A Rule Based Knowledge Transaction Model for Mobile Environments

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Abstract. In this paper, we propose a rule based knowledge transaction model for mobile environments. Our model integrates the features of both mobile environment and intelligent agents. We use logic programming as a mathematic tool and formal specification method to study knowledge transaction in mobile environments. Our knowledge transaction model has two major advantages: (1) it has a declarative semantics inherited from logic programming; (2) it is also flexible in the sense that more complex knowledge transaction processes can be represented in our formalism. We show that our model can be used for knowledge transaction representation, formalization and knowledge reasoning in mobile environments. By illustrating a case study we demonstrate that our transaction model is applicable in practical domains in mobile environments.

Key words: knowledge transaction model, mobile environments, logic programming.

1. Introduction

Study on knowledge base and intelligent agent in mobile environments is a very new and meaningful research topic. As a practical scenario in this research area, a company manager may use mobile host to do the rule based decision making and negotiation. We believe that the investigation on intelligent agent and knowledge base in mobile environments is critical because this will help us to find a way to significantly improve current mobile system development. Comparing to the classical non-mobile environment, the mobile environment has a few specific properties such as mobility and disconnection. The issue of data and knowledge transactions has presented new challenges for researchers in mobile environments. Various proposals and systems have been developed in order to deal with database transaction processing in mobile environments [1, 5, 13, 18]. However, there seems to be a separation between multiagent systems and the intelligent agents community on one side, and the mobile agents community on the other side [14, 17, 22, 23]. Most of current research work concentrate on database not knowledge transaction of mobile environments [1, 5, 13, 18], and also these approaches suffer from a lack of formal specifications, which made these approaches be ac hoc for specific system and environment and could not be applied in general problem domains. As so far no any formal study has been conducted to the issue of knowledge transaction in mobile environment, as the first step, this paper addresses the accounts of knowledge transaction processing language and model in mobile environments. We develop a new knowledge transaction model for mobile environments, which integrates the features of

both mobile environment [1, 5, 18] and intelligent agents [22, 23]. Our knowledge transaction model is logic programming based, and has two major advantages: (1) our knowledge transaction model has a declarative semantics inherited from logic programming [3]; (2) Our knowledge transaction model is also flexible in the sense that more complex knowledge transaction processes can be formalized in our formalism. This model is rule based, and can be used for knowledge transaction representation, formalization and knowledge reasoning in mobile environments. We believe that our knowledge transaction language and model will provide a foundation towards the formal specification and development of real world mobile software systems, as the way of traditional software systems development. By illustrating a case study we demonstrate how our transaction model can be used in practical domains in mobile environments.

The paper is organized as follows. In Section 2, we present some background knowledge on intelligent agent and mobile environments, and then introduce our new environmental model. In section 3, we describe the transaction processing in mobile environments and give background knowledge on logic programming. Then we give mobile semantics to some logic programming concepts and formulas. In section 4, we start from knowledge transaction representation language, then impose a set of rules for knowledge transaction in mobile environments. Lastly we formalize our knowledge transaction model. In section 5, we go through a transaction example to demonstrate how our knowledge transaction model can be used in practical scenario. Finally in section 6, we conclude and summarize our work.

2. Environment Model

To develop our knowledge transaction model in mobile environment, we propose a new environment model, which combines the features of mobile environments [1, 5, 13, 18] and intelligent agents [22, 23]. This environment model can be used to study transaction processing [6, 11], intelligent agent and knowledge base in mobile environment. In our paper, we use this model for knowledge transaction study in mobile environments.

When we study the transaction processing in mobile environments, we choose the environment model discussed in the paper [1, 5, 18] to represent the salient features of mobile environments. We are looking at a Home Server (HS) acting as permanent storage of Mobile hosts' (MH) Files. There are Mobile Support Stations (MSS) providing services to a MH when it is within its cell. The MSS is connected to the HS via hardwires. The MH is continuously connected to a MSS via a radio link while accessing data. It may, however, become disconnected either voluntarily or involuntarily. When a MH registers with a MSS, a proxy is created on its behalf. It then performs various services for the MH including caching of profile, broadcasting of sub-profile, acquiring and releasing of locks and management of messages and page validations.

Home server (HS): permanent storage of the mobile host's files.

Mobile Support Station (MSS): provides services to MH (Mobile Host) such as caching, RPC, etc. It also communicates with MH while it is within its cells. A MH is registered with a MSS when it enters into its range. The MSS is connected to the HS via hardwires.

Connectivity: the MH is continuously connected to a MSS via a wireless link while accessing data. It may, however, become disconnected either voluntarily or involuntarily.

Proxy: a proxy is created for a MH when it registers with a MSS. The proxy contacts the HS to obtain the profile of the MH. It then caches this profile on the MSS and broadcasts the sub-profile to the MH. It acquires and releases locks for the MH and manages its page invalidations and messages. The proxy buffers messages and invalidation until the MH is ready to receive them.

A typical transaction model in mobile environments can be described as shown in Figure 1:

Figure 1. Transaction Model in Mobile Environments

There is a centralized database residing in the HS. On each mobile host, MH, there resides a transaction manager which preprocesses transaction operations; a scheduler which controls the relative order in which transaction operations are executed; a recovery manager which is responsible for commitment and abortion management and a cache manager. We assume that the effect of the scheduling is equivalent to an assignment of a local execution time. The MSS of the MH holds a local clock which synchronizes with this local execution time. The recovery manager updates the list of valid pages by having the MH contacting its proxy who then broadcasts an invalidation report. To have control over the problem of cell migration by the MH, the HS holds a global clock against which all local clocks held by the MSS synchronize via some master-slave algorithm [16].

When we study the intelligent agent in the classical environment, we usually use the following environment model [22, 23] as shown in Figure 2.

Figure 2. Intelligent Agent Model

The idea is that function *see* captures the agent's ability to observe its environment whereas function *action* represents the agent's decision making process. Fundamentally, an agent is an active object with the ability to perceive, reason and act. We assume that an agent has explicitly represented knowledge and a mechanism for operating on or drawing inferences from its knowledge. We also assume that an agent has the ability to communicate. This ability consists of perception (the receiving of messages) and action (the sending of messages). In a distributed computing system, agents need to communicate with each other in order to achieve their goals. For this purpose, intelligent agent has been introduced for more flexible and efficient problem solving. We now propose a new environment model, which contains intelligent agents in mobile environment as shown in Figure 3.

Figure 3. Intelligent Agent in Mobile Environment

In the environment model above, we assume that every Mobile Host (MH) has its own knowledge base (KB) and intelligent agent (A11, A12, A13, A21, A22, A23), every MSS has knowledge base residing on it as well, MSS1 and MSS2 represent different MSS in different geographic areas. In Home Server (HS) level, there is a knowledge base that has a set of rules in it. Every intelligent agent on MH will work on behalf of MH that resides on, all the agents in the same geographic area (i.e. controlled by same HS) will negotiate, communicate, and cooperate with each other to achieve the goal for themselves and their systems. Such as agents can do decision making based on the rules in every knowledge base.

3. Mobile Transaction Processing and Logic Programs

3.1 Transactions in Mobile Environments

In this section, we will briefly describe the transaction processing in the mobile environment and give some background knowledge on logic programming, which will

provide a basis for our logic programming based transaction processing language and model.

A typical transaction T in the mobile environment will look like the following [7];

$$\text{Contact-proxy} \rightarrow r[x] \rightarrow w[x] \rightarrow \text{contact-proxy} \rightarrow \text{inv} \rightarrow \dots \rightarrow \text{contact-proxy} \rightarrow s \rightarrow wu \rightarrow \dots \rightarrow c$$

in which the proxy first acquires the appropriate set of locks for the MH. Once a write is executed, the proxy is asked to broadcast a report of invalidation to proclaim the existence of a new version of x . In this example, the MH, after serving a number of operations of the T , decides to go to sleep voluntarily. This is done by first contacting the proxy and then flushing all its dirty pages (to the MSS) and releasing all the write-locks it holds. Thus the process of voluntary sleep is equivalent to a partial commit. It is a partial one because there might be operations still not executed.

Upon waking up, the MH goes through a process similar to start-up, i.e. there will be fetches of data objects (possibly through the proxy) and lock requests through the proxy. The remaining operations are then executed under the covering of the locks. Finally, the transaction is committed through delayed writes [18] to the MSS.

In the case of involuntary sleep the proxy is not contacted and therefore no invalidation report is broadcasted. Hence any update done by MH is lost. This is equivalent to there being another write to undo the previous write. If the MH holds write-locks while it goes to sleep involuntarily and if it does not wake up beyond a certain system prescribed time interval (as measured from the master clock of the HS), the write-locks are cancelled. Thus the overall effect is that of a partial abort. If the wake-up is soon enough, the locks are still with the MH and the execution of rest of the operations can proceed.

It is also possible for a transaction to be started with the MH being in one cell and completed with the MH in another one. In this case, the transaction T becomes

$$\text{contact-proxy} \rightarrow r[x] \rightarrow w[x] \rightarrow \text{contact-proxy} \rightarrow \text{inv} \rightarrow \dots \rightarrow \text{move} \rightarrow \text{contact-proxy} \rightarrow \dots \rightarrow c$$

Here we have lumped all the activities related to handoff and the creation of a new proxy by a new MSS into the operation *move*.

3.2 Extended Logic Programs: Syntax and Semantics

In the non-mobile environment, traditional logic programming is used as a knowledge representation tool. An important limitation of this method is that logic programming does not allow us to deal directly with incomplete information, and therefore we only can get either *yes* or *no* answer from a query. This is because in the traditional logic programming, *closed world assumption* is automatically applied to all predicates [10], and each ground atom is assumed to be false if it does not been certified to be true in the

program. The query evaluation methods of traditional logic programming give no answer to every query that does not succeed, it provides no counterpart for undecided situations which mean the incompleteness of information in classical axiomatic theories.

When we study knowledge transaction in mobile environments, we should clearly understand that there is a major different between the scenario that the transaction fails and the transaction hangs on due to mobile user's sleep. The first scenario is transaction fails in the sense of its negation succeeds, it is a *no* answer for a query. The second scenario is that transaction does not succeed because of incomplete information, the answer is *unknown* for a query transaction, but may become a definite answer *yes* or *no* after sometime. Therefore, in the mobile environment, we need a method which can deal with incomplete information explicitly, and this method should handle the transaction fails in the sense of its negation succeeds and the transaction that does not succeed in the mobile situation. The extended logic programs (ELPs) [4, 10, 19, 21] can overcome such limitation. It contains classical negation $\neg$ in addition to negation-as-failure *not*. Traditional logic programs provide negative information implicitly through closed-world reasoning, an extended logic program can include explicit negative information. In the language of extended programs, we can distinguish between a query which fails in the sense that it does not succeed and a query which fails in the stronger sense that its negation succeeds. By adding mobile semantics to extended logic programs, we can use this method to study knowledge transaction and deal with the incomplete information explicitly in the mobile environment. The applicability of extended logic programs for formalization of reasoning with incomplete information has been demonstrated in paper [4, 10, 15, 20].

Here, we give mobile semantics to some logic programming concepts and formulas in mobile environments, such as classical negation $\neg$, negation-as-failure *not* [9, 10], and *closed world assumption* [10]. The extended logic programs contain classical negation $\neg$, in addition to negation-as-failure *not*. In mobile semantics, classical negation $\neg$ is defined as explicit negative information, is explicit *no* when transaction is explicit fail. In the situation the mobile host is in voluntary or involuntary sleep, and therefore the information is incompleteness, we say it is absent of atom *A*, noted by *not A*, therefore it is unknown.

We consider *closed world assumption* from mobile semantics as following:

If mobile host is in voluntary or involuntary sleep and sleep time is beyond the limited time, we say we assume *not p* as $\neg p$ at this time, *unknown* become *no* for the transaction. We can express *closed world assumption* by the rule

$$\neg p(x) \leftarrow \text{not } p(x), \quad T \leq x$$

Here T is the time limit for mobile hosts' sleep.

A general logic program [10] can be defined as a set of rules of the form

$$A_0 \leftarrow A_1, \dots, A_m, \text{not } A_{m+1}, \dots, \text{not } A_n,$$

Where $0 \leq m \leq n$, and each A_i is an atom.

An extended logic program is a set of rules of the form

$$L_0 \leftarrow L_1, \dots, L_m, \text{not } L_{m+1}, \dots, \text{not } L_n,$$

Where $0 \leq m \leq n$, and each L_i is a literal. A literal is a formula of the form A or $\neg A$, where A is an atom. The negation sign in the negative literal $\neg A$ represents classical negation, not negation-as-failure, so that expression of the form *not* A , occurring in general logic program, is not literal according to this definition.

The answer set of an extended logic program is normally defined as follows [4];

Let Π be an extended program without variables that doesn't contain not, and let Lit be the set of ground literals in the language of Π . The answer set of Π is the smallest subset S of Lit such that

- (i) for any rule $L_0 \leftarrow L_1, \dots, L_m$ from Π , if $L_1, \dots, L_m \in S$, then $L_0 \in S$;
- (ii) if S contains a pair of complementary literals, then $S = Lit$.

The answer set of a program Π that doesn't contain negation-as-failure can be denoted by $\alpha(\Pi)$.

We say Π entails a literal L , denoted as $\Pi \models L$, if L is true in all answer sets of Π .

In our logic programming based transaction language and model, logic programming is used as a formal specification method to describe both static and dynamic transaction processing.

4. A Logic Programming Based Transaction Model

In this section, we define a logic programming based knowledge transaction model which formalizes the knowledge transaction processing in mobile environments. We start with a complete transaction stage by stage including startup, sleep, wakeup, move/handoff, read, write and commit, to give readers a clear idea what activities are supposed to happen on MH, MSS and HS at every stage. Then we define a transaction processing language $\mathcal{L}$, which contains necessary components for specifying knowledge transactions associated with MH, MSS and HS. Finally, we use language $\mathcal{L}$ to specify a knowledge transaction model that imposes all logic rules to capture transaction features in our mobile environment.

4.1 Transaction Processing at Three Levels

Let us go over a transaction processing stage by stage firstly to see what activities happen on MH, MSS and HS on every transaction stage [18]. Here, we specify the activities for transaction start and commit as well.

Startup is the initial powering up of the mobile computer, after registration the MH can start a query or update transaction. Voluntary or involuntary sleep can happen in the transaction. After the sleep, the MH can wake up to continue the transaction. Also, the MH can start the transaction in one MSS cell and move to another MSS cell to continue the transaction. The last activity of transaction is transaction commit or abort. We show all the possibilities of transaction activity in the Figure 4. The transaction activity can be: startup → start → sleep → wakeup → commit; Or startup → start → move → commit. The transaction can follow the arrow in the figure to process the transaction activities.

Figure 4. Transaction Activities in Mobile Environments

There are different steps are involved on every stage of the transaction;

- Startup

Startup is the initial powering up of the mobile computer. The following are the steps involved in starting up the MH:

Step 1: When the MH is powered on, it registers with MSS. Upon registration, the MH notifies the MSS of its HS address.

Step 2: MSS then creates the proxy process which retrieves the MH profile from HS.

Step 3: HS sends the pages in the MH profile, marks the MH as a valid reader of those pages, and notes where to contact the MH.

Step 4: The proxy receives and caches the MH profile.

Step5: The proxy then broadcasts the sub-profile to the MH, and marks the in-MH-cache bit for those pages

Step 6: The MH receives and caches the sub-profile pages.

- Start Transaction

Step1: The MH requests a query or update transaction.

Step 2: The MH acquires a lock if it is an update transaction.

Step 3: The MSS submits the transaction request to HS.

Step 4: The HS does the transaction after MSS submits the transaction request.

- Sleep

There are essentially two types of sleep – voluntary and involuntary. Voluntary sleep is a planned power down, while involuntary sleep is an unplanned power down, i.e., the system crash or run out of battery power.

Voluntary Sleep:

Step1: The MH flushes its dirty pages, gives up any write locks it holds, and informs the proxy of its intention to sleep.

Step 2: The proxy updates MH-sleep-time and buffers messages and invalidations for the MH until the MH wakes up and is ready to receive them.

Involuntary Sleep:

In this case, the proxy does not know that MH is not listening and continues to broadcast invalidations as normal. The MH will recover missed messages upon wakeup by asking for all messages sent after its disconnection time. Suppose the MH is holding a write lock when it goes to sleep involuntarily and in the meanwhile, another writer may ask HS for the write lock. HS forwards the request to the proxy, and the proxy forwards it to the MH. If proxy does not receive the lock from the MH in a limited amount of time, it invalidates the lock and sends it back to HS. The MH will inevitably lose the updates it had made.

One potential problem is that the sleeping MH process may not return (e.g., MH dies, leaves cell), in which case the proxy may wait around aimlessly. To remedy this problem, the MH state is sent to HS after a system-specific amount of time and the proxy process is killed (the decision is made based on MH-sleep-time or time-MH-contacted-proxy). Should the MH return, the wakeup is treated as a startup process.

- Wakeup

Wakeup is the powering up after a MH has been asleep. Although similar to startup, wakeup has slightly different semantics. The wakeup sequence is as follows:

Step1: Upon wakeup, the MH waits to get MSS's address (beacon).

Step 2: Upon receiving the beacon, the MH sends wakeup notification to MSS and requests missed messages. If the MH has saved its MH-sleep-time (possible in the case of voluntary sleep), it sends this information to the MSS. Otherwise, if the MH had gone to sleep involuntarily (e.g., power failure), the MSS proxy uses time-MH-contacted-proxy and time-invalidation-propagated for each page on its cache to calculate how many old messages should be resent.

- Move/Handoff

Step 1: The MH listens for MSS beacon.

Step 2: When the MH notices that it is in a different region, it contacts the new MSS. The message sent includes the MH's id, MH's HS, MH's old MSS, and last-time-MSS-contacted-MH (for the old MSS).

Step 3: The new MSS contacts the old MSS to get the state of the MH proxy.
 Step 4: The old MSS flushes any dirty pages to HS and sends the proxy state to the new MSS.
 Step 5: The new MSS proxy contacts HS to tell it where to contact the MH.
 Step 6: The new MSS proxy broadcasts any invalidations whose timestamp is later than last-time-MSS-contacted-MH.

- Commit Transaction

Step 1: The HS decides if the transaction should be committed or aborted according to the two phase commit protocol, then commits or aborts the transaction.
 Step 2: The HS sends the transaction result to MSS
 Step 3: The MSS broadcasts the transaction result to MH.
 Step 4: The MH updates the local knowledge base according to the transaction result.

4.2 Logic Programming Formalizations I: The Language $\mathcal{L}$

The syntax of the language $\mathcal{L}$ contains variables of three sorts: situation variable s , fluent variable f , and action variable a . Language $\mathcal{L}$ has one predicate $holds(f, s)$, where f is a fluent function, and s is a situation. The predicate $holds(f, s)$ means that fluent f is true at situation s . The term fluent is introduced in paper [2] to represent predicates and functions whose value changes over time. $\mathcal{L}$ also has a resulting function $res(a, s)$, which denotes a situation resulting from situation s by performing action a . To begin with, $\mathcal{L}$ has one initial situation constant S_0 . There are also some other predicates and function symbols. The sorts of their arguments and values will be clear from their use in the rules.

Now we go over an example to show how to represent knowledge in logic programs. We are given a complete description of the initial state of the world and a complete description of the effects of actions, and we are asked to determine what the world will look like after a series of actions is performed [4]. The most frequently cited example of such reasoning is probably the Yale Shooting Problem (YSP) from [12]. In the Yale Shooting Problem [4], there are two fluents: *alive* and *loaded*, and three actions: *wait*, *load*, and *shoot*. We know that the execution of loading leads to the gun being loaded, and that if the gun is shot while it is loaded, a turkey Fred dies. We want to predict that after the execution of actions *load*, *wait*, and *shoot* (in that order), Fred will be dead. It seems that the commonsense argument which leads to this conclusion is based on the so called axiom of inertia which says, “Things normally tend to stay the same”. As a typical normative statement, it can be represented by the rule

$$y1: holds(F, res(A, S)) \leftarrow holds(F, S), not ab(y1, A, F, S)$$

To represent the effect of the actions *load*, *shoot*, and *wait*, we need only the rule

$$y2: holds(loaded, res(load, S)) \leftarrow$$

And the cancellation rule

$y3: ab(y1, shoot, alive, S) \leftarrow holds(load, S)$

Which represent the priority of specific knowledge about the results of actions over the general law of inertia. Let S_0 be the initial state, and suppose we are given that

$y4: holds(alive, S_0)$

Even though the resulting program γ consisting of $y1$ - $y4$ is not stratified, it is possible to show that it has a unique stable model. It is easy to see that γ entails

$holds(alive, res(load, S_0)), and$
 $\neg holds(alive, res(shoot, res(wait, res(load, S_0))))$

Here, we give another knowledge representation example to discuss a very simple knowledge base update transaction. We have only one fluent: *updated*, and two action: *commit* and *abort*. We know that *commit* will result in the knowledge update. We want to predict that after the execution of action *commit*, knowledge base will be updated.

$K1: holds(F, res(A, S)) \leftarrow holds(F, S), not ab(K1, A, F, S)$

To represent the effect of the action *commit*, we need only the rule

$K2: holds(updated, res(commit, S)) \leftarrow$

If the transaction is abort, the knowledge base won't be updated. So we have cancellation rule

$K3: ab(K1, abort, updated, S) \leftarrow$

In our rule based knowledge transaction model, we start to define a transaction processing language $\mathcal{L}$ to formalize transaction related action and fluent function at MH, MSS and HS level. We first introduce different sorts of functions to characterize the basic components of our language. We use actions and fluents to denote transaction processing activities, results and status. Then $\mathcal{L}$ has the following specific action and fluent functions at different level.

- Mobile Host (MH) level

We have the following action functions:

Move(y, x): denotes MH x moves into MSS y cell.

Query(x): denotes MH x has a query transaction request.

Write(x): denotes MH x has a update transaction request.

Acquire-lock(x): denotes MH x requests a lock.
Flush(x): denotes MH x flushes its dirty pages.
Release-lock(x): denotes MH x releases its write lock.
Request-message(x): denotes MH x requests missed message from MSS y .
Fetch-message(x): denotes MH x fetches missed message from MSS y .
Update-knowledge(x): denotes MH x updates local knowledge base according to the transaction result.

We have the following fluent functions:

Registered(y1, x): denotes MH x has registered in MSS1 $y1$.
Query-requested(x): denotes MH x has requested to start a query transaction.
Trans-start(x): denotes MH x has started a transaction.
Update-requested(x): denotes MH x has requested to start a update transaction.
Locked(x): denotes MH x has got a lock for a update transaction.
Vol-slept(x): denotes MH x has gone to voluntary sleep.
Sleep-sig(x): denotes there is a sleep signal on MH x .
Invol-slept(x): denotes MH x has gone to involuntary sleep.
Lock-cancelled(x): denotes write lock has been cancelled on MH x .
Update-lost(x): denotes updates have been lost on MH x .
Wakeup-sig(x): denotes there is a wakeup signal on MH x .
Message-received(x): denotes MH x has received missed messages.
Registered(y2, x): denotes MH x has registered in MSS2 $y2$.
Knowledge-updated(x): denotes MH x has updated the local knowledge base.
Commit-broadcasting(y, x): denotes MSS y has noticed transaction commit to MH x .
Abort-broadcasting(y, x): denotes MSS y has noticed transaction abort to MH x .
Timeout1(x): denotes MH x has expired a certain time1.

- Mobile Support Station (MSS) level

We have the following action functions:

Create-proxy(y1, x): denotes MSS1 $y1$ creates proxy process for MH x .
Create-proxy(y2, x): denotes MSS2 $y2$ creates proxy process for MH x .
Retrieve(y): denotes MSS y proxy retrieves the MH x profile from HS.
Cache(y): denotes MSS y proxy caches the MH profile.
Broadcast(y): denotes MSS y proxy broadcasts the sub-profile to the MH.
Mark(y): denotes MSS y proxy marks the in-MH-cache bit for those broadcasting pages.
Submit(y): denotes the transaction has been submitted to HS by MSS y .
Update-sleeptime(y): denotes MSS y proxy updates MH-sleep-time.
Buffer(y): denotes MSS y proxy buffers the message and invalidations for MH until the MH wakes up.
Page-broadcast(y1, x): denotes MSS1 $y1$ proxy does the page broadcasting to MH x .
Page-broadcast(y2, x): denotes MSS2 $y2$ proxy does the page broadcasting to MH x .
Cancel-lock(y): denotes MSS y proxy cancels the lock for transaction.
Flush(y1): denotes MSS1 $y1$ flushes any dirty pages to HS.

Broadcast(y, x): denotes MSS y broadcasts the transaction result to MH x .

We have the following fluent functions:

Proxy(y1,x): denotes MSS1 $y1$ has created proxy process for MH x .

Proxy(y2,x): denotes MSS2 $y2$ has created proxy process for MH x .

Cached(y): denotes MSS y proxy has cached the MH profile.

Broadcasting(y): denotes MSS y proxy has done the sub-profile broadcasting to MH.

Marked(y): denotes MSS y proxy has marked in-MH-cache bit for pages.

Trans-submitted(y): denotes that the transaction has been submitted by MSS y .

Buffered(y): denotes MSS y proxy has buffered messages and invalidations for MH.

Page-broadcasting(y): denotes MSS y proxy has done the page broadcasting.

Timeout(x): denotes involuntary sleep time has expired on MH x .

Move-sig(y2): denotes MH has moved to MSS2 $y2$.

Flushed(y1): denotes MSS1 $y1$ has flushed any dirty pages to HS.

Commit-broadcasting(y, x): denotes MSS y has noticed transaction committing to MH x .

Abort-broadcasting(y, x): denotes MSS y has noticed transaction aborting to MH x .

Commit-noticed(z, y): denotes HS z has given transaction commit notice to MSS y .

Abort-noticed(z, y): denotes HS z has given transaction abort notice to MSS y .

- Home Server (HS) level

We have the following action functions:

Send-page(z, y): denotes HS z sends the pages to MSS y in the MH profile.

Mark-MH(z): denotes HS z marks the MH as a valid reader of those pages.

Do-trans(z): denotes HS z does the transaction.

Kill-proxy(z, y): denotes HS z kills the MSS y proxy process.

Send-dirtypage(z,y2): denotes HS z sends any dirty pages to new MSS2 $y2$.

Commit(z): denotes HS z commits the transaction.

Notice-commit(z, y): denotes HS z gives transaction commit notice to MSS y .

Notice-abort(z, y): denotes HS z gives transaction abort notice to MSS y .

We have the following fluent functions:

Sent(z, y): denotes HS z has sent pages to MSS y .

MH-marked(z): denotes HS z has marked the MH as a valid reader for those pages.

Trans-started(z): denotes HS z has started transaction processing.

Proxy-killed(z, y): denotes HS z has killed MSS y proxy process for MH.

Trans-committed(z): denotes transaction has been committed on HS z .

Commit-agreed(z): denotes HS z has got transaction commit agreement.

Abort-agreed(z): denotes HS z has got transaction abort agreement.

Timeout2(z): denotes HS z has expired a certain time2.

Commit-noticed(z, y): denotes HS z has given transaction commit notice to MSS y .

Abort-noticed (z, y): denotes HS z has given transaction abort notice to MSS y .

4.3 Logic Programming Formalizations II: Modeling

Based on the transaction processing language $\mathcal{L}$ defined above, we start to specify and impose all necessary rules to formalize a logic programming based transaction processing model in mobile environment, which models all transaction processing activities, requests, results and constraints on MH, MSS, and HS three levels.

- **Mobile Host (MH) level**

Register

When MH moves into MSS cell, it is registered. The rule for this is as following:

$$r1: \text{holds}(\text{registered}(y1, x), \text{res}(\text{move}(y1, x), s)) \leftarrow$$

After an action $\text{move}(y1, x)$ happens, $\text{res}(\text{move}(y1, x), s)$ becomes the current situation, and $\text{registered}(y1, x)$ is true.

Start a query or update transaction

For a query transaction, as long as MH has a transaction request, the transaction should be started straight away. The rules are as following:

$$r2: \text{holds}(\text{query-requested}(x), \text{res}(\text{query}(x), s)) \leftarrow$$

After an action $\text{query}(x)$, i.e., the MH submits a query request, $\text{res}(\text{query}(x), s)$ becomes the current situation, and $\text{query-requested}(x)$ becomes true.

$$r3: \text{holds}(\text{trans-start}(x), s) \leftarrow \text{holds}(\text{query-requested}(x), s)$$

After $\text{query-requested}(x)$ becomes true, $\text{trans-start}(x)$ is true for a query transaction.

For an update transaction, after MH has a write request, the lock need to acquired firstly to start this transaction. The transaction will start after the lock is available.

$$r4: \text{holds}(\text{update-requested}(x), \text{res}(\text{write}(x), s)) \leftarrow$$

After an action $\text{write}(x)$, i.e., the MH submits a write request, $\text{res}(\text{write}(x), s)$ becomes the current situation, and $\text{update-requested}(x)$ becomes true.

$$r5: \text{holds}(\text{trans-start}(x), s) \leftarrow \text{holds}(\text{locked}(x), \text{res}(\text{acquire-lock}(x), \text{res}(\text{write}(x), s))), \\ \text{holds}(\text{update-requested}(x), s)$$

After an action $\text{write}(x)$, another action $\text{acquire-lock}(x)$ takes place, $\text{res}(\text{acquire-lock}(x), \text{res}(\text{write}(x), s))$ becomes current situation, $\text{locked}(x)$ becomes true, i.e., the MH gets a lock. If both $\text{locked}(x)$ and $\text{update-requested}(x)$ are true, $\text{trans-start}(x)$ is true as well, i.e., a update transaction starts.

Sleep

For a voluntary sleep, the MH informs the proxy of its intention to sleep, and then flushes its dirty pages, gives up any write-locks it holds, after these, the MH goes to voluntary sleep.

$$r6: \text{holds}(\text{vol-slept}(x), \text{res}(\text{release-lock}(x), \text{res}(\text{flush}(x), s))) \leftarrow \text{holds}(\text{sleep-sig}(x), s)$$

After *sleep-sig(x)* becomes true, action *flush(x)* and *release-lock(x)* are taken place, and *vol-slept(x)* becomes true eventually, i.e., the MH is in voluntary sleep.

For an involuntary sleep, we suppose that the MH is holding a write-lock when it goes to involuntary sleep and in the meantime, lock is asked by another writer. HS forwards the request to the proxy, and the proxy forwards it to the MH. If proxy does not receive the lock from the MH in a limited amount of time, it invalidates the lock and sends it back to HS. And therefore, the MH will inevitably lose the updates it had made.

r7: holds(involver-slept(x), s) ←

The *involver-slept(x)* is true, i.e., the MH is in involuntary sleep.

r8: holds(lock-cancelled(x), s) ← holds(involver-slept(x), s), holds(timeout(x), s)

If both *involver-slept(x)* and *timeout(x)* are true, *lock-cancelled(x)* will become true as well, i.e., if the MH is in involuntary sleep and doesn't response to proxy in a period limit time, then the lock is cancelled on the MH.

r9: holds(update-lost(x), s) ← holds(lock-cancelled(x), s)

After *lock-cancelled(x)* becomes true, *update-lost(x)* becomes true as well, i.e., the MH loses all its update.

Wake up

Upon the MH waking up, the MH sends wakeup notification to MSS and requests missed messages. If the MH has saved its MH-sleep-time, it sends this information to MSS. If the MH wakes up from involuntary sleep, the MSS proxy will use time-MH-contacted-proxy and time-invalidation-propagated for each page on its cache to calculate how many old messages should be resent.

*r10: holds(message-received(x), res(fetch-message(x), res(request-message(x), s))) ←
holds(wakeup-sig(x), s)*

After *wakeup-sig(x)* becomes true, the MH has action *request-message(x)* and *fetch-message(x)*, then *res(fetch-message(x), res(request-message(x), s))* becomes current situation, then *message-received(x)* is true on MH.

Move/handoff

When the MH notices that it is in a different region, it contacts the new MSS. The message sent includes the MH's id, MH's HS, MH's old MSS and last-time-MSS-contacted-MH for old MSS. After new MSS contact HS and old MSS, the MSS proxy broadcasts any invalidations whose timestamp is later than last-time-MSS-contacted-MH.

r11: holds(registered(y2, x), s) ← holds(move-sig(y2, x), res(move(y2, x), s))

After action *move(y2, x)* on MH, *move-sig(y2, x)* becomes true, and then *registered(y2, x)* becomes true as well, which means the MH moves and registers in new MSS.

r12: holds(message-received(y2, x), s) ← holds(registered(y2, x), s)

After *registered(y2, x)* is true, *message-received(y2, x)* becomes true as well, the MH receives necessary messages from new MSS.

Transaction Commit

After MH requests a transaction, the transaction will be committed or aborted on the HS according to the two phase commit protocol [6]. After that HS sends transaction result to MSS, the MSS broadcasts the transaction result to MH, the MH updates the local knowledge base accordingly based on transaction commit or abort. If after transaction

started for a period time (timeout1), the MH host still has not got any transaction commit or abort notice from MSS for whatever reason, we use *closed world assumption* in this case, assume *not p* as $\neg p$ at this time, unknown (*not*) becomes no ($\neg$) for the transaction.

*r13: holds(knowledge-updated(x), res(update-knowledge(x), s)) $\leftarrow$
holds(commit-broadcasting(y, x), s), holds(trans-start(x), s)*

If both *commit-broadcasting(y, x)* and *trans-start(x)* are true, then action *update-knowledge(x)* happens, *knowledge-updated(x)* becomes true.

*r14: $\neg$ holds(knowledge-updated(x), s) $\leftarrow$
holds(abort-broadcasting(y, x), s), holds(trans-start(x), s)*

If both *abort-broadcasting(y, x)* and *trans-start(x)* are true, then we know *knowledge-updated(x)* is not true.

*r15: $\neg$ holds(knowledge-updated(x), s) $\leftarrow$ holds(trans-start(x), s), holds(timeout1(x), s),
not holds(commit-broadcasting(y, x), s), not holds(abort-broadcasting(y, x), s)*

If neither *commit-broadcasting(y, x)* nor *abort-broadcasting(y, x)* is holds (true), and time is over the limit, i.e., *timeout1(x)* is holds, then we know *knowledge-updated(x, s)* is not true, it is false.

• Mobile Support Station (MSS) level

Register

After the MH registers with MSS, MSS creates the proxy process which retrieves the MH profile from HS, the proxy receives and caches the MH profile, and then broadcasts the sub-profile to the MH, and marks the in-MH-cache bit for those pages. The rules for these are as following:

r1: holds(proxy(y, x), res(create-proxy(y, x), s)) $\leftarrow$ holds(registered(y, x), s)

After *registered(y, x)* becomes true, the action *create-proxy(y, x)* happens, *res(create-proxy(y, x), s)* becomes current situation, then *proxy(y, x)* is in holds, which means MSS creates a proxy for the MH.

r2: holds(cached(y), res(cache(y), res(retrieve(y), s))) $\leftarrow$ holds(proxy(y, x), s)

After *proxy(y, x)* becomes true, action *retrieve(y)* and *cache(y)* take place, then *cached(y)* is true, i.e., MSS has cached for MH.

r3: holds(broadcasting(y, x), res(broadcast(y, x), s)) $\leftarrow$ holds(cached(y, x), s)

After *cached(y, x)* becomes true, action *broadcast(y)* takes place, then *broadcasting(y)* is true.

r4: holds(marked(y), res(mark(y), s)) $\leftarrow$ holds(broadcasting(y, x), s)

After *broadcasting(y)* becomes true, action *mark(y)* happens, then *marked(y)* becomes true, i.e., the MSS has marked broadcasting pages for MH.

Start a query or update transaction

After MH requests a query or update, MSS submits this transaction request to HS on behalf of MH. If it is a write request, the lock needs to be acquired firstly to submit this transaction.

r5: holds(trans-submitted(y), res(submit(y), s)) $\leftarrow$ holds(query-requested(x), s)

After *query-requested(x)* becomes true, action *submit(y)* happens, *res(submit(y), s)* becomes current situation, *trans-submitted(y)* then becomes true.

*r6: holds(trans-submitted(y), res(submit(y), s)) ←
holds(locked(x), s), holds(update-required(x), s))*

If both *update-required(x)* and *locked(x)* are true, action *submit(y)* will happen and *trans-submitted(y)* then becomes true.

Sleep

For the voluntary sleep, the proxy updates MH-sleep-time and buffers messages and invalidations for the MH until the MH wakes up and is ready to receive them.

*r7: holds(buffered(y), res(buffer(y), res(update-sleeptime(y), s))) ←
holds(vol-slept(y, x), s)*

After *vol-slept(y, x)* becomes true, action *update-sleeptime(y)* and *buffer(y)* will happen continuously and then *res(buffer(y), res(update-sleeptime(y), s))* become the current situation, *buffered(y)* becomes true.

In the involuntary sleep case, the proxy doesn't know that MH is not listening and continues to broadcast invalidations as normal. If the MH is holding a write-lock when it goes to involuntary sleep, in the meantime the lock is asked by another writer, the proxy forwards this request to the MH. If proxy does not receive the lock from the MH in a limited amount of time, it invalidates the lock and sends it back to HS.

r8: holds(page-broadcasting(y, x), res(page-broadcast(y, x), s)) ←

In the involuntary sleep case, action *page-broadcast(y, x)* still happens, *page-broadcasting(y, x)* is still true.

*r9: holds(lock-cancelled(y, x), res(cancel-lock(y, x), s)) ←
holds(invol-slept(x), s), holds(timeout(x), s))*

If both *invol-slept(x)* and *timeout(x)* are true, action *cancel-lock(y, x)* will happen, i.e., proxy will cancel the lock for MH and then *lock-cancelled(y, x)* becomes true.

Wake up

Upon the MH waking up, the MH sends wakeup notification to MSS and requests missed messages. If the MH has saved its MH-sleep-time, it sends this information to MSS. If the MH wakes up from involuntary sleep, the MSS proxy will use time-MH-contacted-proxy and time-invalidation-propagated for each page on its cache to calculate how many old messages should be resent.

*r10: holds(page-broadcasting(y, x), res(page-broadcast(y, x), s)) ←
holds(wakeup-sig(x), s)*

If *wakeup-sig(x)* is true, action *page-broadcast(y, x)* will take place, then *page-broadcasting(y, x)* becomes true.

Move/handoff

After MH contacts and registers in the new MSS, the new MSS contacts the old MSS to get the MH proxy status. The old MSS flushes any dirty pages to HS and sends the proxy status to the new MSS. The new MSS proxy contacts HS to tell it where to contact the MH. The new MSS proxy broadcasts any invalidations whose timestamp is later than last-time-MSS-contacted-MH.

r11: holds(proxy(y2, x), res(create-proxy(y2, x), s)) ← holds(registered(y2, x), s)

After $registered(y2, x)$ becomes true, i.e., MH has registered in new MSS, action $create-proxy(y2, x)$ happens, and then $proxy(y2, x)$ is true.

$r12: holds(flushed(y1), res(flush(y1), s)) \leftarrow holds(move-sig(y2, x), s)$

After $move-sig(y2, x)$ becomes true, action $flush(y1)$ happens and then $flushed(y1)$ becomes true, i.e., old MSS flushes dirty pages for MH.

$r13: holds(page-broadcasting(y2, x), res(page-broadcast(y2, x), s)) \leftarrow holds(proxy(y2, x), s)$

After $proxy(y2, x)$ becomes true, i.e., new MSS has created proxy for MH, action $page-broadcast(y2, x)$ happens, $res(page-broadcast(y2, x), s)$ becomes current situation, $page-broadcasting(y2, x)$ then becomes true.

Transaction Commit

After MSS gets the transaction commit or abort notice from HS, the MSS will broadcast the transaction result to MH accordingly.

$r14: holds(commit-broadcasting(y, x), res(broadcast(y, x), s)) \leftarrow holds(commit-noticed(z, y), s)$

If $commit-noticed(z, y)$ is true, i.e., MSS has got commit notice from HS, action $broadcast(y, x)$ will happen, $commit-broadcasting(y, x)$ then becomes true, which means MSS will sent commit broadcasting to MH.

$r15: holds(abort-broadcasting(y, x), res(broadcast(y, x), s)) \leftarrow holds(abort-noticed(z, y), s)$

If $abort-noticed(z, y)$ is true, i.e., MSS has got abort notice from HS, action $broadcast(y, x)$ will happen, $abort-broadcasting(y, x)$ then becomes true, which means MSS will sent abort broadcasting to MH.

• Home Server (HS) level

Register

At registration stage, HS sends the pages in the MH profile, marks the MH as a valid reader of those pages, and notes where to contact the MH.

$r1: holds(sent(z, y), res(send-page(z, y), s)) \leftarrow holds(proxy(y, x), s)$

If $proxy(y, x)$ is true, action $send-page(z, y)$ will take place, then $sent(z, y)$ becomes true.

$r2: holds(MH-marked(z), res(mark-MH(z), s)) \leftarrow holds(sent(z, y), s)$

After $sent(z, y)$ becomes true, action $mark-MH(z)$ will happen, $MH-marked(z)$ then is true as well.

Start transaction

After MH requests a query or update transaction and MSS submits this transaction request to HS, the HS starts the transaction. In update transaction situation, MSS submits transaction only when lock is available.

$r3: holds(trans-start(z), res(do-trans(z), s)) \leftarrow holds(trans-submitted(y), s)$

After transaction request is submitted by MSS, i.e., $trans-submitted(y)$ is true, action $do-trans(z)$ happens, and $trans-start(z)$ then becomes true, the transaction starts.

Sleep

The sleeping MH process may not return (e.g., MH dies, leaves cell), in this case the proxy may wait around aimlessly. To remedy this problem, the MH status is sent to HS after a system-specific amount of time and the proxy process is killed. The decision is made based on MH-sleep-time or time-MH-contacted-proxy.

$$\begin{aligned} r4: & \text{holds(proxy-killed}(z, y), \text{res(kill-proxy}(z, y), s)) \leftarrow \\ & \text{holds(timeout}(x), s), \text{holds(vol-slept}(x), s) \\ r5: & \text{holds(proxy-killed}(z, y), \text{res(kill-proxy}(z, y), s)) \leftarrow \\ & \text{holds(timeout}(x), s), \text{holds(invol-slept}(x), s) \end{aligned}$$

If MH goes to sleep, i.e., *vol-slept*(*x*) or *invol-slept*(*x*) is true, and also *timeout*(*x*) is true as well, action *kill-proxy*(*z*, *y*) will happen and *proxy-killed*(*z*, *y*) then becomes true.

Move/handoff

After MH moves to new MSS, the old MSS will flush any dirty pages to HS and new MSS will contact HS to get these dirty pages regarding the MH.

$$r6: \text{holds(sent}(z, y2), \text{res(send-dirty}(z, y2), s)) \leftarrow \text{holds(proxy}(y2, x), s)$$

After new MSS creates proxy for MH, i.e., *proxy*(*y2*, *x*) is true, action *send-dirty*(*z*, *y2*) will happen, *sent*(*z*, *y2*) then becomes true, the pages is sent to MSS from HS.

Transaction Commit

According to the two phase commit protocol, if all involved MHs agree to commit the transaction, then the transaction will be committed. If any of them does not agree with commit and want to abort the transaction, then transaction will be aborted. If after a period time (*timeout2*) the transaction is still not be agreed to be committed, then we use *closed world assumption* here to assume the transaction won't be committed any more, unknown (*not*) becomes no ($\neg$) in this scenario. For example in the case one of the involved MH has gone to voluntary or involuntary sleep and therefore no commit agreement can be available from that MH during this time duration. After transaction has been committed or aborted, the HS will send transaction commit or abort notice to MSS.

$$\begin{aligned} r7: & \text{holds(trans-committed}(z), \text{res(commit}(z), s)) \leftarrow \\ & \text{hold(commit-agreed}(z), s), \text{holds(trans-start}(z), s), \text{not holds(abort-agreed}(z), s) \end{aligned}$$

If *commit-agreed*(*z*) and *trans-start*(*z*) are true, and *abort-agreed*(*z*) is not true, i.e. all the parts agree to commit and none of them agrees to abort, then commit action *commit*(*z*) will take place, the transaction is committed, i.e., *trans-committed*(*z*) becomes true.

$$r8: \neg \text{holds(trans-committed}(z), s) \leftarrow \text{holds(abort-agreed}(z), s), \text{holds(trans-start}(z), s)$$

If any part agrees to abort, i.e. *abort-agreed*(*z*) is true, *trans-committed*(*z*) will not be true any more.

$$\begin{aligned} r9: & \neg \text{holds(trans-committed}(z), s) \leftarrow \\ & \text{holds(timeout2}(z), s), \text{holds(trans-start}(z), s), \text{not holds(trans-committed}(z), s) \end{aligned}$$

If transaction commit is not be confirmed, i.e. *trans-committed*(*z*) is not holds, and time is over the limit, i.e. *holds(timeout2*(*z*, *s*), the transaction commit will be assumed to be false, i.e. $\neg \text{holds(trans-committed}(z), s)$.

$$\begin{aligned} r10: & \text{holds(commit-noticed}(z, y), \text{res(notice-commit}(z, y), s)) \leftarrow \\ & \text{hold(trans-committed}(z), s) \end{aligned}$$

The share1 will not be invested if the risk is high. The cancellation rule is

$$i2: \neg \text{holds}(\text{invest}(\text{share1}, \text{MH1}), s) \leftarrow \text{hold}(\text{risk}(\text{share1}, \text{MH1}), s)$$

The MH1 want to invest share1 based on the rule $i1$, $i2$ and initial fact $t2$. MH1 requests an update transaction to do the investment and update its local knowledge base accordingly if this investment transaction is committed in HS level. According to MH level $r4$ and $r5$ in section 4, we have

$$\begin{aligned} t3: & \text{holds}(\text{update-requested}(\text{MH1}), \text{res}(\text{write}(\text{MH1}), s)) \leftarrow \\ t4: & \text{holds}(\text{trans-start}(\text{MH1}), s) \leftarrow \text{holds}(\text{locked}(\text{MH1}), \text{res}(\text{acquire-lock}(\text{MH1}), \\ & \text{res}(\text{write}(\text{MH1}), s))), \text{holds}(\text{update-requested}(\text{MH1}), s) \end{aligned}$$

After MH1 requests an update transaction and the lock has been acquired, the transaction will start.

MSS1 will submit this transaction request to HS. According to MSS level $r6$ in section 4, we have

$$t5: \text{holds}(\text{trans-submitted}(\text{MSS1}), \text{res}(\text{submit}(\text{MSS1}), s)) \leftarrow \text{holds}(\text{locked}(\text{MH1}), s), \text{holds}(\text{update-required}(\text{MH1}), s)$$

As long as MSS submits the transaction to HS, the HS will start the transaction. According to HS level $r3$ in section 4, we have

$$t6: \text{holds}(\text{trans-start}(\text{HS}), \text{res}(\text{do-trans}(\text{HS}), s)) \leftarrow \text{holds}(\text{trans-submitted}(\text{MSS1}), s)$$

Then HS will send commit request to all involved MHs for this investment, if all the involved MHs response yes based on the investment rules, the transaction is committed according to the two phase commit protocol. The HS sends commit notice to MSS. According to the HS level $r7$ and $r10$, we have

$$\begin{aligned} t7: & \text{holds}(\text{trans-committed}(\text{HS}), \text{res}(\text{commit}(\text{HS}), s)) \leftarrow \text{hold}(\text{commit-agreed}(\text{HS}), s), \\ & \text{not holds}(\text{abort-agreed}(\text{HS}), s), \text{holds}(\text{trans-start}(\text{HS}), s) \\ t8: & \text{holds}(\text{commit-noticed}(\text{HS}, \text{MSS1}), \text{res}(\text{notice-commit}(\text{HS}, \text{MSS1}), s)) \leftarrow \\ & \text{hold}(\text{trans-committed}(\text{HS}), s) \end{aligned}$$

The MSS1 then broadcasts the commit result to MH1. According to MSS level $r14$ in section 4, we have

$$t9: \text{holds}(\text{commit-broadcasting}(\text{MSS1}, \text{MH1}), \text{res}(\text{broadcast}(\text{MSS1}, \text{MH1}), s)) \leftarrow \text{holds}(\text{commit-noticed}(\text{HS}, \text{MSS1}), s)$$

All involved MHs will update the local knowledge base accordingly after the MSS broadcasts the commit result to MHs. According to the MH level $r13$ in section 4, we have

$$\begin{aligned} t10: & \text{holds}(\text{knowledge-updated}(\text{MH}), \text{res}(\text{update-knowledge}(\text{MH}), s)) \leftarrow \\ & \text{holds}(\text{commit-broadcasting}(\text{MSS1}, \text{MH}), s), \text{holds}(\text{trans-start}(\text{MH}), s) \end{aligned}$$

Base on the formal definition given in section 4, we have $I(D)$ to denote initial facts and rules with respect to investment domain, we have R to denote the set of general knowledge transaction rules. In this example, $I(D) = \{t1, t2, i1, i2\}$, $R = \{t3, t4, t5, t6, t7, t8, t9, t10\}$, therefore we know the fact ϕ is entailed here from $R \cup I(D)$, i.e. $R \cup I(D) \models \phi$, we have ϕ here as following:

$$\begin{aligned} \phi = & \{ \text{holds}(\text{trans-committed}(\text{HS}), \text{res}(\text{commit}(\text{HS}), S_0)), \\ & \text{holds}(\text{knowledge-updated}(\text{MH}), \text{res}(\text{update-knowledge}(\text{MH}), S_0)), \\ & \text{holds}(\text{invest}(\text{share1}, \text{MH1}), S_0) \} \end{aligned}$$

i.e. the facts that transaction is committed on HS, knowledge base is updated on MHs and share1 is invested on MH1 are entailed in this example.

6. Conclusion

In this paper, we developed and formalized a rule based knowledge transaction model for mobile environments, our model integrated the features of both mobile environments and intelligent agents. We have justified that extended logic programming is a suitable formal specification method to study knowledge transaction in mobile environments. Our knowledge transaction model can be used for knowledge transaction representation, formalization and reasoning in mobile environments. We also demonstrated how our transaction model can be used in practical domains in mobile environments. In the future, we will use this knowledge transaction model to discuss the distributed knowledge transaction processing and multiagent systems in mobile environments.

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