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Adaptive Management System for the Allocation of IP Address Scopes in Multi-Homing Network Environment

[1]Fu-Min Chang, [2]I-Ping Hsieh and [2]Shang-Juh Kao
[1]Department of Finance, ChaoYang University of Technology, 168 Jifong E. Rd., Wufong Township Taichung County, Taiwan
[2]Department of Computer Science, National Chung-Hsing University, 250 Kuo-Kuang Rd., Taichung City, Taiwan

Abstract: The allocation of IP address scopes could be dynamic in multi-homing network environment, as in the case that a user may have many ISPs alternatives. Under such network environment, after allocating IP addresses by the manager, clients can be assigned IP addresses depend on their LAN and ISP. An inappropriate allocation method could result in frequent addresses scopes re-allocation, especially in an unexpected growth of customers. Currently, the modification of IP address scopes is handled manually by experienced engineers, which is time-consuming. In this study, we design and implement an adaptive and automatic IP address scopes management system for efficient IP addresses allocation in the multi-homing network environment. In the system, the dynamic usage of IP addresses in each scope is collected and stored in a database for further analysis. Based on the information of previous usage, an algorithm is developed to predict the future demands of each scope and to identify the scopes which may be altered in the near future. As a fact, the system is able to automatically adjust the allocation of IP address scopes. The experimental results reveal the developed system can reduce the re-allocation time from several tens of minutes to less than 5 minutes per scope adjustment. Through the IP address scopes management system, the frequency of IP scopes replacement can also be effectively reduced.

Key words: Multi-homing environment, IP address scopes management, DHCP server, DHCP relay agent

INTRODUCTION

The allocation of Internet Protocol (IP) (Steve, 1982) addresses scopes (Rekhter, 1993) is an important but easy to be neglectful issue in multi-homing (Bates and Rekhter, 1998) network environment. Multi-homing is the situation which an Internet end-site may connect to multiple service providers simultaneously. The problem of IP address scopes allocation is raised due to the shortage of IP addresses space. Since the number of active users in each scope could be dynamic, an Internet Service Provider (ISP) may not be able to allocate enough IP addresses to meet users' request. Whenever there is an extra request in one scope, we are facing with an adjustment problem. How to develop an efficient addresses allocation mechanism to cope with the dynamic address request in a multi-homing network environment is what we intend to report in this study.

Taking the example of combining several ISPs to form a multi-homing environment, the address allocation problem has been solved by keeping monitoring the remaining IP addresses in each managed scopes periodically. When the number of remaining IP addresses is under a pre-determined threshold, the system will make an alert to the system manager for corresponding adjustment. Currently, there are two ways to cope with the shortage of an IP scope. One is to allocate a larger IP scope from the addresses pool which belongs to the same ISP, the other one is to bring some available addresses from the same ISP but in different scopes to meet the extra addresses request. After adding new IP addresses, the new gateway address, tag, policy and other management information for the new allocated IP addresses scope have to be reset. This solution is complex and time-consuming. In addition, even though IP scopes are usually adjusted manually by experienced engineers, inappropriate decision is still possible, which could make the problem even worse. Moreover, when we adjust the IP scopes in these ways, it is difficult to maintain the original information of addresses usage. Consequently, many tracking or accounting information, such as to determinate the usage of a particular address on a specific date, could

Corresponding Author: Fu-Min Chang, Department of Finance, ChaoYang University of Technology, 168 Jifong E. Rd., Wufong Township Taichung County, Taiwan

be lost. Thus, we can not know some particular IP addresses were used on a specific date by querying database in hand.

In this study, we propose a method to build an IP address scopes management system for the multi-homing environment. The IP addresses utilization is predicted through a simple algorithm and IP address scopes are adjusted accordingly. Specifically, system will deploy a new addresses allocation scheme on the Dynamic Host Configuration Protocol (DHCP) Droms (1997) server for IP addresses adjustment. With the IP address scopes management system, we can efficiently avoid the insufficiency of IP addresses in a scope. Moreover, the currently manual adjustment usually takes tens of minutes. Using the approach proposed in this thesis, the time can be reduced to within few minutes.

The proposed system architecture: Through the operations of DHCP protocol among DHCP server, DHCP relay agents (Patrick, 2001) and DHCP clients, the IP addresses could be distributed to the DHCP clients automatically in the multi-homing network environment. Based on DHCP, we construct an adaptive and automatic IP address scopes management system by adding two components: DHCP server agent and IP address scopes management system. With this system, scopes which IP addresses are going to be exhausted in a short period of time will be identified and a modification procedure is employed to automatically adjust the IP scopes. Finally, the system will distribute a new IP scope to replace the identified one and avoid the situation of IP addresses insufficiency.

System architecture: As shown in Fig. 1, the system architecture consists of five components: DHCP server, DHCP server agent, DHCP relay agents, DHCP clients and IP address scopes management system. The functions of DHCP server, DHCP relay agents, DHCP clients are the same as traditional ones. The DHCP server agent is located in between DHCP server and IP address scopes management system. It is used to pass the query commands given by our management system to DHCP server. It also receives the execution results from the DHCP server and passes it back to the IP address scopes management system. The IP address scopes management system plays the most important role in our system. It is not only to detect the IP addresses utilization periodically but also adjusts scopes automatically.

The IP address scopes management system includes three parts: core system, database and management interface. The core system collects the information about IP addresses allocation of each scope. All information will be stored in the database. Based on the collected information, the utilization of IP addresses is also calculated in the core system. Eventually, it will make a new allocation on the DHCP server by means of prediction results. The database records the information of IP addresses allocation, utilization of each scope and the IP address scopes pool that created by managers. Going along with IP address scopes, the database also consists of policies, tags and other attributes for those scopes. The management interface can display the information of each scope, such as the number of IP addresses in the scope or the free percentage of IP addresses in the scope. Through the management interface, the managers could create scopes, scope attributes, policies, policy attributes, policy options and tags.

Core system: The core system consists of three functional modules: information collection module, IP addresses utilization prediction module and allocation module. Structural modules of the core system are shown in Fig. 2. Each module of the core system is described in the following.

Information collection module: The information collection module is responsible of collecting the usage of IP addresses about each IP scope. Through querying the DHCP server, this module could collect the related information of IP addresses allocation, such as the attributes of scopes, policies and tags. The collected

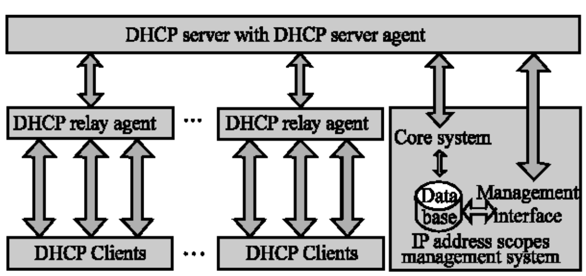

Fig. 1: System architecture

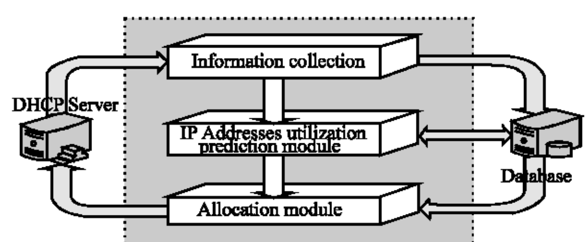

Fig. 2: Structural modules of the core system

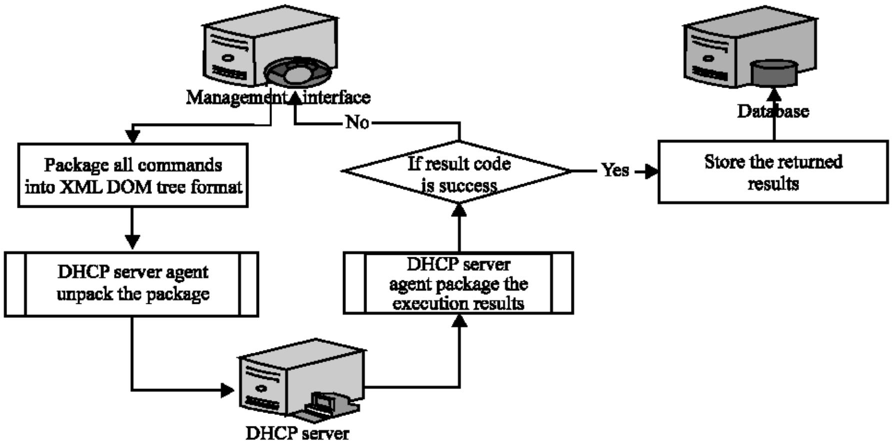

Fig. 3: Operational flowchart of the information collection module

information also was recorded in the database for the calculation of IP addresses utilization. This process is repeated after a period of time continuously.

When querying the DHCP server, the querying commands will be transferred into a specific Extensible Markup Language (XML) (Bray *et al*., 2004) Document Object Model (DOM) (Wood *et al*., 2000) Tree format and sent to the DHCP server agent. After receiving the commands, the DHCP server agent will parse it as a transaction and execute all commands in it. The querying results will also be transferred into the XML DOM Tree format and sent back to the information collection module. If the execution is success, the querying results will be recorded in the database. The operation flow of information collection module is illustrated in Fig. 3.

IP addresses utilization prediction module: Based on the collected information from the information collection module, the IP addresses utilization prediction module could calculate the utilization of IP addresses in each scope and predict the availability by the consumption rate of IP address. This work is carried out by Eq. 1 and 2. In Eq. 1, through finding the maximum number from the history record, the maximum growth number of IP addresses in the scope per day can be obtained. By Eq. 2, dividing the difference between allocated IP addresses and used IP addresses by the maximum growth number that calculated before, the available remaining days of each scope are predicted.

$$\text{Maximum Growth Number of IP Addresses} = \text{Max}\ \{\text{Growths in the history record}\} \quad (1)$$

$$\text{Remaining Days available in a Scope} = \frac{\text{Allocated IP Address} - \text{Consumed IP Addresses}}{\text{Maximun Growth Number of IP Addresses}} \quad (2)$$

If the value of the available remaining days in a scope is less than the configured value, the scope should be adjusted and its scope name will be passed to the allocation module for future modification. Otherwise, this module will execute again after a period of time.

Allocation module: After identifying the IP scopes that will exhaust their IP addresses in a short period, the new deployment should be made in the DHCP server to prevent the problem of insufficient IP address. This reseach is carried out by the allocation module. When the IP scope needed to be adjusted is figured out, the allocation module will look for an appropriate scope in the pool. The conditions for choosing a candidate scope are: (1) it has a larger amount of IP addresses and (2) it has the same ISP tag as the one to be replaced. Due to the same ISP of both scopes, their IP addresses can be easily switched. After deciding the new IP addresses scope, the allocation module will allocate it and reset all configurations on the DHCP server. To avoid breaking down users connections, the original scope is not recalled immediately. By using the deactivating command, all deactivated IP addresses in the original scope can be used continuously but can not be assigned to the new users. When a new user requests for an IP address, one of the IP addresses from the new scope will be assigned. With this method, the transparent replacement can be implemented. The original smaller scope is recycled to the addresses pool after a period of time and the new scope could work continually. The operation flow of allocation module is shown in Fig. 4.

IP addresses database and management interface: Since our system takes advantages of much information from the DHCP server, we record those data in different datasheets included in our database. All the datasheets

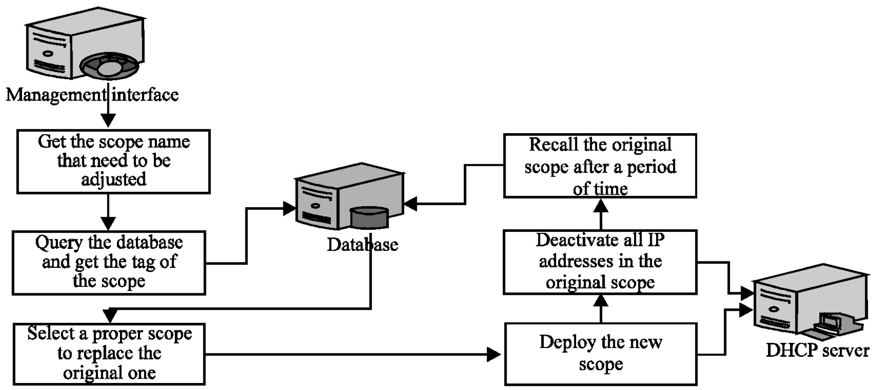

Fig. 4: Operational flowchart of the allocation module

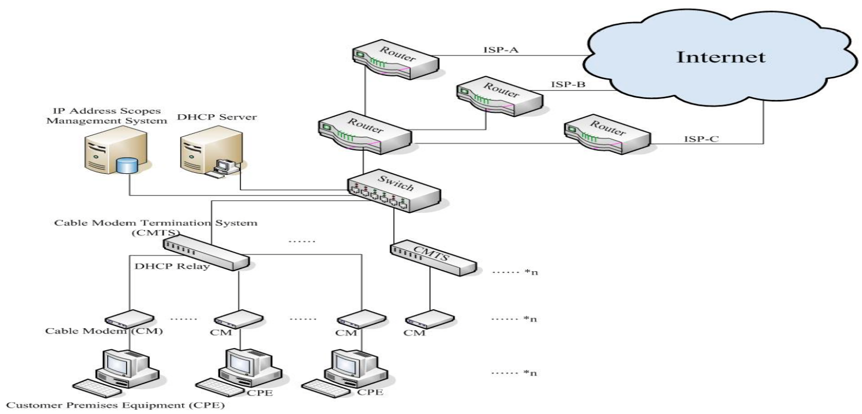

Fig. 5: Components of actual environment

in the database are classified into three clusters: Pools, allocated information and predict information. The pools cluster, also called to-be-allocated information cluster, includes five datasheets, NewScopeAttr, NewPolicy, NewPolicyOpt, NewPolicyAttr and NewTag. These datasheets record the setting and related information of IP address scopes which are ready to be allocated in the DHCP server. The allocated information cluster also includes five datasheets, Scope, ScopeAttr, Policy, PolicyAttr and Tag. These datasheets record the data which are collected from the DHCP server. In the prediction information cluster, three datasheets, Report, Predict and Scope Name, are included. All datasheets in this cluster record the data used to calculate and predict the IP address utilization of each scope.

The management interface includes three functions: Display, creation and simulation. The display function presents the current state on the DHCP server, such as the growth curve of consumed IP addresses in a scope and the summary of all scopes. The creation function is used to make a new scope, policy and tag in the IP address scopes pools ready to be allocated. Since the scopes and policies have several attributes or options, the creation function could support the managers selecting the attributes or options they want to set. Due to the experimental environment is a virtual environment, it doesn't allow lots of clients to request for the IP addresses from the DHCP server. Thus, the simulation function is employed to simulate the usage states of IP addresses. Once the simulation function is executed, it will deactivate a random number of IP addresses in the selected scope as they have been used already. We assume the random number is in the range of 4 to 7. This number represents the growth number of IP addresses in the scope one day.

The system implementation and demonstration: In order to verify the system's feasibility, we take into account the actual network system and develop a simulated network environment. The actual network environment, which motivates this study, is composed by upstream ISP routers, border router, switches, DHCP server, IP Scope Management System, Cable Modem Termination Systems (CMTS) Yun *et al*. (2002), Cable Modems (CM) Sadiku and Aduba (2000) and Customer Premises Equipments (CPE) Burson and Baker (1993). The components of actual environment are shown in Fig. 5.

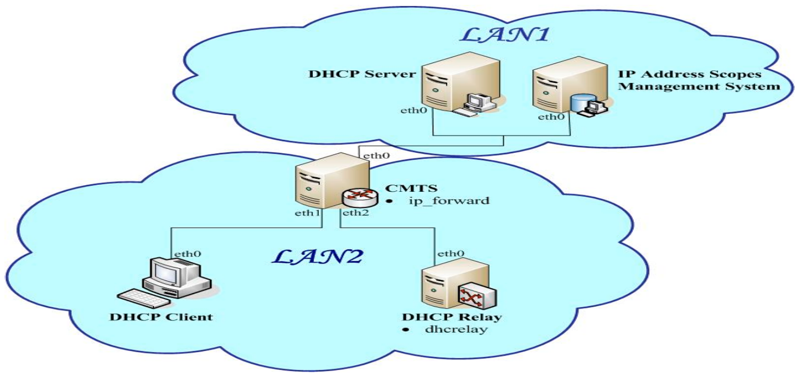

Fig. 6: Simulation environment

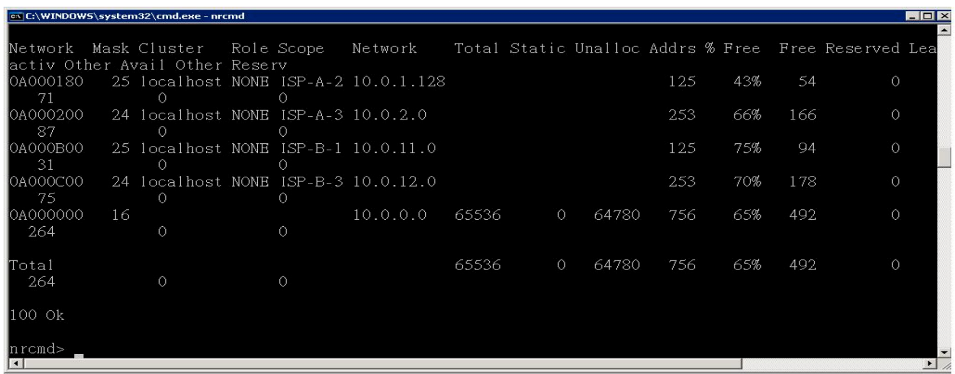

Fig. 7: Results of executing report dhcp-only command

Since our management system arranges the allocation of IP scopes on the DHCP server, the results may influence thousands of customers. If the connection is broken down due to our adjustment, many users may suffer from the discontinuity of their Internet usages. Thus, a simulation environment is built and all implementations on the simulated system are carried out. The simulation environment, as shown in Fig. 6, consists of two regions: LAN1 and Lan2. LAN1 includes the DHCP Server and IP Scope Management System, while DHCP Client and DHCP relay are located in LAN2. The gateway and CMTS are used to connect across these two regions. We adopt the VMware (1998) software to simulate the experimental environment. VMware is a kind of simulation software and it can simulate some virtual machine with several network interfaces which belong to different Local Area Network (LAN) (David *et al*., 1978). When a new virtual machine is built in VMware, some information must be set up, such as Operation System (OS) or kernel name, interfaces…etc. When we select an Ethernet (Frank *et al*., 2003) interface, the region this interface connects to should be set up. Moreover, if different virtual machines have interfaces with the same region, they connect to the same LAN in the virtual environment. Our system is developed by JAVA (1996) language and (Borland JBuilder, 2005). In the following, the detailed operations of IP address scopes management system for detecting and adjusting IP scopes are presented.

The core system: The core system includes three functional modules: information collection module, IP addresses utilization prediction module and allocation module. In the information collection module, the report dhcp-only command (Cisco system, 2002) is employed to collect the current state of all scopes allocated on the DHCP server. It collects the information of free IP addresses number, free IP addresses percentage of each scope and other useful information. The collected information will be recorded in the database for future use. The results of executing report dhcp-only command on the DHCP server are shown in Fig. 7.

In the IP addresses utilization prediction module, based on the Eq. 1 and.2, we can obtain the maximum consuming number of IP addresses in the scope and predict the remaining days of each scope. Taking scope ISP-A-1 with 125 IP addresses as an example, I f the consumed IP addresses of it in a week is 5,4,3,6,5,3,2, we can find the maximum number is 6. Then the free IP addresses is 125-5-4-3-6-5-3-2=97 and the remaining days is 97/6 = 16. These data are recorded in another datasheet. Based on these results, we can determine which scopes need to be adjusted. The decision rule is: if the remaining days are less than our threshold, this scope will be replaced by a new scope with more IP addresses. As the example above, if the scope ISP-A-1 keeps consuming IP addresses up to 102 IP addresses and the free IP addresses is 125-102=23. Assuming the system threshold is 4. Then the remaining days is 23/6=3 in scope ISP-A-1 less than the threshold, it will be adjusted.

In order to build a valid allocation, policies, tags and scopes, must be created first. This research is carried out by the allocation module. Table 1 and 2 list the policies and tags created in the database and Table 3 lists the scopes pool. The allocation module could be triggered when a scope is selected to replace another scope in the DHCP server. Under this situation, allocation module will set up all related options and attributes of this scope in the DHCP server.

Table 1: Policies

Policy name	DNS	Gateway
ISP-A-1	10.0.1.2	10.0.1.126
ISP-A-2	10.0.1.2	10.0.1.254
ISP-A-3	10.0.1.2	10.0.2.254
ISP-A-4	10.0.1.2	10.0.3.254
ISP-B-1	10.0.11.2	10.0.11.126
ISP-B-2	10.0.11.2	10.0.11.254
ISP-B-3	10.0.11.2	10.0.12.254
ISP-B-4	10.0.11.2	10.0.13.254

Table 2: Tags

ISP	Tag name
ISP-A	ISP-A
ISP-B	ISP-B

The IP address scopes management system: The management system includes three functions: creation, query and simulation. There are implemented with objects created in the core system. Table 4 shows the major web pages of each function and their usages. According to these objects and datasheets mentioned above, the relationships between these three functions are shown in Fig. 8. Based on this architecture, we implement the management interface for our IP address scopes management system.

Create function is used to create policies, tags and scopes in the pool by managers. Since every policy has more than one option and attribute, our system can create all of them by selecting the option or attribute name then fill in the value you want to set. Figure 9 is display all policies, tags and scopes after selecting the create function. So as creating tags and scopes, each scope has attributes but tag only has its name.

In the Query function, we can get a summary of all allocated scopes in the main query page. It shows the utilization and free number of IP addresses in each scope. Figure 10 shows the summary page in the query function. After selecting a scope name, it shows the growth curve of IP addresses utility of this scope as Fig. 11.

In the simulation function, we can see a brief digest about the growth of IP addresses in each scope. It shows the growth number last time and the maximum growth number of IP addresses in this scope. Besides, we also can view the total number and free number of IP

Table 3: Scopes

Scope name	Network number	Subnet mask	Start IP	End IP
ISP-A-1	10.0.1.0	255.255.255.128	10.0.1.1	10.0.1.125
ISP-A-2	10.0.1.128	255.255.255.128	10.0.1.129	10.0.1.253
ISP-A-3	10.0.2.0	255.255.255.0	10.0.2.1	10.0.2.253
ISP-A-4	10.0.3.0	255.255.255.0	10.0.3.1	10.0.3.253
ISP-B-1	10.0.11.0	255.255.255.128	10.0.11.1	10.0.11.125
ISP-B-2	10.0.11.128	255.255.255.128	10.0.11.129	10.0.11.253
ISP-B-3	10.0.12.0	255.255.255.0	10.0.12.1	10.0.12.253
ISP-B-4	10.0.13.0	255.255.255.0	10.0.13.1	10.0.13.253

Table 4: Major interfaces and their usages

Function	Interface Name	Usage
Creation	Create scope.jsp	Create new scopes.
	Scope attr.jsp	Create attributes for scopes.
	Create policy.jsp	Create new policies.
	Policy attr.jsp	Create attributes for policies.
	Policy option.jsp	Create options for policies.
	Create tag.jsp	Create new Tags.
Query	Query now.jsp	Query current status of all scopes.
	image.jsp	Display the growth curve of a selected scope.
Simulation	detect.jsp	Predict and detect if any scope needed to be adjusted.
	simu.jsp	Simulate the depletion of IP addresses in a scope.
	Simuindex.jsp	Display the simulation results.

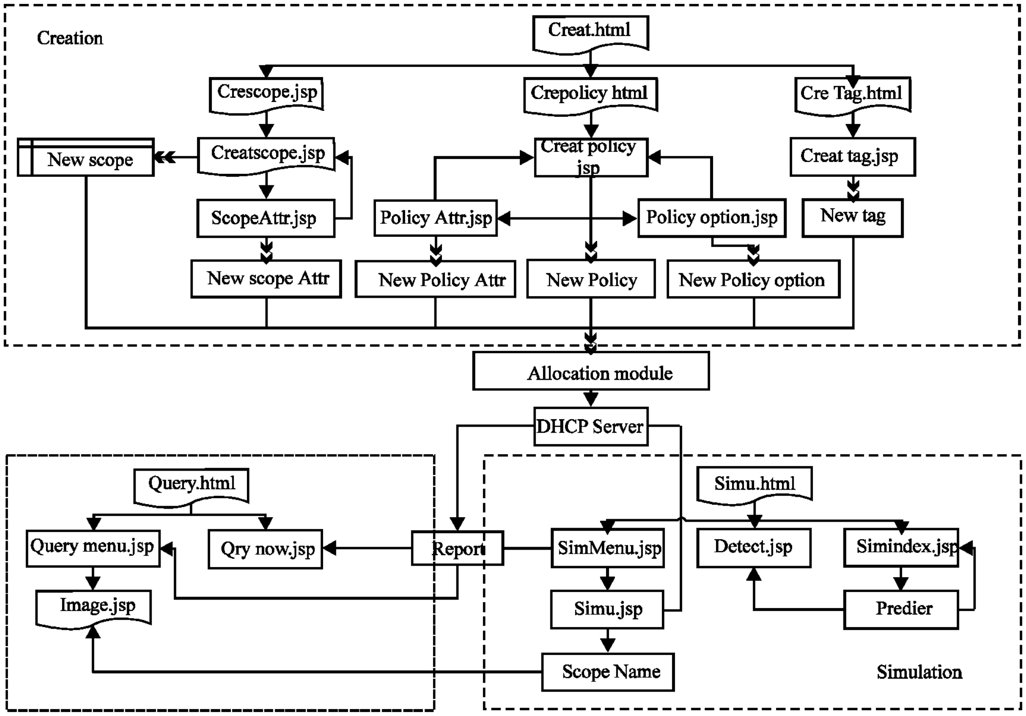

Fig. 8: Relationships between creation, query and simulation

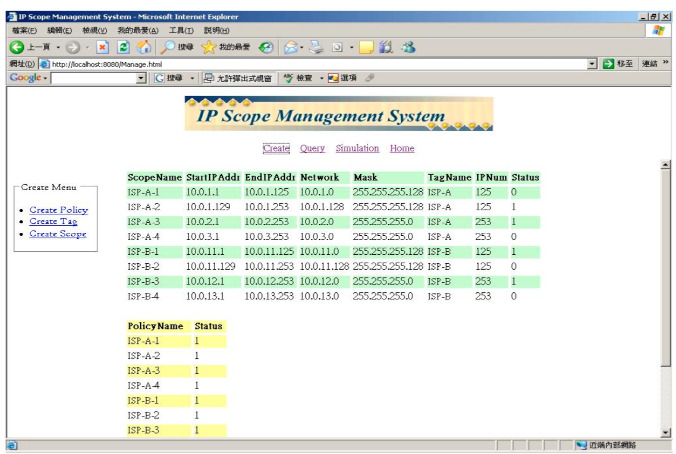

Fig. 9: Display of all created scopes and policies

addresses in each scope. By selecting a scope, the simulation function will generate a random number as the growth number of IP addresses first and it will deactivate those number of IP addresses in the DHCP server. Finally, the simulation function will record this number and print out the growth curve. Figure 12 and 13 show the brief digest of simulation status of all allocated scopes and the growth curve of only one selected scope.

A sub-function of detecting is also included in the simulation function. When we enable the detecting function, it will check the remaining days of all scope. If the remain-day of a scope is less than our threshold, the brief digest will display this scope in red and be adjusted soon. Besides, the detecting page will refresh and execute detection every 30 sec. Figure 14 shows the detecting process. Because of the exhaustion of IP addresses in ISP-A-2 Scope, our system will allocate ISP-A-4 Scope to replace it. Figure 15 shows the adjusting results.

An application scenario: By taking the allocations of scope ISP-A-2, ISP-A-3, ISP-B-1 and ISP-B-3 as an example, in this scenario, ISP-A-2 will be replaced by

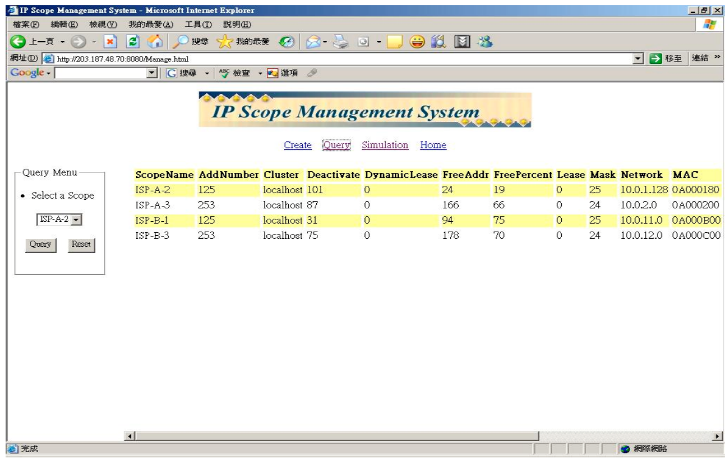

Fig. 10: Main page of query function

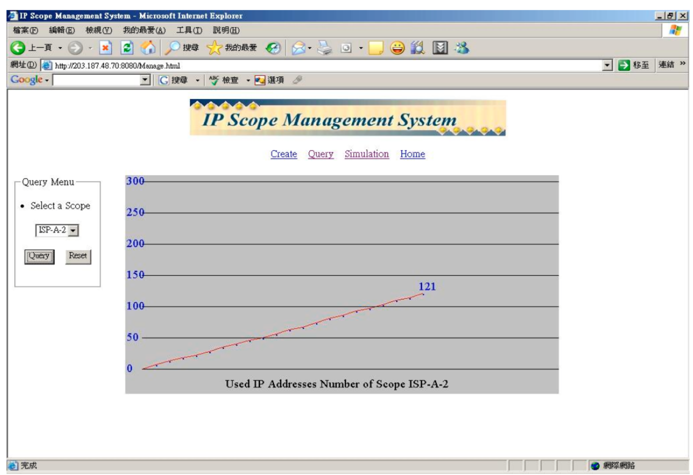

Fig. 11: Utility growth curve of a scope

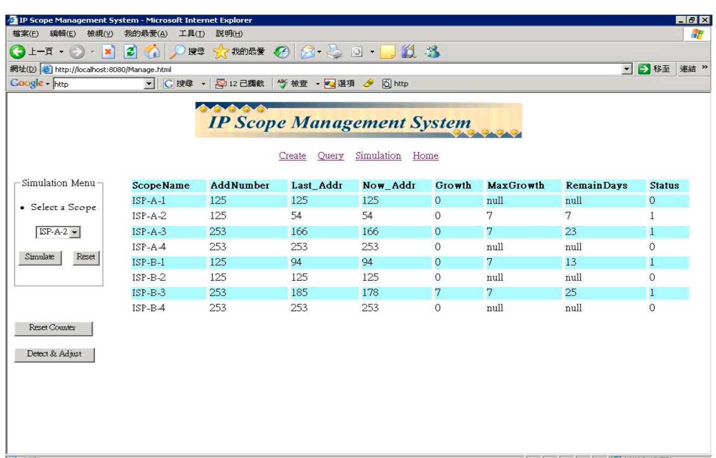

Fig. 12: Brief digest of simulation function

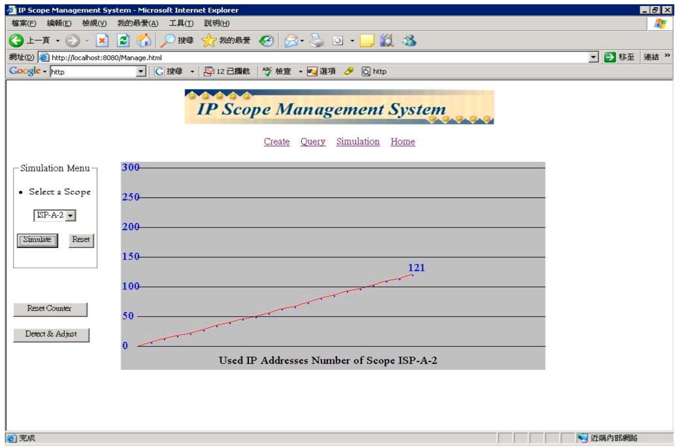

Fig.13: Growth curve of selected scope

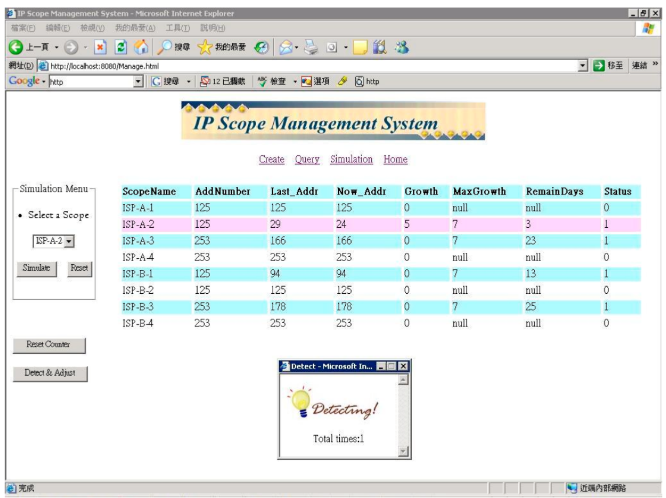

Fig. 14: Enabling the detection function

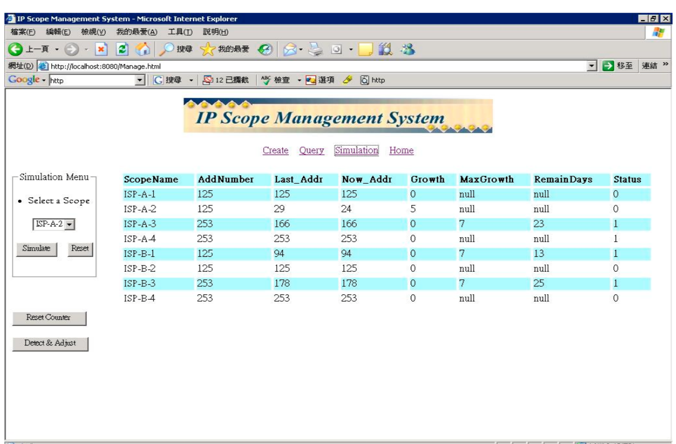

Fig. 15: Detection and adjusting results

ISP-A-4 as shown in the following steps. Corresponding interfaces are displayed in Fig. 9 to 15.

Step 1: Creating data as shown in Table 1 to 3 by using the creation functions. Those settings are going to be the pools and ready to be allocated and distributed later.

Step 2: Allocating scope ISP-A-2 with 125 IP addresses, ISP-A-3 with 250 IP addresses, ISP-B-1 with 125 IP addresses and ISP-B-3 with 250 IP addresses on the DHCP server

Step 3: Enabling the detection function and keeping the detecting window opening.

Step 4: Executing the simulation function repeatedly to get the situation.

Step 5: Keeping simulating the IP addresses usage in scope ISP-A-2 until getting the quantitative number. The system will search over the datasheet of this scope by Eq. 1 and find the maximum growth number of IP addresses. In this case, the maximum number is 7 and the free number of IP addresses in this scope is 24 now.

Step 6: Assuming the system threshold is 4 and the remaining days in scope IPS-A-2 is 24/7 = 3 less than our system threshold. Therefore, it is necessary to be adjusted.

Step 7: The detection function will search for a suitable scope in the pool. In this case, scope ISP-A-4 fits the request. It has the same tag as ISP-A-2, which means that ISP-A-4 belongs to the same ISP as ISP-A-2 does. Accordingly, we can use scope ISP-A-4 to replace scope ISP-A-2. As a result, more IP addresses can be distributed after replacing.

Step 8: System will first allocate scope ISP-A-4 on the DHCP server, then scope ISP-A-2 and scope ISP-A-4 will coexist for a period of time. Finally, the system will recall the scope ISP-A-2 and finish this replacement.

The adjusted results are displayed as Fig. 15. It solves the problem of addresses exhaustion of scope ISP-A-2 successfully. In addition, comparing to manual adjustment that usually takes tens of minutes, this addresses allocation time using IP address scopes management system takes less than 5 minutes.

Summary and future works: In this study, an automatic and effective IP address scopes management system is developed under a simulated multi-homing network environment. Management functions of monitoring, analyzing and adjusting IP addresses usage in each scope are implemented. By querying the DHCP server periodically, the system collects the distribution and monitors the usage of IP addresses allocation in each scope. After analyzing the usage of IP addresses allocation by executing a simple prediction, the system can automatically detect and adjust the IP scope that will exhaust IP addresses in a short time. This system can greatly improve the current alarm system, which sends an alarm to the manager when there are only three IP addresses left in a scope. A first-fit strategy for IP scopes replacement is adopted. That is the system will look for a suitable scope in the pool sequentially to substitute to to-be-replaced one. This approach can reduce the adjustment time of an IP scope from original tens of minutes to few minutes. By keeping the collections of IP addresses allocation in the database, the system can trace the original distribution of IP addresses for further examination.

As more and more devices becoming Internet equipped, multi-homing network environment could also be extended from small to medium enterprises or even home networks. Even though the available addresses of IPv6 (Hinden and Deering, 1998; 2006) are much larger than that of IPv4, the problem of the adjustment of IP scopes still exists under multi-homing network environment. The frequency of IP scopes adjustment could be much less in IPv6 networks due to the larger addresses available in a scope, but the management system is still required. How to modify the proposed system to fit for the IPv6 networks is one of future works (Pekka, 2005). In addition, the problem of the link disconnection and keeping static IP address assignment unchanged also needed to be solved.

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