Formal Description of Mobile IPv6 Protocol

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Abstract. Formal technique is the basis of automatic test generation. Mobile IPv6 is a complicated and distributed protocol with many discrete behaviors. It is difficult to describe the entire protocol by some formal model. The idea of hierarchical protocol description is proposed. Finite state machine (FSM) and multi-node finite state machine (MN-FSM) are defined. Mobile IPv6 protocol is divided into four layers. FSM and MN-FSM are used to describe network system, mobile IPv6 nodes, inner data structure management and discrete behaviors. Test sequences can be generated automatically based on these formal models.

1 Introduction

Mobile IPv6 is the mobility solution in network layer [1]. Conformance testing is very necessary to guarantee an implementation consistent to its standard specification [2]. Mobile IPv6 is in its growing stage, so it is necessary to study mobile IPv6 conformance testing.

Test generation is the key issue in conformance testing. Formal technique is the basis of automatic test generation. How to describe mobile IPv6 by formal technique must be solved before test generation. Considering state explosion and plentiful discrete behaviors, it is not practical to describe the entire mobile IPv6 protocol by some formal model. We propose the idea of hierarchical protocol description. Finite state machine (FSM) and multi-node finite state machine (MN-FSM) are defined to describe mobile IPv6.

2 Hierarchical Protocol Description

Mobile IPv6 protocol can be described in four sections, which are network system, nodes, inner data structure (IDS) management and discrete behaviors. Four types of nodes, including mobile node (MN), correspondent node (CN), home agent (HA) and common router (CR), are defined. Each type of node is also a self-governed system. Also, three types of IDSs, including binding cache (BC), binding update list (BUL) and home agent list (HAL), are defined.

For distributed system, compared to trying to describe entire protocol by single formal model, hierarchical description can reduce complexity [3]. Mobile IPv6 protocol can be described in four layers (Fig 1).

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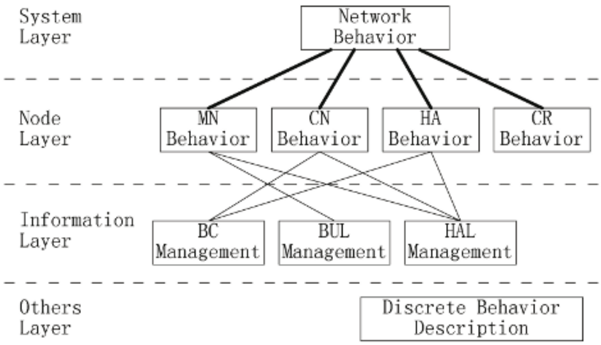

Fig. 1. The composition of mobile IPv6 protocol. Four types of nodes (MN, CN, HA and CR) are the core section. Mobile IPv6 network is composed of these types of nodes. IDS management is the most important mission that these nodes must perform. Discrete behavior description is the necessary section.

Finite state machine (FSM) is the most popular model for describing network protocols [4]. We add a behavior function to the traditional FSM definition, which is used to describe behaviors that don't change state nor generate output event.

2.1 Description for Network System (NS)

The state of mobile IPv6 network system can be described by the following properties.

1. M_p: location of mobile node. M_p = {home, foreign}.
2. HR_{flag}: flag of home registration (HR). $HR_{flag} = \{0, 1\}$.
3. CR_{flag}: flag of common registration (CR). $CR_{flag} = \{0, 1\}$.

Let S be the set of states for network system. $S = M_p \times HR_{flag} \times CR_{flag}$. Removing the invalid or unstable states from S, only three valid states remain is S. For mobile IPv6 network, all input events are manual behaviors. Under any circumstance, no output event happens, but related behaviors will happen. State transition graph for network system is shown in Fig 2.

2.2 Description for Mobile IPv6 Nodes

We take MN description as an example to present how to describe mobile IPv6 nodes. The MN's main task is to maintain its current location on home agent and correspondent nodes. In one lifecycle of movement, MN's behaviors can be presented as follows (Fig 3).

1. At first, MN attaches at home link and is in stable state.
2. MN detects movement from home link, and then generates care-of address.
3. Mobile node performs HR, and then is in stable state.
4. MN receives a tunnel packet, performs CR, and then is in stable state.
5. MN receives another tunnel packet, repeat last step.
6. MN detects itself returning to home link, and then de-registers HR and all CRs.
7. Then MN completes one lifecycle of movement.

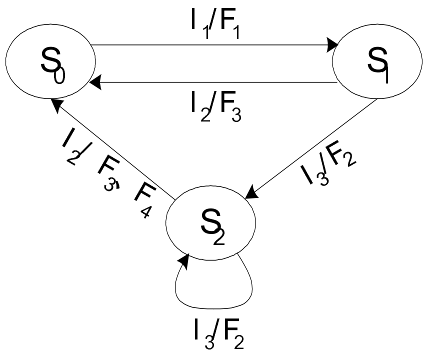

Fig. 2. State transition graph for NS

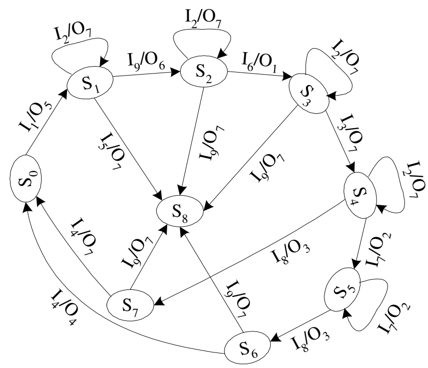

Fig. 3. State transition graph for MN

2.3 Description for Inner Data Structure Management

We take BC management as an example to present how to describe IDS management. BC is composed of many BC entries (BCE). BCE's state is determined by its remaining lifetime. In CN, each BCE stands for a mobile node. Let FSM M = (S_e, I_e, O_e, of, tf, bf) be the formal model for single BCE management (Fig 4).

Based on description for single BCE management, we propose multi-nodes finite state machine (MN-FSM) to describe BC management in a particular mobile IPv6 network (Def 1).

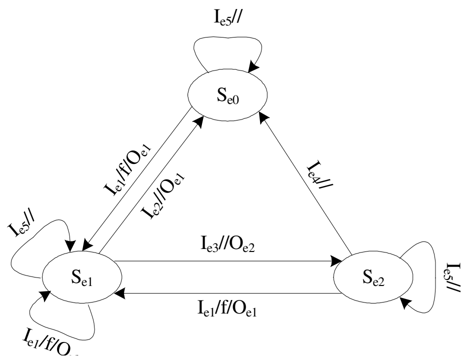

Fig. 4. State transition graph for BCE management

Definition 1. Multi-Nodes Finite State Machine

MN-FSM is used to describe BC management by CN in a particular mobile IPv6 network. Let MN-FSM M = (S, I, O, N, of, tf, V, bf, sf, SB_{0B}), in which:

- *N: the set of mobile nodes. If there are n mobile nodes, N = {1, 2, ... , n}.*
- *S: the set of states. Each state is the combination of all BCEs' current states.*
- *S_0: the initial state. $S_0 = \{<1, S_{e0}>, \ldots, <n, S_{e0}>\}$.*
- *I: the set of input events. $I \subseteq N \times I_e$.*
- *O: the set of output events. $O \subseteq N \times O_e$.*
- *of: the output function. of: $S \times I \rightarrow O$.*
- *tf: the state transition function. tf: $S \times I \rightarrow S$.*
- *V: a n-column vector. Each element stores the related BCE's lifetime that has been updated latest.*
- *bf: the behavior function. bf resets the vector V based on the valid binding updates latest.*
- *Sf: the signal generation function.*

BC management with two BCEs is described (Fig 5), in which tf and of are defined as follows.

If in Fig 4

$S_{ei} \rightarrow I_{ea}/f/O_{eb} \rightarrow S_{ej}$

Then in Fig 5

$\{<1,S_{ei}>,<2,*>\}\rightarrow<1,I_{ea}>/bf/<1,O_{eb}>\rightarrow\{<1,S_{ej}>,<2,*>\}$

And

$\{<1,*>,<2,S_{ei}>\}\rightarrow<2,I_{ea}>/bf/<2,O_{eb}>\rightarrow\{<1,*>,<2,S_{ej}>\}$

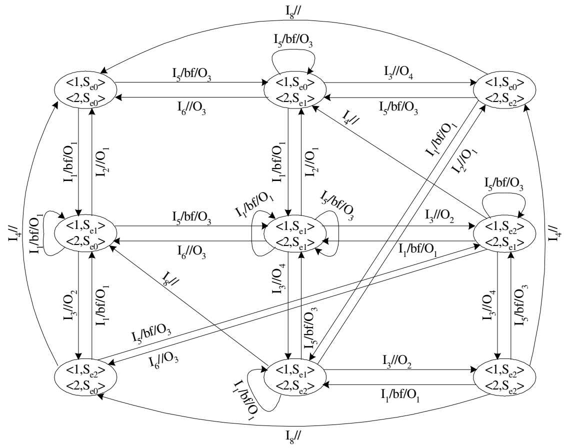

Fig. 5. State transition graph for BC management with two BCEs

3 Conclusion

Formal description is the base of conformance testing. This paper proposes the method of hierarchical description. The entire mobile IPv6 protocol is divided into four layers and each layer is described separately. Based on formal description for mobile IPv6 protocol, we can use test generation method for FSM model to generate mobile IPv6 test sequences, such as T-method, U-method etc. We also have developed test system, and tested many kinds of mobile IPv6 devices and obtained some valuable results [5].

References

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