A Case Study Design of Border Gateway Routing Protocol Using Simulation Technologies

Chengcheng Li
School of Information Technology
University of Cincinnati
Cincinnati, OH 45221
Chengcheng.li@uc.edu

ABSTRACT

This paper presents a case study that is designed to teach students hands-on experience on designing and implementing Border Gateway Protocol (BGP). This case study was used as a final project in a senior level computer networking class to evaluate students' understanding of key networking concepts and proficiency of configuring and implementing a wide range of network technologies. Through doing the BGP project, students reviewed and learned other foundational networking topics other than BGP, including Interior Gateway routing Protocols (IGPs), IPv6, switching, load balancing, policy based routing, and access control. Students had the chance to explore the rich features of BGP attributes to manipulate routes between the autonomous systems in a network simulation lab environment. This BGP case study comprehensively review the key knowledge unites of the networking class and can be used as an assessment tool evaluating students' understanding and overall performance.

Keywords: Network Modeling, Simulation, Emulation, Virtualization, BGP

1. INTRODUCTION

BGP is the dominating Exterior Gateway Protocol used today. It is exclusively developed for routing data traffic on the Internet and has been used to build the backbone networks of the Internet Service Providers (ISP). BGP is currently in the fourth version since its release in 2005. The design of BGP is significantly different from that of the IGPs, such as RIP, EIGRP, OSPF, and ISIS which are usually briefly discussed in college level networking classes. BGP are able to advertise networks without having an active interface in these networks. In other words, BGP routers are capable of advertising a huge amount of routing information to their peers or neighbors without having the reachability of these networks verified. In fact, the BGP routing table can contain tens of thousands of routes as the number of routes on the Internet has been grown exponentially over the years, especially after IPv6 has been adopted. BGP routers on the boundaries of the ISP networks propagate all the routes in their BGP table to the BGP peers, generating huge network traffic and demanding large computing and storage resources. Therefore, BGP needs to be enabled with care. With limited knowledge of BGP, inexperienced system administrators may redistribute the BGP or the Internet routes into enterprise networks. Doing so can quickly bring down the entire network, because many routers do not have the sufficient storage or processing capacity for the huge amount of BGP routing information traffic, causing devastating network outage. And it is usually unnecessary for all the routers to learn all the routes on the Internet except for the gateway or autonomous boundary routers. BGP is not enabled on an enterprise network unless this network is in a mulithoming or transit autonomous system (AS), in which there are more than one exits to the ISPs for load balancing and fault tolerance. For most small and mid-sized enterprise networks, BGP is not needed. However, BGP is the only routing protocol that provides loop-free interdomain routing between AS's. Mastering BGP concepts and configuration process is a must have skill for network engineers working for the ISPs.

BGP is a path vector protocol with a routing algorithm similar to that of distance vector protocols. But the convergence time of BGP may take from seconds to hours because there are constant large amount of route changes on the Internet, and we certainly don't want the Internet, triggered by all these changes, to be updated very frequently. Otherwise, the internet will be very unstable and the network bandwidth will be wasted on exchanging unnecessary routing information. BGP uses a rich set of parameters to manipulate the route attributes and therefore prioritizes certain routes over the others. The network engineers have a full control over choosing the optimal routes for data traffic. However, obtaining proficiency of configuring these attributes needs practice and comprehensive understanding of BGP processes and concepts. The field engineers may need to take several courses in BGP before actually having a hands-on on the production ISP networks.

2. CASE STUDY DESIGN

BGP is introduced in many networking classes, but seldom is discussed in detail due to its complexity. Additional on-the-job training is usually required for the system engineers and administrators before they work for the ISPs. It is considered a difficult task to simulate the internet traffic in a lab environment. BGPlay provides a web interface to demonstrate real time BGP traffic between AS's on the Internet [1]. But the configuration functionality is not provided. There are BGP simulation and modeling tools based on NS-2 (Network Simulator) [2][3], supported by an NSF grant. Both ns-BGP and BGP++ provide BGP extensions to NS-2 for BGP traffic simulation [4][5]. However, these NS-2 extensions have a steep learning curve and require programming and scripting skills that many IT students don't have.

An open source network simulation and modeling toolkit was introduced in the author's previous research that incorporates lab activates that covers a wide range of network concepts from routing, switching, security, IT services, QoS, VoIP, multicasting, IPv6, to IT infrastructure design and implementation. A BGP project was designed as the final project for a senior network class. And it's completely implemented by using the tools that are installed either one students' personal laptops or a cloud lab hosted on our "Sandboxes" supported by Vmware vSphere.

Diagram 1 shows four routers representing AS2000, an enterprise network, and AS 1000, an ISP network. AS2000 uses the proprietary EIGRP routing protocol as its IGP. AS1000 uses OSPF, a hierarchical IGP commonly used by ISPs. More than one physical links between the routers are used to provide load balancing and redundancy. This lab sets up a multihoming topology with more than one exits of the enterprise network facing the ISP. Students are required to configure the network from both the enterprise and the ISP's engineers' perspectives to implement correct routing policies and route traffics through the desired routing paths.

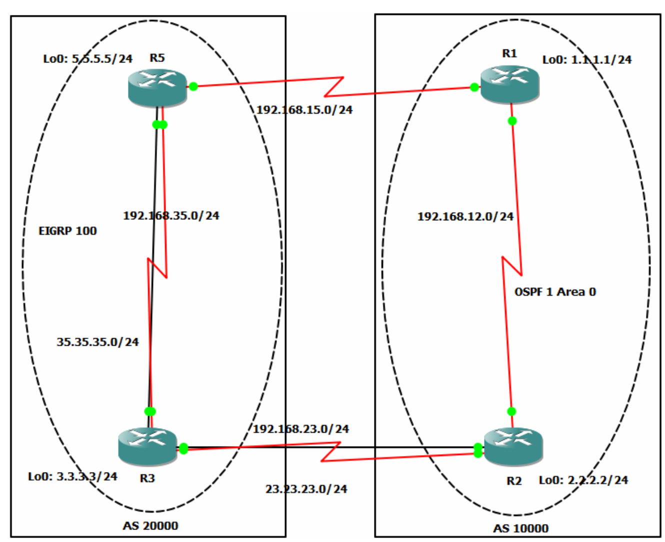

Diagram 1. Network Topology of BGP Case Study

The network concepts and individual steps of the project were discussed during the class lectures accompanying with instructor lab demonstrations. Students are required to examine the default behaviors of BGP and write them into a report with the screenshots and explanations of the routing and BGP tables. There are two routes for R5 to reach 192.168.12.0/24, the network inside the AS1000, one through R1 and the other through R3. By default, R5 uses R1 to reach 192.168.12.0/24 because the routes learned from R1- an eBGP neighbor is preferred to R3 – an iBGP neighbor when other attributes of these two routes remain the same. Based on the project requirements, students working as the system administrator of the ISP, need to change the BGP attribute of 192.168.12.0/24 on R1 so that R5 prefers R3 to get there. And then the students need to work as the system administrator of AS2000, the enterprise network, and change the route attributes three times only on R5 to change the route preferences between R3 and R1. The final report would include the configuration process and detailed descriptions of BGP attributes that were modified. The correctness of the project implementation can be conveniently verified through examining the BGP and routing tables. Diagram 2. is a screenshot extracted from a sample student report. The highlighted fields show that this student correctly modified the default attributes multiple times for R5 to take R1 or R3 as the next hop to reach 192.168.12.0/24 network.

The network concepts that this project covers in an upper computer networking class is summarized in Table 1.

Network Concepts	Implementation
IP Scheme Design	Design the IP networks for efficient use of given IP space.
IGP Implementation	Configure EIGRP, OSPF areas, and load balancing; use virtual interfaces as routing sources for better stability of routing updates
eBGP	Provide TCP connections for BGP peers; modify the multi-hop behavior
iBGP	Use virtual interface for routing sources; use the next-hop-self on the AS boundary routers to provide a routable address for the iBGP peers
Propagate Routes through BGP	Advertise and verify BGP routes
Traffic Identification and Isolation	Create access control lists to identify data traffics and apply them to the inbound or outbound directions of the correct interfaces
Policy Based Routing	Create route policies based on the lab requirements for BGP route manipulation. The attributes that are used in this project include but not limited to weight, route origin, multi-exit discriminator, and AS path

Table 1. Network Concepts and Skills Covered by the BGP Case Study

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   Network          Next Hop            Metric LocPrf Weight Path
r> 1.1.1.0/24       1.1.1.1                                0 10000 i
*> 2.2.2.0/24       1.1.1.1                 65             0 10000 i
*> 3.3.3.0/24       35.35.35.3          409600         32768 i
r>i5.5.5.0/24       3.3.3.3             409600    100      0 i
*> 35.35.35.0/24    0.0.0.0                  0         32768 i
* i                 3.3.3.3                  0    100      0 i
*  192.168.12.0     1.1.1.1                500    300      0 10000 10000 10000 10000 i
*>i                 3.3.3.3                  0    100    255 10000 i
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Diagram 2. The BGP Table from a Sample Student Submission

3. FINDINGS AND DISCUSSIONS

Based on the end-of-semester survey, the majority of the students claimed that the project is very challenging but also a great learning experience to comprehensively review the networking concepts learned through the semester. Instructor lab demonstration and in-class hands-on teaching are critical components for some of them finally complete the project. Two third of the class find the lab environment is easy to set up and stable to use. They also appreciate the online lab as a backup option, supported by the university's VMware vSphere cloud infrastructure. The average time for the students to complete the project is between 12 to 16 hours which is the appropriate workload for the grade weight assigned to the project. The project can be easily extended to cover other advanced topics in computer networking based on the needs from different concentrations of IT curricula. A design of an advanced project is provided below.

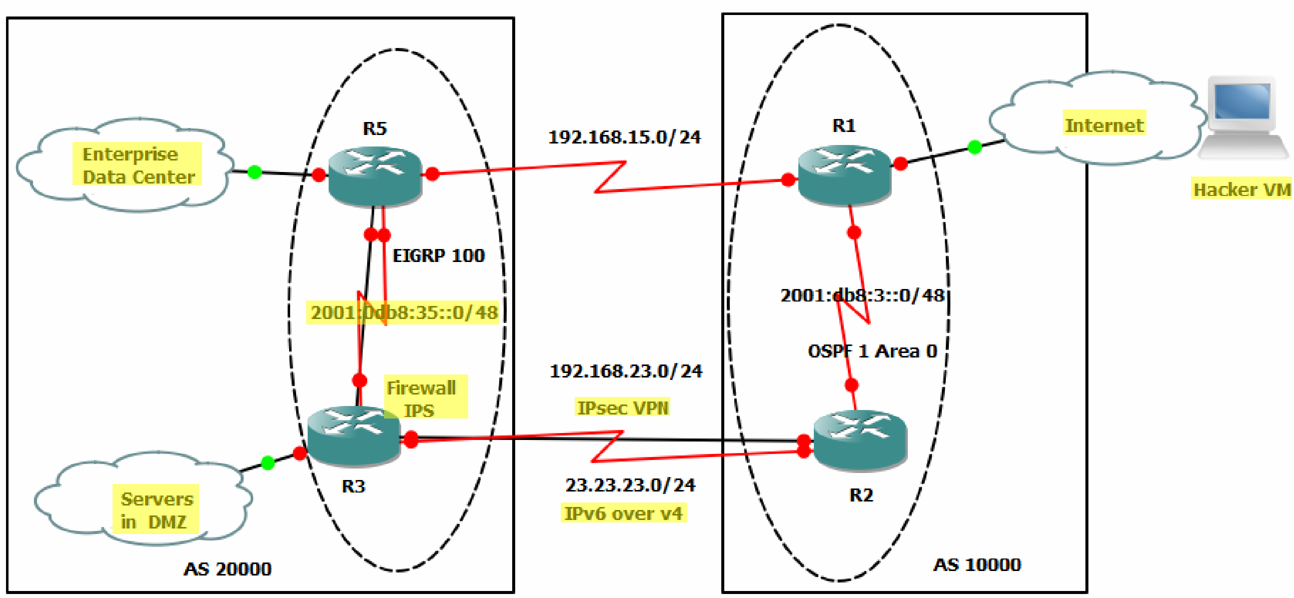

Diagram 3. Extended Project Design to Cover IPv6, Cybersecurity, and Server Virtualization

In the extended project design, dual stack of IP protocols needs to be implemented to route both IPv4 and IPv6 traffics. BGP configuration also needs to be modified to support IPv6. R3 is redesigned to provide firewall, IPS, and VPN services for secure connections to the resources in the enterprise network. An IPsec VPN tunnel can be constructed between R3 and R2. VirtualBox Linux virtual machines will be installed and connected to R3 and R5 to simulate the servers and datacenters that should be isolated and protected by the firewall. Another virtual machine connected behind R1 will simulate hacking activities to test the IPS and Firewall on R3.

4. CONCLUSIONS

This paper summarizes the design and implementation of a BGP case study project used in a senior computer networking class for the students to have a comprehensive review of key networking concepts, especially in Policy Based Routing on BGP route optimization which is usually neglected in IT curricula due to the complexity of the protocol and the difficulty of simulating the BGP process in a lab environment. The BGP project can be implemented on the students' personal laptop computers with a set of open source network emulation and simulation tools. Students find the project is challenging and relative to their learning goals. The lab setup and material can be easily adopted by other IT curricula. The contents and objectives of this project can be extended to cover many networking concepts, providing students valuable hands-on experience that is required by IT employers.

5. ACKNOWLEDGEMENT

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