



## A Formal Petri Net Based Model for Antivirus Update Agent System

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### Abstract

*In this paper, a formal model for antivirus update agent system is presented based on mobile agent technology and predicate/transition Petri nets. The mobile agent system contains two mobile agents called DCA and UNA. It sends out agents to update antivirus on client computers in a network. Each agent takes on a specified responsibility. First, DCA roams through the network and check the last date of updating of antivirus on client computers. Then, by passing the list of unupdated client computers to UNA, next migration is started. The mobile agent system is modeled with logical agent mobility method (LAM) using Petri nets. Each agent is modeled with a predicate/transition Petri net. In this model, the antivirus updating system consists of a set of components to identify different locations and a set of connectors to specify the interactions among the components. Connectors and components are modeled with PrT Nets.*

**Keywords:** mobile agents, antivirus update agent system, logical agent mobility

### 1. Introduction

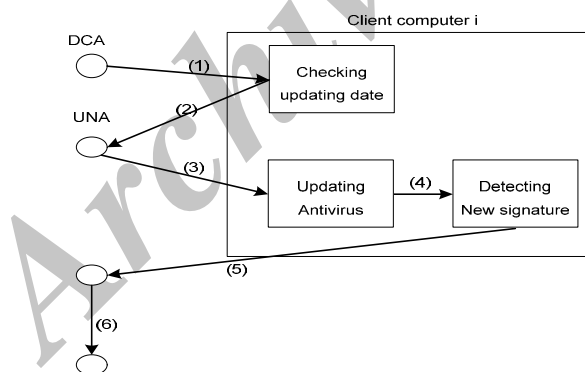
Agent paradigm is considered as a promising option for system and service architecture of the next generation networks. It is because agents are conceptually and intrinsically communication and cooperation oriented [1]. Mobile agents are software abstractions of executing programs [2] that can migrate from machine to machine across a heterogeneous network representing users in various tasks [3]. The use of mobile agents can bring several advantages such as reducing network traffic, improving locality of reference, asynchronous and decentralized execution, load balancing, dynamic adaptation, allowing the user to disconnect from the network when agents are performing a task and flexible maintenance. There are plenty of applications that benefit from mobile agent paradigm such as E-commerce, distributed information retrieval, workflow management, monitoring, and automated software installation.

The major advantages of mobile agents are flexibility and high performance, which are mainly achieved by dynamic transformation from remote call (access) into local performing (accessing code and data). Generally speaking, the strengths of mobile agents can be summarized in: latency reduction and bandwidth conservation, dynamic load balancing, support for disconnected operation and support for dynamic deployment in mobile computing environments [4][5].

The rest of this paper is organized as follows: Section 2 describes the antivirus update agent system. Section 3 gives a brief introduction to Predicate/ Transition Petri nets. Section 4 describes the logical agent mobility method. Section 5 formally models the antivirus update agent system with logical agent mobility method. In section 6, we conclude this work and discuss the future work.

## 2. Antivirus Update Agent System

Antivirus update agent system (AUAS), which is proposed in this paper, is a kind of automated software installation that benefits from the application of mobile agents. Mobile agents have several advantages in automated software installation. By migrating to a client computer, an agent can invoke resource operations locally, eliminating the network transfer of intermediate data. By migrating to various client computers within a network, an agent can continue executing even if the network link goes down. The main tasks for mobile agents in AUAS are to update antivirus and detect new and unknown viruses on client computers in a networked environment. Basically, the act of updating antivirus contains two stages: update signature database and update executable code. Sending out only updated files from previously installed versions, instead of complete update files, will maintain network traffic and avoid congestion in the network routes. But updating executable code typically replaces complete modules of an antivirus scanner. Therefore the antivirus engine needs to have the functionality to register, remove, update and add modules of its own. However, Mobile agent system contains two mobile agents: Date-Check-Agent (DCA) and Update-Newsig-Agent (UNA). DCA and UNA reside in the server, as shown in Figure 1.



*Figure 1. Tasks of mobile agents*

Task of DCA is to roam through the network and check the last date of updating of antivirus (the most recent) on client computer. The UNA is responsible for updating signature database and executable code of antivirus engine. It also detects new or unknown viruses that their signatures don't exist in the signature database of antivirus, yet and send them to server for reporting to antivirus provider company. First DCA visits every client computer, and check the last date of updating of antivirus. If the antivirus has not been updated, it inserts the client name as a record into its Queue (1). Next, it migrates to another client computer within the computer network. Finally, if all

client computers have been visited and checked, DCA will return to server with results as a list of unupdated client computers (2). Server uses these results to specify the traveling itinerary for UNA mobile agent. Then, server assigns mobile agent UNA to travel across specified client computers in order to update (3) and detect new and unknown viruses, respectively (4). After all specified client computers update and detect for new viruses, UNA returns to server with results as new signatures (5). Finally, server will report the new signatures that UNA has returned, to antivirus provider in order to examine the signatures and find the opposition algorithm, if needed. To present our proposed model of the mobile agent system we use Logical Agent Mobility (LAM) method based on a class of Petri nets called predicate transition (PrT) nets. In the rest of this paper, we first give a brief introduction to PrT nets and LAM method for modeling agent mobility. Then, we demonstrate the scenario of updating antivirus within a network using LAM model.

### 3. Predicate/Transition Petri Nets

Here for quick reference we give a brief definition of predicate/transition Petri nets, which will be referred to as PrT nets in this paper. PrT nets are a subclass of high level Petri nets [6]. The reader is referred to [7][8] for a more detailed version of PrT nets. A Predicate Transition Petri net is a seven tuple  $PrT = (P, T, F, \Sigma, L, \varphi, M_0)$ , Where

$P = \{p_1, p_2, \dots, p_m\}$  is a finite set of predicates (first order places),

$T = \{t_1, t_2, \dots, t_n\}$  is a finite set of transitions ( $P \cap T = \emptyset, P \cup T \neq \emptyset$ ),

$F \subseteq (P \times T) \cup (T \times P)$  is a set of arcs.  $(P, T, F)$  forms a directed net. No connections between two predicates or two transitions.  $\Sigma$  is a structure consisting of some sorts of individuals (constants) together with some operations and relations.

$L$  is a labeling function on arcs.  $\varphi$  is a mapping from a set of inscription formulae to transitions. The inscription on transition  $t \in T$ ,  $\varphi(t)$ , is a logical formula built from variables and the individuals, operations, and relations in structure  $\Sigma$ ; Variables occurring free in a formula have to occur at an adjacent input arc of the transition.  $M_0 : P \rightarrow \{0, 1, 2, \dots\}$  is the initial or current marking, which defines number of tokens per predicate. Alternatively, the initial marking can be defined as  $M_0 = \bigcup_{p \in P} M_0(p)$ .

A marking is an arrangement of tokens (elements subject to change) in predicate, representing state. An initial marking represent the initial state. The marking of a predicate under a certain state is a set of instead of a formal sum of tokens. These nets are more or less like first-order logic programs. From the perspective of formal verification, the reachability analysis of these PrT nets is made more efficient. It should be emphasized that transitions are the active components and predicates and tokens are passive. A transition is enabled if each of the input predicate contains tokens. An enabled transition may fire (an event happens) removing one token from each input predicate and depositing one token in each of its output predicates. And a firing sequence is a sequences  $\langle t_0, t_1, \dots, t_n \rangle$  such that it can enabled and fired in  $m_0$ ,  $t_1$  is enabled and fires in  $m_1$ , etc.

Each agent is modeled with a PrT net, called agent net. The interface, the behavior, and the state of an agent are modeled by some input/output predicates for

incoming/outgoing messages, the transitions, and the predicates of the agent net, respectively. Particularly, a concrete state of the agent is a marking of the agent net. More precisely, an agent net is a PrT net, to which an input predicate is associated for incoming messages and an output predicate is associated for outgoing messages. For a more detailed discussion the reader is referred to [9]. We use  $AN$  for agent nets and  $AN.x$  to denote the element  $x \in AN$  for a specific agent, throughout this paper. Tokens in Petri nets are passive, whereas agents are active. To bridge the gap between tokens and agents, a two layer approach has been proposed. Thus, we will allow an agent net to be packed up as part of a token in another PrT net (a system net in next section).

#### 4. Logical Agent Mobility Model

A logical agent mobility (LAM) model specifies a mobile agent system as a set of components (COMP) and a set of (external) connectors (CONN). In deed, a LAM model addresses the behavior of the mobile agents and their interactions in a multi agent system. In this section we give a brief description about LAM. For a rigorous discussion about logical agent modeling please refer to [9] and [10], and for a discussion about agent-oriented software modeling the reader is referred to [11]. Different component identifies different locations for mobile agents. The connectors specify the interactions among the components. A component is a structure, which is made up of an environmental part and an internal connector, both represented with PrT nets. A connector is defined as a PrT net structure to model the connections among certain components. An agent can migrate from one component to another by transition firing at runtime because the whole agent net is used as part of a structured token in the PrT nets modeling components and connectors. Therefore, the migration results in the change of agent location. When an agent is being transferred, no transition in the agent net is enabled. The internal connector of a component is responsible for the dynamic connection of the environmental part with a changing number of mobile agents.

**Definition 1.** A LAM model  $\Lambda = (COMP, CONN)$  is specified by a finite set of components  $COMP = \{(CM_1, SN_1, ICN_1), (CM_2, SN_2, ICN_2), \dots\}$  and a finite set of connectors  $CONN = \{CN_1, CN_2, \dots\}$ , where  $CM_i$  is the location of component  $i$ ,  $SN_i$  is the system net and  $ICN_i$  is the internal connector net.

The system net will be defined later in this section. Agents are distributed in components by means of packing agents up as parts of tokens in system nets and connector nets. The environmental part of a component provides facilities for agent mobility (e.g., execution place, activation, and deactivation) and an internal interface for dynamic connection with a group of agents through the internal connector. We model the environmental part of a component with a system net, as specified in the following.

**Definition 2.** A system net  $SN = (P, T, F, \Sigma, L, \text{p}_{ex-in}, \text{p}_{ex-out}, \text{p}_{in-in}, \text{p}_{in-out}, M_0)$  for component  $CM$  is specified as a PrT net  $(P, T, F, \Sigma, L, M_0)$ , an external input predicate  $\text{p}_{ex-in}$  and an external output predicate  $\text{p}_{ex-out}$ , an internal input predicate  $\text{p}_{in-in}$ , and an internal output predicate  $\text{p}_{in-out}$ .

The structure of a system net belongs to certain components with their associated connector nets can be composed into a PrT structure. Agent mobility (transfer) can be simulated in system nets by transition firings. This is because these net structures and their states can be packed up as parts of token in PrT nets. In a system net structure, if a transition is enabled (activated) an agent (modeled as part of a token), migrates from an input predicate to an output predicate. A sequence of transition firings will move the agent from one component to the other through the component net structure [9].

## 5. Formal Model for AUAS

In this section we describe the formal model for antivirus update agent system based on LAM model and predicate/transition Petri nets. An antivirus is installed on every client computer in the network, and every day, server assigns the mobile agents to update the Antivirus on the client computers and returns with the results. Specifically, there are three machines, namely,  $CM_1$ ,  $CM_2$ , and  $CM_3$ , where  $CM_1$  is the server and  $CM_2$  and  $CM_3$  are the client computers, which their antivirus software should be updated. We use LAM model to formally specify this scenario. The LAM model for this scenario can be defined as  $(COMP, CONN)$ , where  $COMP = \{(CM_1, SN_1, ICN_1), (CM_2, SN_2, ICN_2), (CM_3, SN_3, ICN_3)\}$ ,  $CONN = \{CN\}$ , and  $CN$  is the connector among  $CM_1$ ,  $CM_2$ , and  $CM_3$ .  $CM_2$  and  $CM_3$  provide a service agent for updating antivirus and detecting unknown viruses and checking the last date of updating of antivirus on the client computer. Figure 2, shows the system net  $SN$  for this scenario.

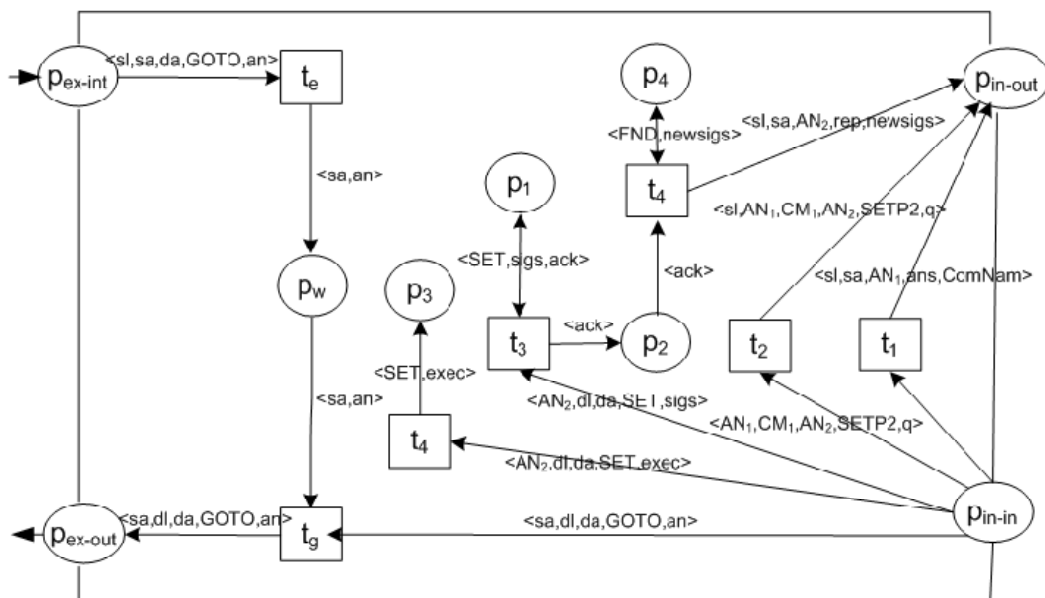


Figure 2. The system net (SN) for updating antivirus

The system nets for  $CM_2$  and  $CM_3$  are similar to  $SN$  but do not have transition  $t_2$  and its associated arcs and labels.  $CM_2$  and  $CM_3$  provide a service agent for updating signature database and updating executable code of antivirus engine and detecting unknown viruses which are modeled by transitions  $t_3$ ,  $t_4$  and  $t_5$ , respectively. They also

provide another service agent for checking the last date of updating of antivirus which is modeled by transition  $t_1$ . Because,  $t_4$  has to start its task after updating signature database, it should wait until it receives an acknowledgement (Ack) from  $t_3$  and then starts to detect unknown viruses. When the task of detecting virus finished, it employs structure  $\langle \text{FND}, \text{newsigs} \rangle$  to represent replies for reporting, where *newsigs* contains new signature that  $t_3$  has found.  $\text{SN}_1$  is also similar to  $\text{SN}$ , but does not have  $t_1$ ,  $t_3$ ,  $t_4$ ,  $t_5$ ,  $p_1$ ,  $p_2$ ,  $p_3$  and their associated arcs and arc labels.  $\text{CM}_1$  also provides a service agent for passing list of the clients that their antivirus need to be updated, from agent DCA to agent UNA. Figure 3 shows the PrT net for connector CN, which builds the connections among  $\text{CM}_1$ ,  $\text{CM}_2$ , and  $\text{CM}_3$ .

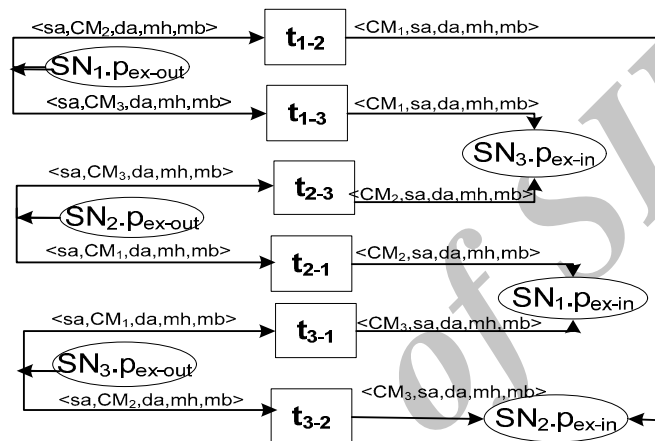


Figure 3. Prt net for connector CN

The internal connector nets  $\text{ICN}_i$  ( $i = 1, 2, 3$ ) is shown in Figure 4.

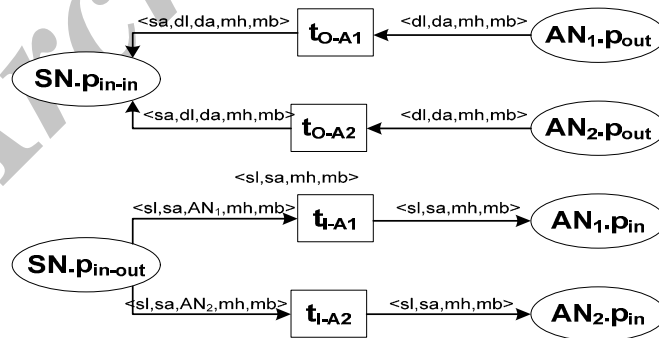


Figure 4. Prt net for internal connector (ICN)

Figure 5, shows the agent net AN for mobile agent DCA ( $\text{AN}_1$ ), which may generate three types of messages as output: requests of migration ( $t_3$ ), checking date ( $t_4$ ) and passing unupdated client names ( $t_5$ ). One of  $t_3$ 's predicate,  $p_2$ , specifies the traveling itinerary of agent DCA. Predicate  $p_3$  specifies the system date.

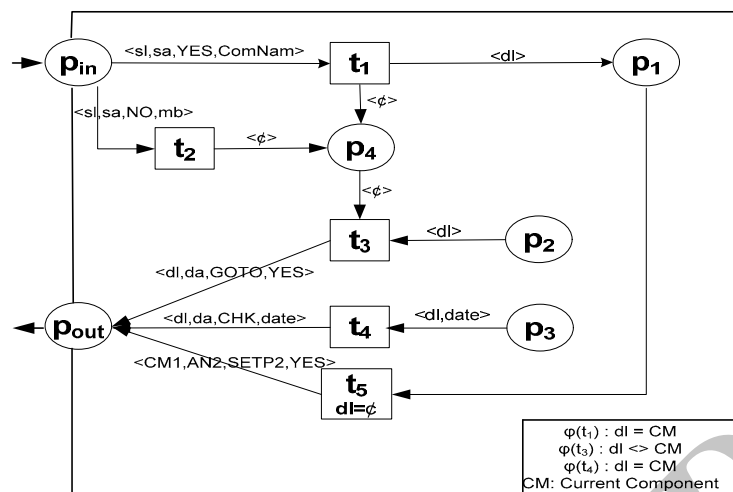


Figure 5. Agent net AN for mobile agent DCA

Transition  $t_1$  receives an affirmative result of updating status from  $CM_2$  ( $CM_3$ ) and save the name of current component into predicate  $p_1$ . Transition  $t_2$  handles negative answers (means current component has updated antivirus). Note that  $AN_1$  has only one type of incoming messages: i.e., feedback if client antivirus is updated or not.

Figure 6, shows the agent net AN for mobile agent UNA ( $AN_2$ ), which may output two types of messages: requests of migration ( $t_2$ ) and updating Antivirus ( $t_3$ ). And it has two types of incoming messages: receive new signatures ( $t_4$ ) and unupdated client names ( $t_1$ ). And Transition  $t_1$  puts these names into predicate  $p_2$ , and in this manner,  $p_2$  (like  $p_1$  in DCA agent) specifies the traveling itinerary of agent UNA ( $AN_2$ ). Predicate  $p_3$  specifies which signatures and modules should be sent for updating. Transition  $t_4$  receives new signatures and puts them into predicate  $p_1$ .

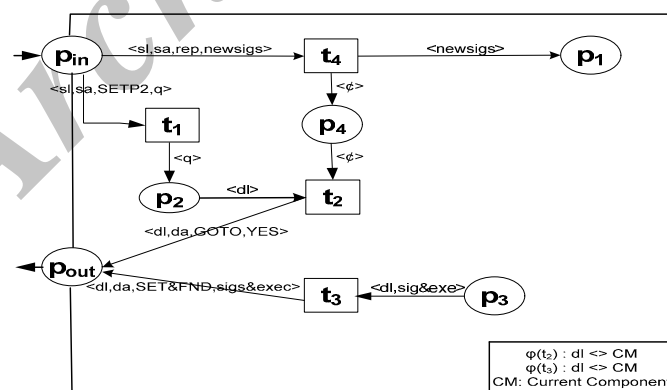


Figure 6. Agent net for mobile agent UNA

Now, we illustrate how the whole model works. Suppose in the initial state,

$$AN_1.M_0(p_2) = \{ \langle CM_2 \rangle, \langle CM_3 \rangle, \langle CM_1 \rangle \}$$

specifies the agent is going to visit CM<sub>2</sub>, CM<sub>3</sub> and CM<sub>1</sub> (for return).

$$AN_1.M_0(p_3) = \{ \langle CM_2, current\_date \rangle, \langle CM_3, current\_date \rangle \}$$

$$AN_1.M_0(p_4) = \{ \langle \emptyset \rangle \}$$

$$SN_1.M_0(p_w) = \{ \langle AN_1, AN(P, T, F, \Sigma, L, \quad, M_0) \rangle, \langle AN_2, AN(P, T, F, \Sigma, L, \quad, M_0) \rangle \}$$

Agents AN<sub>1</sub> (DCA) and AN<sub>2</sub> (UNA) are originally located at CM<sub>1</sub>. SN<sub>2</sub>.M<sub>0</sub>(p<sub>1</sub>) and SN<sub>3</sub>.M<sub>0</sub>(p<sub>1</sub>) contain virus signatures and SN<sub>2</sub>.M<sub>0</sub>(p<sub>3</sub>) and SN<sub>3</sub>.M<sub>0</sub>(p<sub>3</sub>) contain executable code of AV engine.

AN<sub>2</sub>.M<sub>0</sub>(p<sub>3</sub>) contains new signatures and new modules for updating Antivirus:

$$AN_2.M_0(p_4) = \{ \langle \emptyset \rangle \}$$

Other predicates in AN<sub>1</sub>, AN<sub>2</sub>, SN<sub>*i*</sub> (*i*=1, 2, 3), ICN<sub>*i*</sub> (*i*=1, 2, 3), and CN do not have any token. Therefore, at the beginning, no transition at the system level is enabled. However, AN<sub>1</sub>(DCA) is running on CM<sub>1</sub>(SN<sub>1</sub>). The only enabled transition in AN<sub>1</sub> is t<sub>3</sub>, by substitution  $\langle dl = CM_2 \rangle$ . That is, AN<sub>1</sub> request to move to CM<sub>2</sub>, token will pass through AN<sub>1</sub>.p<sub>out</sub>, ICN<sub>1</sub>, SN<sub>1</sub>.p<sub>in-in</sub>, and reach SN<sub>1</sub>.p<sub>ex-out</sub> (the token is  $\langle AN_1, CM_2, AN_1, GOTO, AN \rangle$  at this point). Thus, transition CN.t<sub>1-2</sub> in connector CN is enabled. The firing of CN.t<sub>1-2</sub> puts token  $\langle CM_1, AN_1, AN_1, GOTO, AN \rangle$  into SN<sub>2</sub>.p<sub>ex-in</sub>. during migration, the agent is inactive. As soon as agent arrives at SN<sub>2</sub>, SN<sub>2</sub>.t<sub>e</sub> may activate the agent AN<sub>1</sub>. Thus, the agent restarts. The only enabled transition is t<sub>4</sub> for checking the last date of updating. Through ICN<sub>2</sub>, the message will reach SN<sub>2</sub>.p<sub>in-in</sub>, which enables SN<sub>2</sub>.t<sub>1</sub> to check the date. Then, the result will go through SN<sub>2</sub>.p<sub>in-out</sub>, ICN<sub>2</sub> and, finally, reach AN<sub>1</sub>.p<sub>in</sub>, which enables exactly one of transitions t<sub>1</sub> (if reply is YES) or t<sub>2</sub> (if reply is NO) in AN<sub>1</sub>.

Suppose the reply is YES (means CM<sub>2</sub> has unupdated antivirus) and only t<sub>1</sub> is enabled in AN<sub>1</sub>, then the firing of t<sub>1</sub> puts a token  $\langle \emptyset \rangle$  in p<sub>4</sub>, and enables t<sub>3</sub> for next round of migration and also save the current component name in p<sub>1</sub>. Likewise, agent AN<sub>1</sub> will move to and check the last date of updating of CM<sub>3</sub> and, the result will reach AN<sub>1</sub>.p<sub>in</sub>, suppose reply is NO (means CM<sub>3</sub> has updated antivirus) and only t<sub>2</sub> is enabled in AN<sub>1</sub>. Firing of t<sub>2</sub> deposits a token  $\langle \emptyset \rangle$  in p<sub>4</sub>, and enables t<sub>3</sub> for next round of migration (going back to CM<sub>1</sub>). Upon the arrival of token at SN<sub>1</sub>.p<sub>ex-in</sub>, the SN<sub>1</sub>.t<sub>e</sub> may activate the agent AN<sub>1</sub>. The only enabled transition in AN<sub>1</sub> is t<sub>5</sub>. Firing of t<sub>5</sub> puts unupdated clients list in AN<sub>1</sub>.p<sub>out</sub>. Through ICN<sub>1</sub>, the list will reach SN<sub>1</sub>.p<sub>in-in</sub>, which enables SN<sub>1</sub>.t<sub>2</sub>. Firing of SN<sub>1</sub>.t<sub>2</sub> may activate the agent AN<sub>2</sub>, and through ICN<sub>1</sub>, pass the list to AN<sub>2</sub>. The list specifies the traveling itinerary of agent AN<sub>2</sub> (UNA). Consequently, whereas only CM<sub>2</sub> has unupdated antivirus, the traveling itinerary is:

$$AN_2.M_0(p_2) = \{ \langle CM_2 \rangle, \langle CM_1 \rangle \}$$

It means that AN<sub>2</sub> is going to visit CM<sub>2</sub> and CM<sub>1</sub> (for return). Likewise, agent AN<sub>2</sub> move to CM<sub>2</sub>. Upon the arrival of token  $\langle CM_1, AN_2, AN_2, GOTO, AN \rangle$  at SN<sub>2</sub>.p<sub>ex-in</sub>, the SN<sub>2</sub>.t<sub>e</sub> may activate the agent. Firing of AN<sub>2</sub>.t<sub>3</sub> and through ICN<sub>2</sub>, new signatures and modules will reach SN<sub>2</sub>.p<sub>in-in</sub>, which enables SN<sub>2</sub>.t<sub>3</sub> and SN<sub>2</sub>.t<sub>4</sub>, which in turn update



executable code of antivirus engine and signature database, respectively. After finishing the task of  $SN_2.t_3$ , the  $SN_2.t_3$  puts token  $\langle ack \rangle$  in  $SN_2.p_4$ , which enables  $SN_2.t_4$  for detecting unknown viruses (for this task  $SN_2.t_4$ , use  $SN_2.p_4$  that contains behavior signature database).

Consequently, the reply (new signatures) will go through  $SN_2.p_{in-out}$ ,  $ICN_2$  and, finally, it reaches  $AN_2.p_{in}$ , which enables  $AN_2.t_4$  for saving new signatures in  $AN_2.p_1$ . It puts a token  $\langle \epsilon \rangle$  in  $p_4$ , and enables  $t_2$  for next round of migration (go back to  $CM_1$ ). The sequence of firings is as follows:

$AN_1.t_3$ ,  $ICN_1.t_{O-A1}$ ,  $SN_1.t_g$ ,  $CN.t_{1-2}$ ,  $SN_2.t_e$ ,  $AN_1.t_4$ ,  $ICN_2.t_{O-A1}$ ,  $SN_2.t_1$ ,  $ICN_2.t_{1-A1}$ ,  $AN_1.t_1$ ,  $AN_1.t_3$ ,  $ICN_2.t_{O-A1}$ ,  $SN_2.t_g$ ,  $CN.t_{2-3}$ ,  $SN_3.t_e$ ,  $AN_1.t_4$ ,  $ICN_3.t_{O-A1}$ ,  $SN_3.t_1$ ,  $ICN_3.t_{1-A1}$ ,  $AN_1.t_2$ ,  $AN_1.t_3$ ,  $ICN_3.t_{O-A1}$ ,  $SN_3.t_g$ ,  $CN.t_{3-1}$ ,  $SN_1.t_e$ ,  $AN_1.t_5$ ,  $ICN_1.t_{O-A1}$ ,  $SN_1.t_2$ ,  $ICN_1.t_{1-A2}$ ,  $AN_2.t_1$ ,  $AN_2.t_2$ ,  $ICN_1.t_{O-A2}$ ,  $SN_1.t_g$ ,  $CN.t_{1-2}$ ,  $SN_2.t_e$ ,  $AN_2.t_3$ ,  $ICN_2.t_{O-A2}$ ,  $SN_2.t_5$ ,  $SN_2.t_3$ ,  $SN_2.t_4$ ,  $ICN_2.t_{1-A2}$ ,  $AN_2.t_4$ ,  $AN_2.t_2$ ,  $ICN_2.t_{O-A2}$ ,  $SN_2.t_g$ ,  $CN.t_{2-1}$ ,  $SN_1.t_e$ .

## 6. Conclusion

In this paper, we presented an antivirus update agent system based on mobile agent technology and PrT nets. We introduced two mobile agents; DCA and UNA. The tasks of agents are checking the update status of client computers, updating antivirus and finally detecting unknown signatures. These are for reporting to antivirus provider for applying different algorithm on new signatures to find the methods of opposition to new viruses. This ultimately leads to upgrade the antivirus program.

For modeling this agent system we benefit from logical agent method. A mobile agent system considered as a set of connectors and a set of components. Agent connectors and components are modeled with PrT nets which are called agent connector net and system net, respectively. The mobile agent modeling is an efficient way for analysis of automated software installing like antivirus update agent. Because resource operations can be locally implemented. This will reduce the network traffic, significantly. Moreover, mobile agents can operate asynchronously and less independent of the network. It is more stable than client-server based applications.

## 7. References

- [1] S.N. Gujar, G.R. Bamnote, R.S. Apare, M.A. Pund and S.R. Gupta, "Mobile Agent Based Distribute System Computing in Network," *International Journal of Recent Trends in Engineering*, vol. 2, no. 4, November 2009.
- [2] M.R. Genesereth and S.P. Ketchpel, "Software Agents," *Comm. ACM*, vol. 37, no. 7, pp. 48-53, 1994.
- [3] A. Fuggetta, G. Picco and G. Vigna, "Understanding Code Mobility," *IEEE Trans. Software Eng.*, vol. 24, no. 5, pp. 342-361, May 1998.
- [4] R.S. Gray, G. Cybenko, D. Kotz and D. Rus, "Mobile Agents: Motivation and State of the Art," *Handbook of Agent Technology*, J. Bradshaw, ed., 2001.
- [5] C.G. Harrison, D.M. Chess and A. Kershenbaum, "Mobile Agents: Are They a Good Idea?" *IBM Research Report*, 1995.
- [6] H.J. Genrich, "Predicate/Transition Nets", In: *High level Petri Nets. Theory and Application*. K. Jensen and G. Rozenberg, eds., pp. 3-43, 1991.
- [7] H.J. Genrich, "Predicate/Transition Nets", *Petri Nets: Central Models and Their Properties*, W. Reisig, and G. Rozenberg, eds., pp. 207-247, 1987.
- [8] H.J. Genrich and K. Lautenbach, "System Modeling with High Level Petri Nets," *Theoretical Computer Science*, vol. 13, pp. 109-136, 1981.

- [9] D. Xu, J. Yin, Y. Deng and J. Ding, "A Formal Architectural Model for Logical Agent Mobility," *IEEE Trans. Software Eng.*, vol. 29, no. 1, pp. 31-45, January 2003.
- [10] M. Kohler, D. Moldt and H. Rolke, "Modeling Mobility and Mobile Agents Using Nets Within Nets", Proc. Of *Int. Conf. on Application and Theory of Petri Nets, LNCS*, vol. 2769, pp. 121-139, June 2003.
- [11] H. Xu and S.M. Shatz, "A Framework for Model Based Design of Agent-Oriented Software", *IEEE Trans. Software Eng.*, vol. 29, no. 1, pp. 15-30, Jan. 2003.

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