FROM ACTIVE TO PASSIVE: PROGRESS IN TESTING OF INTERNET ROUTING PROTOCOLS

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Abstract Routing protocols play an important role in the Internet and the test requirements are mounting. To test routing protocols more efficiently, several enhanced techniques are applied in our Protocol Integrated Test System. The Implementation Under Test is modeled as a black box with windows. The test system is endowed with multiple channels and multiple ports to test distributed protocols. The test suite and other related aspects are also extended. Meanwhile, a passive testing is introduced to test, analyze and manage routing protocols in production field, capable of performing the conformance test, the interoperability test and the performance test. Necessary algorithms and techniques were worked out for the passive testing to cover the scope from the protocol state machine to the routing information manipulation. This paper presents our efforts to test Internet routing protocols with both the active testing and the passive testing.

Keywords: routing protocol, test structure, passive testing

1. INTRODUCTION

High performance and stable routing protocols dominate the performance of the Internet. Currently the most commonly used routing protocols are RIP [1], OSPF [2] and BGP [3]. There are other routing protocols like [4-6], but despite their importance, the test activity is still rather limited due to the fact that the original test theories, structures and systems were aimed at communication protocols. While routing protocols possess different features.

Several deficiencies were encountered when we started our work on routing protocol test with the Protocol Integrated Test System – PITS [7].

Then the Implementation Under Test (IUT or module under test MUT) is modeled as a windowed black box and tested with a multiple channel test method. The test suite has evolved into a heterogeneous one, while the test data of different types can be described in their appropriate formats. Enhanced techniques mainly focus on the Reference Implementation (RI). In cooperation with the Enhanced RI (ERI), the packet extension technique helps to describe the whole test activity integrally and uniformly.

Some abnormalities will only appear in practice and/or over a long time, such as route oscillations [8], useless route advertisements [9] or even exhausted routers. Although the active testing helps a lot to uncover the deficiencies of the implementations of routing protocols [10] [11], it can hardly deal with these problems. The passive testing [12] can be performed in production field over a long period of time without interference on the network. It is able to perform the conformance, interoperability and performance tests. Therefore, the passive testing has also been adopted in our work on routing protocol test. Corresponding techniques have also been worked out [13][16].

All the following methods are applied in the test activity. We have built an Enhanced Reference Implementation [19] for PITS. An intelligent online BGP-4 analyzer[20] has been implemented and then a prototype of a more general online test system [21]. Another important advance is that the active testing and the passive testing are combined, which helps us in the effort to cover all features of routing protocols in our test. These techniques are applicable for RIP, OSPF and BGP. In this paper, we will mainly focus on BGP-4 as the example.

2. FEATURES AND TEST REQUIREMENTS OF ROUTING PROTOCOLS

Compared with communication protocols such as TCP/IP, routing protocols are quite different. First, the purpose of the routing protocol is to collect the information needed to do routing [1], which is a basic summary of routing protocol functions. Another extraordinary character is the nature of distributed systems, which can be found from both the interaction between different routers and the communication between the interfaces of one single router. No matter the designation or the implementation, there are several important databases to store the routing information. The information flow among these databases is connected by the internal processes which dominate the correctness and efficiency of routing protocol implementations.

For a routing protocol, there is no “upper level protocol” at all. However the interaction of routing protocols is much more complex. For example, BGP-4 will talk with neighbor peers while exchanging information with other routing protocols such as OSPF on the same router. A more detailed discussion can be found in [14]. For the testing of communication protocols, the protocol state machine is heavily relied upon. The state machines only describe a small part of the behavior of routing protocols. The majority of a routing protocol activities begins after it enters a “stable” state (e.g. established state for BGP-4).

Therefore, the testing of routing protocol should cover (1) the packet structure, (2) the protocol state machine, (3) the interoperability, (4) exchange and manipulation of routing information, (5) performance evaluation and (6) other features such as the policy-based routing and the route flap damping.

3. CURRENT TEST SYSTEM AND DEFICIENCIES

3.1 Structure of PITS

PITS is the second generation of the test system we developed. Figure 1 shows the structure of PITS. PITS exploits test suites in TTCN[15] format and adopts a concurrent interpretive test execution method for high efficiency. The test suite generation tool TUGEN generates a TTCN-formatted test suite from the formal description of the protocol. Test Execution (TE) is the key engine in the test process, responsible for test process control and the generation of all the information needed in the test report. PITS is a general tester, that is, TE works independently of any particular protocol. All the protocol-related information is reflected in the test suite and the corresponding RI.

Figure 1 Protocol Integrated Test System

3.2 Deficiency and limitation of current test system

Since PITS was mainly aimed at the testing of communication protocols, some deficiencies were uncovered when testing routing protocols.

Originally, RI works in a very simple way, communicating with TE to get commands and data and sending/receiving data packets through the service provider. Test data and correct results are written in the test suite in advance and it is up to TE to accomplish the final comparison and judgement. Since there are large amounts of data transmission and routing information processing and TE depends on interpretive means to execute, TE can hardly accomplish the numerical calculation.

In traditional work, the test system only sets up a communication channel with the MUT and always exploits only one port. With such a test structure, only the packet structure and the protocol state machine can be tested. Since the routing protocol possesses features of distributed systems, the test system must be able to provide multiple ports. Only then can routing information exchange and processes be tested. Even if multiple ports are available, the entire scope of the testability is restricted to the data that the routing protocol module sends out. In addition, testing the correctness of the routing protocol under different conditions is also very important, especially for policy-based routing. Manual configurations are not only time-consuming but also error prone. On the other hand, the routing protocol is always implemented in the router while interacting with other modules. These modules provide the information and the access to the routing protocol module and the whole router through standard interfaces. In the original test structure, since the test system only connects with the MUT, this information and access can't be exploited at all.

There are further limitations regarding TTCN. It is difficult to describe certain cases with TTCN and it is almost impossible for TE to execute it. We believe that the latest TTCN-3 has greater ability and flexibility. However, the necessary editor, the executing environment, is under development.

The router always has a powerful processing ability while the speed of the test system is relatively much slower. When the test case shown in figure 2 is executed, there may be possible packet loss.

No	Behavior Description	Label	Constraints Ref	Verdict
	...			
1	T! OPEN_PACKET		C1_OPEN	
2	START T_HOLD			
3	T? KEEPALIVE_PACKET		C1_KEEP	
4				
5	? TIMEOUT			FAIL
6	T? OTHERWISE			FAIL
	...			

Figure 2 The test case with the possibility of packet loss

When step 1 is interpreted, the data and the command are sent to RI. RI then sends out the packet OPEN_PACKET. MUT will respond with a KEEPALIVE_PACKET. Since the speed of the router is rather fast, this packet is sent back immediately. At that time, if step 3 hasn't finished its interpretation RI will not accept the response packet. Further, when step 3 is done and RI is informed to receive some packet, what RI actually receives may be some other packet and step 6 will then be entered. The other scenario is that RI receives nothing at all. When the timer T_HOLD expires, step 5 will be entered.

4. ENHANCING TECHNIQUES

In order to solve these problems discussed above, the test system needs to be enhanced accordingly. After some analysis, almost all the enhancements are related to RI.

4.1 Functional sub-modules introduced into RI

In order to release TE from the heavy burden of the calculation, the dynamic calculation and the data generation sub-modules are introduced (shown in figure 3).

Figure 3 RI and enhanced RI with functional sub-modules

The test data generation sub-module in the ERI selects the test data or generates new test data with some algorithm according to the demand of TE. The packet composer sub-module forms the data packet and sends them out while the dynamic computation sub-module calculates the expected results. Response from the IUT (or MUT) is first processed by the packet parser sub-module, after which the results are compared with what are expected and finally presented to TE. Through these means, ERI accomplishes the calculation originally taken by TE, which improves the efficiency of the test execution.

4.2 Windowed black box model and multiple channels test method

In order to take full advantage of the information and access provided by the system (for example, a router) where the MUT resides, the windowed black box model and the multiple channel test method are adopted. The windowed black box takes into consideration not only the MUT but also other modules interacting with it. These modules offer standard interfaces and provide the tester with several windows to enhance the observation and the control of the MUT in the routing protocol test. Accordingly, the multiple channel test method is exploited. In traditional work, the test system only sets up a communication channel with the MUT, we call this channel a “basic channel”, as in [10]. The principal difference of the multiple channel test method is that not only does the test system set up a communication channel with the MUT, it also sets up channels with other modules interacting with it (shown in figure 4).

Figure 4. Multiple channels test method and test structure

The C_0 is the basic channel between the test system and the MUT. $M_1, M_2, \dots, M_k$ are the k modules (will have been tested in advance) interacting with the MUT. The test system sets up channels $C_1, C_2, \dots, C_k$ with these modules. The main idea of the multiple channel test method is to take full advantage of the information available to enhance the observability and the controllability, thus promoting the test efficiency and the coverage. The multiple ports needed to test distributed protocols can be easily implemented by expanding the channels.

4.3 Partition of acceptance sub layer and submission sub layer

In order to avoid possible packet loss in high-speed networks, RI is partitioned into two sub layers: the acceptance sub layer and the submission sub layer. The acceptance sub layer takes charge of receiving packets from the MUT, stores them in a buffer and maintains them. The submission sub layer fetches the packets and provides them to TE according to its demand. The acceptance sub layer makes RI independent of the speed of the lower

network and the packet loss can be avoided by managing a proper interval between test case execution.

4.4 Relation of enhanced techniques

The structure of the ERI is shown in figure 5, which also explains the relation of these enhancing techniques. The acceptance and the submission sub layers reside at the bottom of the ERI. All the sub layers above can take advantage of them to make up for the speed gap. In the middle of the ERI structure, are basic and extended channels. Each channel can provide multiple ports in order to test distributed routing protocols. Meanwhile, each channel possesses functional sub-modules such as dynamic calculation and data generation (details can be referred to in figure 3) which can provide more processing ability and flexibility. The topside of the ERI contains the command/data dispensation and collection sub-module, communicating with TE, getting data/command, dispensing it to corresponding channels and returning the result to TE for the final verdict.

Figure 5 Structure of the Enhanced Reference Implementation

It can be seen that the ERI overcomes the problems discussed above and possesses these features: (1) functionally compatible with the former RI; (2) no effect on the syntax and semantic integrity of TTCN; (3) provides multiple channels to increase the observability and the controllability of the MUT; (4) multiple ports to test distributed routing protocols; (5) reduces the burden of TE and improves the flexibility of PITS. (6) enhanced functionality suitable for the routing protocol test.

4.5 Describing the test activity in the test suite integrally and uniformly

The multiple channel test method also brings new problems. One is how to describe the test activity uniformly and integrally. Therefore, the packet expansion technique is raised. For example, four types of BGP-4 packets are defined in [3] and we defined type 128-143 for the data sent through the configuration channel and 144-161 for the auxiliary information channel. This definition does not contradict current usage of packet types and is unlikely to cause future conflicts. However, there is no actual data in the data field of the packet with special type values. Instead, there is only an index. Corresponding channels will look up the data in their mapping tables. This form of representation is a natural extension of the PIXIT (Protocol Implementation eXtra Information) which can act as an external part of the test suite.

5. APPLIED PASSIVE TESTING IN ROUTING PROTOCOL TEST

5.1 Brief of passive testing

Some abnormalities will only appear in practice and/or over a long time, such as route oscillations [8], useless route advertisements [9] and sometimes even exhausted routers. Although active testing can do a lot to promote the quality of the network equipment, it can hardly deal with such problems. Therefore, we also adopted the passive testing [12] in our work. The passive testing is an online test method as shown in figure 6.

Figure 6. Model of the passive test

Compared with the active testing, the passive testing is simple in structure, while possessing more feasible and powerful abilities to perform the conformance and the interoperability tests and even analysis of the performance. Additionally, it allows more IUTs and OLTs, enabling distributed test methods.

5.2 Algorithms and methods for passive testing

Algorithms to test the protocol state machine can be found in [13]. As to routing information manipulation, one generic method is topology analysis. The main idea is that correct routing information must describe the network topology correctly. We construct the topology from the routes exchanged and compare it with the actual topology. If differences are found, then there may be some errors in the routing information manipulation. Since we can get the constructed network topology from the OSPF routing information base, we mainly focused on the topology analysis for BGP-4, which can be found in [16]. Other methods like the internal process simulation are also exploited. Different modules are implemented to process the routing information collected online similarly to what the processes in the router will do. The correct scene is calculated and compared with the actual result. For BGP-4, the internal process simulation covers the generic route selection, route selection with policy constraints, and the route flap damping, etc.

5.2.1 Testing of route selection with policy constraint

Route selection with policy constraints is an important feature of BGP-4. These policies directly serve the relations of the Internet Service Providers (ISP) and their customers. Three basic relations are classified (client-provider, provider-provider and customer with backup) and corresponding policies are presented. Policy conformance and violations are defined.

Definition 1. Policy conformance $\text{Conf} = \langle \text{Conf}_i, \text{Conf}_e \rangle$, where Conf_i is the import conformance which evaluates the process when receiving routing information. Conf_e is the export conformance which evaluates the process when advertising routing information.

Suppose PS_r is the series of policies to be enforced on the received routes. $\text{PS}_r = [P_{r1}, P_{r2}, P_{r3}, \dots, P_m] \forall R_i \in R_RCV, R_i' = P_m(P_{r_{m-1}}(\dots P_{r1}(R_i)))$, denoted as $R_i' = \text{PS}_r(R_i)$. R_i' is route of import conformance: $R_i' \text{ Conf}_i \text{ PS}_r$

Suppose PS_s is the series of policies to be enforced on the routes to be sent out. $\text{PS}_s = [P_{s1}, P_{s2}, P_{s3}, \dots, P_{sm}] \forall R_j \in R_ACP, R_j' = P_{sm}(P_{s_{m-1}}(\dots P_{s1}(R_j)))$, denoted as $R_j' = \text{PS}_s(R_j)$. R_j' is route-of export conformance: $R_j' \text{ Conf}_e \text{ PS}_s$.

Then two basic types of policy violations can be defined; other violations can be made out of these two.

Definition 2. Penetration: if $\exists R_k \in R_ACP, \neg (\exists R_i \in R_RCV, \text{PS}_r(R_i) = R_k)$, then “penetration” occurs, that is, the route is accepted after the route calculation and selection while it actually should not be.

Definition 3. Leak: if $\exists R_k \in R_SNT, \neg (\exists R_i \in R_ACP, \text{PS}_s(R_i) = R_k)$, then “leak” occurs, that is, the route is delivered while it actually should not be.

A separate module was implemented. With policy configurations (provided by the network operator), this module can find the basic policy violations and other subtle abnormalities.

5.2.2 Testing of route flap damping

Route flap is another serious problem of the Internet routing [9][17] and the “merit way” is the damping method now in use [18]. However, to our best knowledge, there is no test to evaluate the damping effect. Therefore, we worked out a simple but practical one (shown in figure 7). In this state machine, the flap of a single route, the interaction between two routes (replacement) and the condition with an alternative route are all covered. Since the route selection will finally go down to the comparison between two routes, this model is applicable for generic conditions.

Figure 7. State machine of route flap damping

The flap module follows this state machine and performs the merit value calculation (increase and decay). Therefore, not only can the passive testing find the existence of the route flap and its severity, it can also evaluate the effect of the route flap damping.

6. IMPLEMENTATIONS AND TEST ACTIVITIES

6.1 PITS with ERI

The basic channel can support up to 8 ports and two extended channels: the auxiliary information and the configuration channels. The auxiliary information channel is set up to access the information needed in the routing protocol test in its session with the SNMP; the configuration channel connects through telnet and configures the routing protocol and the router with corresponding commands. A test case is shown in figure 8.

Dynamic Part				
Test Case Name:		UPDATE_ALL_IBGP		
Group:		bgp-4/IBGP/UPDATE_ALL_IBGP		
Purpose:		Test the information manipulation of IBGP		
Default:		NULL		
Comments:		NULL		
No	BehaviorDescription	Label	Constraints Ref	Verdict
1	T! TO_CONF		C_TO_CONF	
2	+ ESTABLISHED			
3	T! UPDATE01		C_UPDATE01	
4	T! UPDATE01		C2_UPDATE01	
5	START T_HOLD			
6	T? FROM_AUX		C_FROM_AUX	
7	START T_KEEP			
8	T? KEEP_ALIVE01		C_KEEPA_LIVE01	PASS
9	? TIMEOUT			FAIL
10	T? OTHERWISE			FAIL
11	? TIMEOUT			FAIL
12	T? OTHERWISE			FAIL
Extended Comments: NULL				

Figure 8 An example of a test case

In this case, the configuration channel and the auxiliary information channel are exploited. This example also demonstrates how the test activity is described integrally and uniformly.

In the acceptance sub layer, a buffer of 1600 X 40 bytes is set aside. There is no packet loss in a 10M or 100M Ethernet environment.

6.2 Online intelligent analyzer

The intelligent online BGP-4 Analyzer [20] is our first application of the passive testing. Compared with earlier work, this analyzer offers more efficient means for both the protocol test and the network management. It can test the state machines of BGP peers', from which some conclusions on the conformance and the interoperability can be drawn. As to the routing information manipulation, the analyzer simulates internal processes, such as the route advertisement and route withdrawal, the policy monitoring and the flap damping. The analyzer can be set to focus on some specified routing information or on certain BGP speakers' behavior. It can also collect statistics and provide basic performance parameters regarding the frequency and the amount of the data interaction. Also, the analyzer can re-display the procedure, making it easy to analyze and eliminate faults. Further, it can generate a TTCN-formatted test suite with the recorded data. Besides, it has a friendly graphical user interface (GUI) running on Linux and can attend to multiple NICs simultaneously. Data is stored in a compressed form in consideration of working over a long period time.

6.3 Online test system

As a more generic system for all the routing protocols and other distributed protocols, we have implemented the prototype of an online test system [21]. The framework is shown in figure 9. There are five main components. The input component includes a protocol state machine description module, a protocol packet structure description module and a set condition module. The communication component includes a communication interface module and a condition check and filter module, which shields the difference among communication protocols of different layers. The condition check and filter module further processes the data collected and provides the test component with a uniform interface. The test component is the kernel of the OLTS, including the protocol state machine test module, the internal process simulation module and the statistics module. The cooperation component is used to organize multiple OLTS instances. The test result module, the LOG module and other modules belong to the conclusion and presentation component, which composes a test report, provides graphical presentations and generates the test suite.

For each protocol to test, a specific communication interface module is coded, descriptions of the protocol state machine and the protocol packet structure are input and the necessary internal process simulation module is applied or implemented. OLTS is implemented on a Sun Ultra 1 - Solaris and a x86-Linux separately in order to widen its application and verify its portability

Figure 9. Framework of OLTS

Specific modules will be implemented for different communication media to shield the difference of the lower level. For example, the interface has been implemented for the most popular Ethernet, which is able to capture all the data of upper level protocols. On x86-Linux, the packet socket is exploited and DLPI (Data Link Provider Interface) [22] operating /dev/le on the Sun Ultra 1 - Solaris. For other communication media, there has been no difficulty encountered so far (even for a non-broadcast point to point link).

Based on this, the virtual network interface (VNI) is further implemented. VNI aims to provide a uniform interface that the main process can operate. When new communication media is introduced, the only requirement is to map its interface to the uniform interface.

The internal process simulation is done via a module stack; the modules can be pushed onto the stack for different protocols and test purposes.

In consideration of testing in a distributed environment, Simple Cooperation Protocol (SCP) [23] is defined for the cooperation component, which enables multiple instances of OLTS's to work together in different places of the network. We still have a tool set, including the packet composer. It can be controlled through a control channel by other systems such as PITS.

One of the most interesting aspects is that the active testing and the passive testing are combined. The active testing and the passive testing have both advantages and limitations of their own. The active testing can send out the desired packets; the passive testing can work in production field over a long time. By combining the active testing and the passive testing, we can expect a better efficiency.

An example is the erroneous session shown in figure 10. It is first captured by the analyzer. 166.111.69.91 is one port address of the commercial router and 166.111.69.75 is that of the Router II. This session shows that due to the incorrect implementation of BGP-4 of Router II, UPDATE packets are sent out repeatedly instead of OPEN after the TCP connection is established. But the response of the commercial router is not correct either. After it responds with a NOTIFICATION packet (line 2 in figure 10), it answers with the same UPDATE (line 5 in figure 10), which contradicts the protocol specification and leads to problems of the conformance and the interoperability along with the extra cost of the network bandwidth.

FROM	TO	TIME	TYPE
166.111.69.75	166.111.69.91	12/24 17:21:39	BGP_UPDATE
166.111.69.91	166.111.69.75	12/24 17:21:39	BGP_NOTIFY
166.111.69.75	166.111.69.91	12/24 17:21:44	BGP_UPDATE
166.111.69.91	166.111.69.75	12/24 17:21:48	BGP_UPDATE
166.111.69.75	166.111.69.91	12/24 17:21:49	BGP_UPDATE
166.111.69.91	166.111.69.75	12/24 17:21:54	BGP_UPDATE
166.111.69.75	166.111.69.91	12/24 17:21:59	BGP_UPDATE
166.111.69.91	166.111.69.75	12/24 17:22: 4	BGP_UPDATE
166.111.69.75	166.111.69.91	12/24 17:22: 9	BGP_UPDATE

Figure 10 An erroneous session recorded

Then this fault was confirmed with the active testing and several other similar faults were uncovered with this indication.

The test structure used in the policy-based routing test is shown in figure 11. BG_t is a real router, while W_1 and W_2 are two online test systems. N_1 and N_2 are two nodes, each of which may be a real router or an active test system. N_1 sets up an EBGP connection with BG_t and N_2 , BG_t an IBGP connection, W_1 watches the session on EBGP and W_2 on IBGP. With different configurations, variant tests can be performed. In a production field, N_1 and N_2 are all real routers, online test systems W_1 and W_2 monitor if there is any leak or penetration. Under the constructed test environment, N_1 and N_2 are test systems and they can actively test policy-based routing to detect violations.

The test structure of the route flap damping (shown in figure 12) also covers both the active testing and the passive testing. There are three types of nodes in this structure: flap source nodes, router nodes and detector nodes. The router nodes construct a network. The flap source nodes inject flap into the network at different positions and the detector collects the information about the flap damping. The test is in an active one. However, if the network is a real network, it will generate flap itself. Then the set of flap source nodes can be empty and the test switches into a passive mode.

Figure 11 Test structure for policy based routing test

Figure 12 Test structure for route flap damping

Figure 13 Topology constructed with the data collected from the backbone of CERNET

With both the active testing and the passive testing, a large number of test activities have been performed. We have tested some commercial routers in our lab and we have performed the test on the backbone of CERNET [24]. Figure 13 is the topology constructed with the data collected on CERNET. We compare this constructed topology with the actual one to discover errors in routing information manipulation. We also offer test support to the development of routers. Their pass ratio is considerably promoted and therefore the quality is improved accordingly.

7. CONCLUSIONS

Despite the great importance of routing protocols, test activity is still quite limited compared with the testing of communication protocols. In addition to our previous work, reference [11] discusses the testing of IP routing protocols in the environment generated by software tools. Craig Labovitz has collected the routing data for two years and published several papers [17]. Currently there are some commercial test systems, such as HP Router Tester [25] and NetCom Systems Smartbits [26], etc. They mainly focus on the performance of the system. They are all active testers and possess a high degree of industrialization. The price is rather expensive and they are always difficult to extend. For example, users can't develop test suites for new protocols.

This paper presents our efforts to cover important features of Internet routing protocols. However, there is still quite a lot to do. Routing protocols are still progressing, while models, methods and other techniques still need further refinement. At the same time, more efforts must be expended within the field of the protocol test, through which the validity of new methods can be proved and new problems can be discovered.

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