An Algorithm of Physical Network Topology Discovery in Multi-VLANs

Xiaobo Ma*, Tingting Yu
College of Information Engineering, Inner Mongolia University of Technology, Hohhot, Inner Mongolia, 010080, P. R. China
*Corresponding author, e-mail: mxbohappy@163.com

Abstract

The most recent physical topology discovery knowledge of the Ethernet network is the key to network management tasks. Virtual LANs (VLANs) allow network managers to completely break the correlation between the logical and physical network by grouping the interfaces of the same network elements into different subnets. An efficient and general algorithm for discovering physical network topology across multi-VLANs is very necessary. Our topology discovery algorithms are simple for VLANs if we know the VLANs interface groups. The algorithm based on MIB information of SNMP standard is widely supplied by modern IP network elements and does not need modify the operating system software running on hosts or elements. The experimental results prove the correctness of the algorithm and the sufficient and necessary conditions for the uniqueness of the restored topology.

Keywords: physical topology discovery, multi-VLANs, address forwarding table, 802.1Q

1. Introduction

Network topology is the methods and forms of the connection between the nodes in the network. Network topology discovery is important for the establishment of network simulation model and the network performance measurements and server location and fault analysis, is the basic premise of effective network management, is also an important scale to measure the success or failure of the business network management system.

A physical LAN according to the different rules is logically divided into different subnets by VLAN (Virtual Local Area Network), the subnets are in different broadcast domain, and are not limited by physical location. In actual network, VLAN technology is widely used. A switch may have more than one VLAN in running network, so when switches interconnected, that need to transfer more than one VLAN information. But the 802.1Q of each manufacturer is not the same, so often there are some problems for interconnection. In addition, core routers and backbone switch and the secondary node switches and so on, due to some reasons such as management and security, the management IP address and the IP address of the cascade user or device are not in the same VLAN.

Layer-2 network topology discovery involves network layer devices, namely layer-2 switch. Since they are devices based on the data link layer, so using the traditional TCP/IP approach is difficult to find the connection between them. The main network management tool developers at home and abroad have added layer-2 topology discovery into their products. However, these tools are based on the related products of manufacturer without generality. For these reasons, we propose the algorithm to automatically discover the physical network topology across multi-VLANs and apply to network devices from different manufactures [1, 2].

2. Related Work

Ref. [3] proposed multi-subnet physical topology discovery algorithm that not including dumb devices, but it requires the address forwarding tables are complete, and in most cases, the network topology structure we drawn is not only. Ref. [4] they proposed that multi-subnet physical topology discovery algorithm can find the “dumb” devices, however, when address forwarding tables are not accurate, it can’t find the correct network topology. Ref. [5], Lowekamp proposed the algorithm that can find the network topology and the hubs when the address
forwarding tables are incomplete, but the algorithm is applicable to single-subnet, it is very easy to make mistakes in the multi-subnet. In order to find multi-subnet physical topology in the case of incomplete address forwarding tables, Ref. [6], they put forward a method of "two stage": the first stage, they tried to use the rules to expand the address forwarding table, if they can make address forwarding table complete, then enter the second stage, use the algorithm in Ref. [3] to find the connection of network devices, however, it is very difficult to make the incomplete address forwarding complete, sometimes, can’t come true. A algorithm of physical topology discovery based on spanning tree protocol is given in the Ref. [6, 7], but most of the network providers will not regularly provide the root information of spanning tree, which is not different from the bridges information [8].

3. Research Method

Nodes are network switches, routers and servers. N represent nodes, N_i represent the node of the number i. Switches and routers are collectively called network devices, represented by E, E_i represent the network devices of the number i. P represent the ports of the network device, P_i represent the port of the number i, P_ij represent the jth port of the device E_i. S represent Servers, and S_i is the server of the number i. Link includes the link between network devices and the link between the servers and network devices, represented by L, L_ij represent the link between N_i and N_j.

In order to solve the problems caused by loop in the Ethernet, we introduce the spanning tree protocol, making the network topology into a tree structure without circuit. In the tree structure, if an upper node is connected directly to one node, we say that it is parented off this node. Lower-nodes directly connected to a node is called the node's child node. The node without parent node is called the root node, there is only one root node in a tree structure. The notes that haven’t child nodes are called leaf nodes; all the upper layer nodes in the same branch are known as the higher-level nodes of the node. All the lower-layer nodes in the same branch are known as the lower-level nodes of the node. The port that a network device linked to its parent port is called uplink port of the device; apart from uplink port, the other ports are called downlink port. In the MAC address forwarding table, if MAC forwarding information of a port does not contain the MAC information of the other network devices, the port is called leaf port.

4. Results and Discussion

Physical network topology discovery algorithm across multi-VLANs proposed in this paper is based on the spanning tree topology, namely active link topology. In the spanning tree topology discovery process, choice a node in the network as root node, start from the root node to gradually find the spanning tree topology in the network, the correctness of topology discovery mainly depends on the completeness of the MAC address forwarding table. In the tree network topology structure, if the MAC address forwarding table of one node contains MAC information of all the higher-level nodes and the lower-level nodes in the node, so the MAC forwarding table of the node is complete.

Because the mechanism to achieve VLAN by device manufacturers is different, it is difficult to propose a general method to obtain VLAN configuration information. Only a few big companies like Cisco which supports 802.1 Q protocol. The Low-end switches, some support, some do not support, the routers and servers also do not support 802.1 Q.

4.1. The Nodes Supporting 802.1Q Protocol

(1) Find out the network IP addresses and MAC addresses of all the nodes. Select a backbone node as root node, “ping” other nodes. If the network management station is connected to the root nodes, the network management station asynchronously sends ICMP packet to all devices, if the corresponding devices send back the response, can determine the existence of the devices and they are active, each node can obtain IP address and MAC address information of his higher-level nodes and lower-level nodes, this can make MAC forwarding tables of all the nodes are complete.

(2) Read MAC forwarding table of each node, if it is a server node, the MAC forwarding table is empty; if it is switch or router node, then MAC forwarding table only contains the MAC address information of node, other MAC address are omitted.
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(3) Transfer MAC forwarding table into different sets by the port, represent with $M, M_{ij}$ refer the MAC set of port $P_{ij}$ (MAC set of j ports of $E_i$). $A_i$ refer MAC set of $E_i$’s all ports. So, $M_i=[MAC_1, MAC_2, ..., MAC_i, ..., MAC_n]$ (MAC set represent a node, $MAC_i$=MAC forwarding table of $P_i$). $A_i=[M_{i1}, MAC_{i2}, ..., MAC_{ij}, ..., MAC_{in}] (j=1, 2, ..., n, n$ represent the port count of $E_i$).

The MAC set of the root node $E_1$, for each MAC set $M_{1x}$ in $A_1$ is not null ($x=1, 2, ..., n, n$ is the port count of the root node), perform the following operations:

a) Let $U=$MAC address of $E_1 \cup M_{1x}$.

b) For each node $N_i \in M_{1x}$, delete the elements that do not belong to $U$ from $M_{ij}$ (j =1, 2, ..., n, n is the port count of $N_i$), after that, if there is one and only one set $M_{st}$ to satisfy the following conditions: $M_{st}=[MAC_1]$ (MAC$_1$ is the root node $E_1$), then we said the node $N_s$ is the child node of the root node $E_1$, and $E_1$ is the parent node of $N_s$. The link between them is: the port $P_{1x}$ is connected with the port $P_{st}$.

For MAC collection $M_{1x}$ of $E_1$, step a) and b) are repeated, we can find all child nodes of the root node $E_1$, namely first-level nodes of the spanning tree topology. The sub-tree of the spanning tree which consists of each first-level node and its lower-level nodes (if they exist). The root node of sub-tree is first-level node. Use the above method of sequentially, we can gradually find the entire network topology. It should be noted that uplink port of the root node of sub-tree should be ignored in the process of the application, the MAC set corresponding the uplink port is not dealt with.

4.2. The Nodes Partially Supporting and Unsupporting 802.1Q Protocol

For switches which can obtain all the MAC address of VLAN, can be treated like Cisco switches, only obtain MAC address forwarding table is different. If switches which don’t implement Bridge MIB across VLAN or can’t implement Bridge MIB, or the MAC address forwarding table without the MAC address information of the parent node, the steps a) in section 4.1 need the following improvements:

1) If there is only one element in $M_{1x}$, shows there is only one lower-level node in $M_{1x}$’s the port, namely a child node of the current root node, and the downlink port is the $M_{1x}$’s corresponding port. Then check that if all the port MAC set $M$ of $M_{1x}$’s nodes contain MAC address of the current root node, there are the following two cases:

The first case: one set contains MAC address of the current root node, and the corresponding port in the set is the downlink port.

The second case: If there is no any set contains MAC address of the current root node, it may be MAC forwarding table is incomplete. In this case, we can solve it according to the following section 4.3.

Thus, we can determine the topology relationship between two nodes, and then can skip the step b), the node must be leaf node.

2) When $M_{1x}$ contains more than one element, we still execute it according to the normal steps.

4.3. Router and Server Nodes

Router belongs to the layer-2 device, and doesn’t realize the Bridge MIB. And MAC forwarding table of server nodes must be empty. Both fit the second case in section 4.2. Similarly, we can obtain topology connection between routers and servers.

4.4. Incomplete and Cascade Nodes

The above methods solve the topology discovery problem of nodes which have the incomplete MAC forwarding table, but the precondition is that this node has only one layer, that is to say, the node has no child nodes. When this switch is cascade, the port MAC set $M_{1x}$ of the current root node may contain more than one node, in this case, the above method also can’t handle, the step b) of section 4.1 need to do the following improvement: after delete the $M_{1x}$, if there is not any set is $\{E_i\}$, shows the lower-level nodes of the current root node are not all incomplete, or the child nodes of the current root node are not incomplete. In this case, because nodes in $M_{1x}$ are in the same subnet, we can treat it as an independent spanning tree topology, so use the above method can find the topology relationship between them.
4.5. Algorithm Procedure

In the tree topology discovery algorithm, there are three ways: the depth-first search and breadth-first search or a combination of the two. Usually, they adopt the way to combine breadth-first and depth-first. First find all child nodes of the current root node (breadth-first), then use sub-tree constructed with the child nodes as root nodes and their lower-level nodes to discover topology (depth-first). The way is high efficiency, but the algorithm is comparatively complex. In this paper, we adopts depth-first topology discovery, use recursive invocation to discovery topology automatically, make the algorithm simpler to implement. Algorithm procedure is shown in Figure 1.

5. Conclusion

The application of the virtual local area network (VLAN) technology can effectively controlled broadcast message, enhance the network security, and make the change for the network configuration is more flexible and convenient. But it makes corresponding relationship of logical network topology and physical connection between devices more-complex. The
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algorithm achieved the physical network topology discovery across multi-VLANs, based on Bridge MIB, by referencing some private MIBs to obtain MAC forwarding table of multi-VLANs, and used certain mathematical analysis process of to obtain physical topology of network nodes. The algorithm has extensive applicability.

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