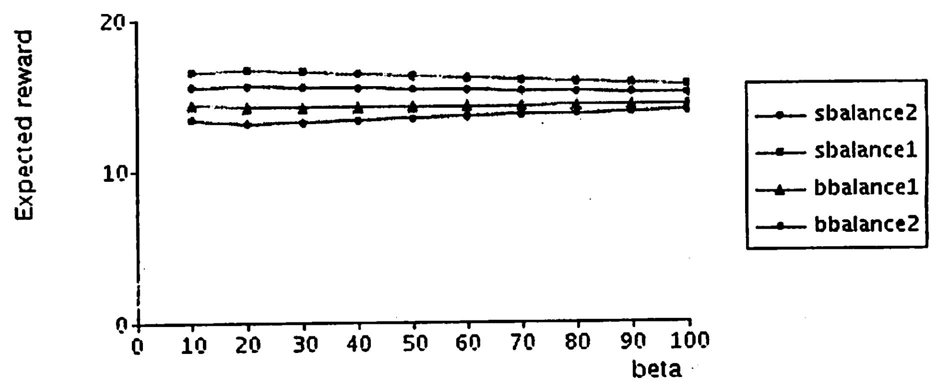


Figure 11(a)

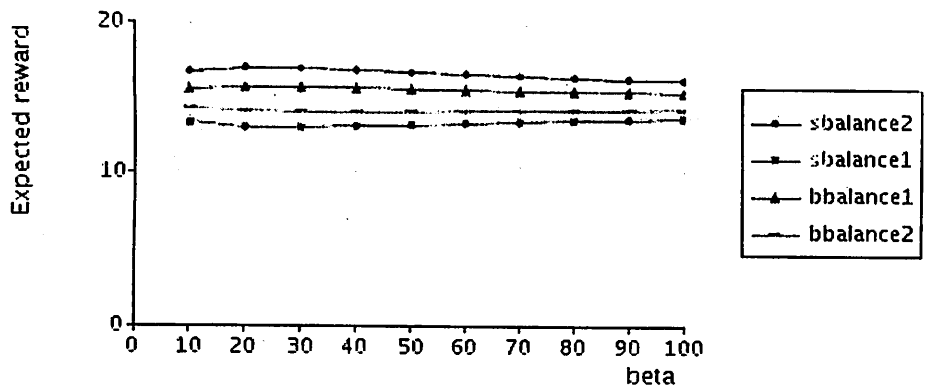


Figure 11(b)

Figure 11(a) shows the balance of both the seller and the buyer each time they made exchange from type 1 currency to type 2 currency. Figure 11(b) shows the balance of both the seller and the buyer each time they made exchange from type 2 currency to type 1 currency. We can see from Figure 11(a) that with the increase of beta sbalance2 and bbalance1 increase, while sbalance1 and bbalance2 decrease. With beta = 100 the gab between the balances became narrow. We notice also in Figure 11(a) the values of the balances became very near with beta =100 more than in the case of Figure 11(b), and that is due to the different of the values of C1, C2, sm_1 and sm_2.

6 Conclusion and further work

In this work we studied and analysed the lightweight currency protocol, by using PRISM. PRISM allows us to measure different properties of the system, for example we study the effect of different interest rates on the total currencies in the bank, different commission fees on the seller income, also we study the effect of the rate of posting an offer on the balances of both the seller and the buyer.
For generalization of this work we can- for example- increase the number of different currencies, allow the user to switch between sell and buy currencies with different interest rates. Add deposit and withdrawn to the model. Another generalization is to allow more than one seller and more than one buyer and allow bargain between them.

Another interesting point for further work is to study the stock exchange system and analysis it using PRISM, try to know how to make the right decisions in such systems.

Acknowledgment

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"تقييم التبادلات للعملات البديلة على الإنترنت بإستخدام نموذج PRISM للمراجعة الإحتمالية "

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ملخص باللغة العربية

زادت فى الآونة الأخيرة أهمية التجارة الإلكترونية e-commerce وزاد حجم التعامل من خلالها نتيجة التطور و الإنتشار الهائل و السريع للكمبيوتر والإنترنت.

ومع زيادة التجارة الإلكترونية ووجود مايعرف بالسوق الإلكترونية e-market والتى يكون تحميل الملفات و نقل البيانات والمعلومات بسرعة فائقة- حيث أن سرعة تداول المعلومات ونقلها عامل أساسى فى إتخاذ القرار السليم فى الوقت المناسب- و شراء أماكن تخزين للملفات المرئية جزء مهم من السلع المعروضة، أصبح يوجد إحتياج ضرورى لعملات من نوع آخر، عرفت بإسم العملات البديلة أو المتممة alternative or complementary currencies. وعلى سبيل المثال يوجد فى اليابان وحدها ٦٠٠ نوع من العملات البديلة. و العملات البديلة تعمل بالتوازى مع العملات التقليدية و لا تتنافس معها.

أحد نظم العملات البديلة هو نظام العملة البديلة الخفيفة Lightwieght currency protocol، وقد سمى بهذا الأسم نظرا لكونه مرن فى الإنتقال و التداول بين الأشخاص و المؤسسات ولا يخضع لتحكم الشخص أو المؤسسة التى عملت على إصداره.

ويعتبر نموذج PRISM أحد النماذج الهامة للتقييم الكمى و الكيفي للنظم الدينامية المحدودة finite state systems والتى تتحدد حركتها (إنتقالها من حالة إلى أخرى) بقيم إحتمالية أو عشوائية. وقد إستخدم نموذج PRISM فى تقييم العديد من الأنظمة المختلفة. فعلى سبيل المثال تم إستخدامه لدراسة إتفاقيات أمن المعلومات على شبكة الإنترنت security protocols.

وفى هذه الورقة البحثية تم تقييم نظام العملة البديلة الخفيفة LCP بإستخدام PRISM، حيث تم عمل نموذج للنظام يمثل مكونات النظام: البائع و المشترى و البنك الإفتراضى وأيضا الأنشطة التى يقوم بها كل منهم، ثم دراسة تأثير معدلات الفائدة المختلفة على صافى الربح الخاص بالبنك، دراسة قيمة عمولة البائع على صافى ربحه، و أيضا تم دراسة تأثير سرعة الإعلان عن وجود فرصة للبيع على عمليات البيع و الشراء. ومن بيانات النتائج يمكن إتخاذ القرار المناسب، فمثلا يمكن للبنك تحديد معدل الفائدة الذى يعطى له صافى ربح مرتفع وفى نفس الوقت لايخسر مشتريين على المدى الطويل.

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