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Research and Implementation on Algorithm of Automatic Physical Topology Discovery in Heterogeneous Multi-subnet

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Abstract: Knowledge of the up-to-date physical Ethernet network topology is crucial to a number of import network management tasks, including network resource management, root-cause analysis, event correlation. Thus, effective and universal algorithms for automatically discovering physical network topology are very necessary. In this paper, we investigate the problem of the physical topology of large, heterogeneous multi-subnet that may include multi-vendor, uncooperative network elements. Then, we present a novel and effective algorithm for automatically discovering physical network topology in heterogeneous multi-subnet. Our approach utilizes only generic standard SNMP MIB information and does not require any modifications for the network elements and the operating system. The experimental results prove the correctness of the algorithm and the sufficient and necessary conditions for the uniqueness of the restored topology and demonstrate that our tool can automatically discover the accurate physical network topology even for large, heterogeneous network configurations.

Key words: Physical topology discovery, heterogeneous multi-subnet, address forwarding table, automatically

INTRODUCTION

Physical network topology refers to the characterization of the physical connectivity relationships that exist among entities in a communication network. Discovering the physical network topology is a prerequisite to many critical network management tasks, including network resource management, root-cause analysis, event correlation, etc. Knowledge of network element connectivity is essential to filter out secondary alarm signals and correlate primary alarms to pinpoint the original source of failure in the network. Furthermore, a full network physical topology map enables a proactive analysis of device and link failures. However, there are very few tools for network managers to maintain accurate network device connections. Without good tools there is a high probability of making wrong decisions either on adjusting network performance or in identifying network faults and network traffic bottlenecks.

In view of current research status, physical topology discovery algorithms are still not perfect, they just simply found the connection between switch and switch, but can not ignore the existence of a large number of hosts in the network, the connectivity relationships between host and switch is also a top priority of the physical layer topology discovery. Most of the algorithms for discovery physical (i.e., layer-2) network topology use the IP MIB and Bridge information of network nodes. However, switches and bridges are involved in limited information exchanges. And these algorithms fail to discover network topology for multi-subnet that may include hubs and *semihubs*. Furthermore, lack of automated solutions for capturing physical network topology information means that network managers are forced to manually input such information for each management tool. This situation mandates the development of effective, general algorithms for automatically discovering the up-to-date physical network topology. Additionally, challenge in the design of such algorithms is dealing with the lack of established, industry-wide standards maintained locally by each network element and the diversity of elements and protocols presenting today's multi-vendor IP networks.

Taking into account the characteristics of the actual network environment, in this paper we investigate the problem of finding the physical layer network topology of heterogeneous multi-subnet that may include uncooperative network elements (both hubs and *semihubs*). Our algorithm use only generic MIB

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information and does not require any hardware or software modifications of the network element. Our algorithm is based on the minimum number of connections between two nodes. The algorithm also guarantees the discovery of all possible topologies that are defined by a given set of input MIBs and can automatically discover physical network topology in heterogeneous multi-subnet.

RELEVANT PROTOCOL

SNMP (Simple Network Management Protocol) provides unified interfaces that obtain information from switches and defines a series of standard Management Information Base (MIB), including MIB-? and Bridge MIB. SNMP is designed to be unrelated with protocol, so it can be used in other transport protocols, provides a method in collecting information of network management from device on the network, also provides a way for the device in reporting issues and errors to network management workstation. Through the access for MIB information related to the switches and combining Spanning Tree State Table, may determine the connectivity relationships between the switches. In this way, the connectivity relationships of the network devices on the second layer are universal. Currently, almost every network equipment manufacture supports SNMP.

RELEVANT RESEARCH

In order to solve the problem of physical topology discovery in heterogeneous multi-subnet, the domestic and foreign scholars have conducted the related research and presented some algorithms.

Breitbart *et al.* (2004) proposed a method to identify the connection between switches in single subnet and multi-subnet. According to the direct connection theorem can determine the connection between switches in single subnet, by impossible connection theorem remove impossible connection on ports to obtain the topology structure in multi-subnet. But in order to ensure the existence of the physical connection between network devices in different subnets, the algorithm uses a lot of sufficient conditions, so it is very difficult to get enough information for the network physical topology and require the address forwarding table of each switch is complete, they are very difficult to meet in fact.

Lowekamp *et al.* (2001) proposed a topology discovery algorithm based on incomplete address forwarding table by the indirect connection theorem, but the algorithm has some limitations and it is not to determine the connection between bridges. In addition, the algorithm is very easy to make mistakes in multi-subnet and can not fully discover network devices.

Bejerano *et al.* (2003) proposed a topology discovery algorithm in multi-subnet based on complete address forwarding table. First the algorithm constructs a rough path between different nodes and then constructs a set of path constraints for each path, use the path constraint information to constantly refine rough path, finally determine the only path. The algorithm is Instable, but also requires that the address forwarding table is complete.

The lemma and algorithm of Zheng and Zhang (2002) applies to physical topology discovery in single subnet, but it is very easy to make mistakes in multi-subnet. Because communication between devices in different subnets have to pass through routers, in this case, the connection between switches can not be found only by asynchronous sending ICMP packets to ensure the complete address forwarding table of switch. And if there are dumb devices will not be able to judge the connection between network devices.

In view of the complexity of heterogeneous multi-subnet, must propose a general and perfect algorithm, can overcome the above algorithm's shortages, can accurately and comprehensively discover network devices in the incomplete address forwarding table

RELEVANT THEORETICAL FOUNDATION

Definition 1: No network management devices are referred to as dumb devices. Maybe they are hubs, the switches without management addresses or the IP objects which do not match with SNMP community string (Ma, 2008).

Definition 2: We denote the jth port of the switch S_i in the network by S_{ij} (Zheng and Zhang, 2002).

Definition 3: A_{ij} is represented by the set of MAC addresses that have been seen as source addresses on frames received at S_{ij} (Zheng and Zhang, 2002).

Definition 4: Let A_{ij} be the MAC addresses set of S_{ij}, if A_{ij} contains the MAC address of the marked node, we denote S_{ij} by uplink port. if A_{ij} does not contain the MAC address of the marked node, we denote S_{ij} by downlink port (Zheng and Zhang, 2002).

Definition 5: If A_{ij} for S_{ij} of switch S_i does not contain any other switch's MAC addresses, we denote S_{ij} by leaf port.

Definition 6: If all downlink ports of switch S_i are leaf ports, we say S_i is leaf switch (Ma, 2008).

Definition 7: We denote the switch except for root switch and leaf switch by intermediate switch.

Lemma 1: We say A_{ij} is complete if A_{ij} contains the MAC addresses of all switches and routers from which frames can be received at S_{ij} (Breitbart *et al.,* 2004).

Lemma 2: A router R is directly connected to a port S_{ij} if and only if S_{ij} is a leaf port and A_{ij} contains the MAC address of R (Breitbart *et al.*, 2004):

Lemma 3: If switch S_i and switch S_k meet the following conditions:

$$A_{ij} = \bigcup_{n=0}^{n=N} A_{kn} \cup \{S_k\}$$

(n = 1, 2, …, N, N is the port count of switch S_k and n is not equal to the port ID of uplink port set), then S_{ij} is directly connected to S_k's uplink port S_{kl} (Ma, 2011).

Theorem 1: if S_k is a leaf switch and switch S_k and S_i meet the condition: $A_{ij}=\{S_k\}$, then the S_k's uplink port S_{kl} is directly connected to S_{ij}.

Proof: According to the Definition 6 and properties of the leaf switch, we can deduce that the leaf switch has not sub-trees. So S_k's downlink ports set is null and by Lemma 3, we can draw Theorem 1 is true.

Theorem 2: Let S_{ij} be the downlink port of switch S_i, if the MAC address of any other switch is not contained in A_{ij}, then S_{ij} must be connected to the host or idle.

Proof: According to the definition of downlink port, assume the downlink port S_{ij} was connected to other switch S_i, then send a "Ping" packet to S_i, the ICMP data packets back from S_i must enter S_{ij} through the uplink port of S_i, so the MAC address of S_i must appeared in the address forwarding table of the downlink port. Assumption is wrong, theorem is right

Theorem 3: If the downlink port of a switch is a leaf port and there are multiple MAC addresses of network devices in this leaf port, then there must be dumb devices between this leaf port and network devices.

Proof: If the MAC address set of the switch S_i's downlink port is not null, then it means that multiple devices connect with S_i's downlink port; if the downlink port is a leaf port, then other switch's MAC addresses will not appear in the leaf port, so we can deduce that the leaf port is directly connected to non-switch nodes. In conclusion, there must be dumb devices between S_i's downlink port and other switches' uplink port.

Ratiocination: Based on Theorem 3, we have deduced there are dumb devices between S_i's downlink port and other switches' uplink port, if the inflow of S_i's downlink port is equal to the outflow of these switches' uplink ports, then the dumb devices are hubs, otherwise they are dumb switches.

ALGORITHM DESCRIPTION

1. Divide the network which will run physical topology discovery algorithm into multiple areas and name for each area
2. Give a router IP address, one or more groups of address range and the corresponding area name
3. Download all subnets from the router and reserve the subnets within given areas
4. Download the subnet mask and IP address of all ports from the router and calculate every subnet's gateway address
5. Scan each subnet to get the router queue, the switch queue and the active host queue
6. Download ARP (Address Resolution Protocol) table from the router and analyze the MAC address of every switch, router, host and subnet gateway interface
7. Merge MAC addresses, merge routers or hosts that the same MAC address corresponding to a different IP address into a MAC address set
8. Give other routers' IP addresses, repeat 3~7 until find all switches, routers and hosts in the network
9. Send "Ping" to all switches, routers and hosts from the network management station outside the subnet, then update the address forwarding table for each switch
10. Send "1.3.6.1.2.1.4.21" to every switch in the switch queue, obtain every switch's address forwarding table, determine the leaf switches according to the Definition 6, delete the leaf switches from the switch queue and generate the leaf switch queue
11. Determine every switch's uplink port set and downlink port set according to the Definition 4
12. Determine the connection relationship between switch and router according to Lemma 2
13. Determine all hosts connected with leaf switches, if there are dumb devices, can determine them

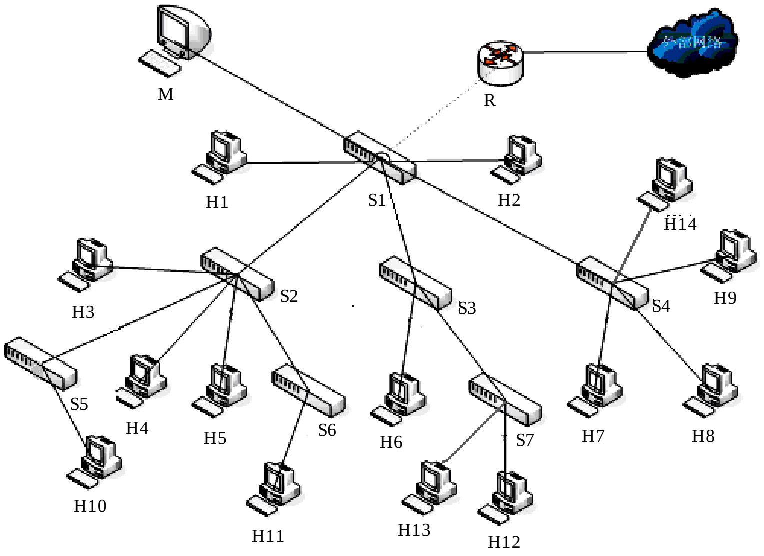

Fig. 1: Results of network topology

according to Theorem 3 and can determine the type of dumb devices according to the Ratiocination

14 Remove the first element from the switch queue, take it as pre-tested switch, analyze the downlink port address forwarding table of the pre-tested switch, determine the connection relationship between pre-tested switch and other leaf switches, if there are dumb devices, can determine them according to Theorem 3 and can determine the type of dumb devices according to the Ratiocination

15 Traverse every switch's downlink port address forwarding table in the switch queue, delete the leaf switch record containing the downlink port address forwarding table of the pre-tested switch

16 After traversing, if the pre-tested switch become a leaf switch, then delete it from the switch queue and add it into the leaf switch queue, otherwise, push it into the end of the switch queue

17 Repeat 13~16 until the switch queue is null, then can obtain the topology map of the area;

18 For other regions, jump to (2) and continue until obtain all areas' topology maps, so obtain the entire network topology map

ALGORITHM TEST

In order to verify the algorithm's correctness, depends on the above topology discovery algorithm, do the experiment in the laboratory and use Breadth First strategy and combine javascript to show results in web forms. The experimental results show that the algorithm can correctly run, completely find network devices, the connectivity relationships of the network devices conform to the actual situation, achieve the desired purpose. The experimental results are shown in Fig. 1. In the Fig. 1, R is the exit router, M is the host which runs physical topology discovery algorithm and monitor computer, S_1-S_7 are the switches, H_1-H_{14} are the managed hosts, clouds which is at right of R marks external network

CONCLUSIONS

Automatic discovery of physical topology information plays a crucial role in enhancing the manageability of modern IP networks. Despite the importance of the problem, earlier research and commercial network management tools have typically concentrated on either:1)discovering logical (i.e.,layer-3) topology, which implies that the connectivity of all layer-2 elements (e.g., switches and bridges) is ignored; or 2) proprietary solutions targeting specific product families. In this paper, we have proposed a simple and practical algorithm for discovering the physical topology of a heterogeneous multi-subnet Ethernet network that contains hubs. Our algorithm relies on standard SNMP MIB information that is widely supported in modern IP networks. Our algorithms can handle switched domains comprising one or more subnets and can be readily extended to deal with incomplete information and VLANs. The results clearly validate our methodology, demonstrating the accuracy and practicality of the proposed algorithms. We are currently in the process of optimizing our implementation and conducting more extensive experimental tests and hope to be able to report more detailed performance results in the near future.

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