CSCI 4273/5273
Programming Assignment 3
Fall 2001

Due date: 12/13/01

Goal: The goal of this programming assignment is to implement a routing mechanism for a simplified internetwork. This routing mechanism is very similar to the routing mechanism used in today's Internet. In the process, we will learn how hierarchy can be used to build routing mechanisms that can scale quite well to a very large internetwork.

Grade: 15% of your final grade is allocated for this assignment.

Scalability is the most important requirement for a routing protocol being designed for a large internetwork such as the Internet. Scalability in routing protocols entails maintaining a good and stable performance as the number of hosts, routers, and networks increase significantly. The key technique that has been used to build scalable routing protocols is to use hierarchy in the internetwork organization. In this assignment, we will implement a routing mechanism that uses hierarchy and is scalable. This routing mechanism is very similar to the one used in today's Internet.

Assume that the internetwork consists of a set of autonomous systems (AS) that are interconnected to one another, and each AS consists of a set of networks interconnected to one another by an arbitrary set of routers. Routing mechanism consists of BGP for routing between various AS, and a distance vector protocol with in each AS. For simplicity, we will assume that the structure of the internetwork is fixed, and the only changes that can occur are changes in link cost, failure of a link, and recovery of a link.

An AS is identified by a unique integer id. Each AS is assigned a block of n consecutive class C IP addresses, where $n = 2^k$ for some integer k. The value of n may be different for different AS. An AS may assign a sub-block of its IP addresses to another AS. For example, a provider AS may assign a subset of its IP addresses to one of its customers. For simplicity, we will assume that the IP address prefix of an AS does not change. Each network in an AS is assigned a class C IP address.

A router is configured with the following information: (1) the AS id of the AS to which it belongs, (2) an IP address for each network interface it is connected to, (3) a set of <link id, link cost> for all links that directly connect it to other routers in its AS, (4) a set of <link id, AS id> for all links that directly connect it to other AS, and (5) whether it is a BGP speaker. In addition, a BGP speaker is configured with (1) address prefix of the AS to which it belongs, (2) a set of AS to whom it advertises complete paths, (3) the IP addresses of the BGP speakers of all these AS, and (4) the IP addresses of all border routers in its AS.

A host is configured with an IP address and the address of a default router that is connected to the same network as the host.

The internetwork for this assignment consists of 6 AS interconnected to one another as shown in Figure 1. Assume that the address prefixes of these AS are as follows:

AS0: 128.92.0.0/18 : 64 class C IP addresses

AS1: 128.92.64.0/18 : 64 class C IP addresses
AS2: 128.92.16.0/20 : 16 class C IP addresses
AS3: 128.92.0.0/22 : 4 class C IP addresses
AS4: 128.92.64.0/20 : 16 class C IP addresses
AS5: 128.92.16.0/22 : 4 class C IP addresses

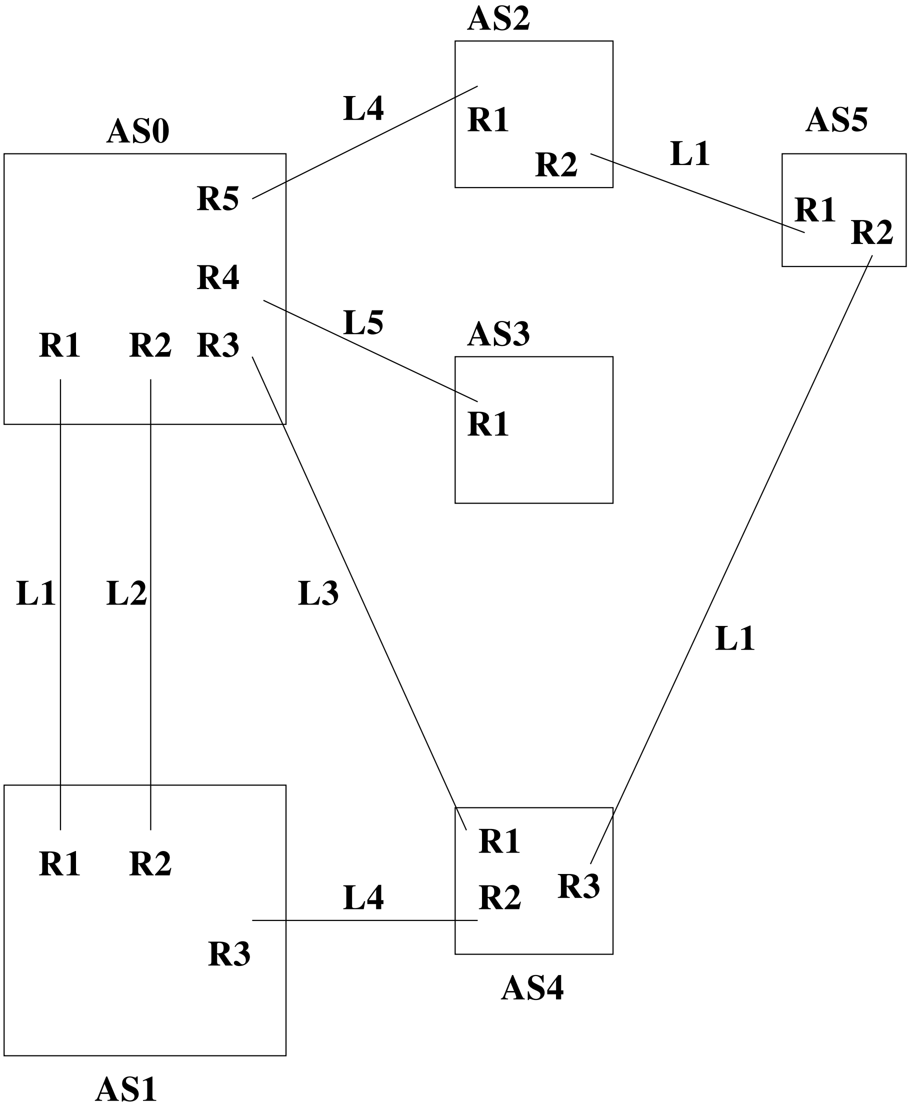

Figure 1: Interconnection between autonomous systems

AS0 consists of six routers—R0, R1, R2, R3, R4, and R5, and seven networks—N0, N1, N2, N3, N4, N5, and N6. Interconnection between the six routers along with link cost is shown in Figure 2. R3 is the BGP speaker. IP addresses of the networks and the routers are as follows:

N0: 128.92.32
N1: 128.92.33
N2: 128.92.34
N3: 128.92.35

N4: 128.92.36
N5: 128.92.37
N6: 128.92.38
R0: 128.92.35.4
R1: 128.92.32.5 and 128.92.33.8
R2: 128.92.34.11
R3: 128.92.38.10
R4: 128.92.36.17
R5: 128.92.37.41

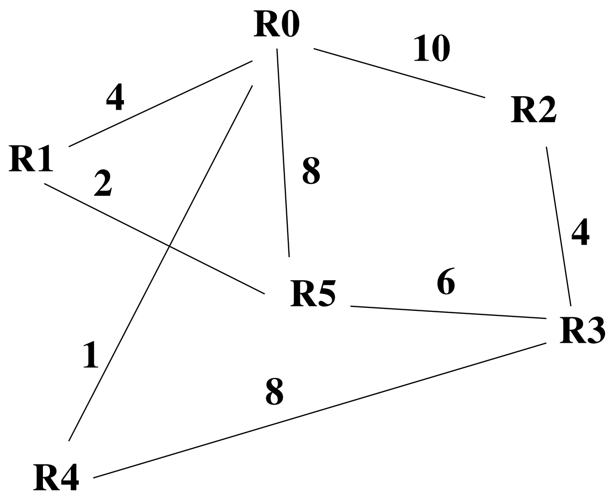

Figure 2: Router interconnection in AS0

AS1 consists of three routers—R1, R2, and R3, and three networks—N1, N2, and N3. R1 is connected to R2 via link of cost 4, and R2 is connected to R3 via link of cost 7. R2 is the BGP speaker. Router and network addresses are as follows:

N1: 128.92.80
N2: 128.92.81
N3: 128.92.82
R1: 128.92.80.5
R2: 128.92.81.7
R3: 128.92.82.18

AS2 consists of three routers—R0, R1, and R2, and three networks—N0, N1, and N2. R0 is connected to R1 via a link of cost 3, R1 is connected to R2 via a link of cost 7, and R2 is connected to R0 via a link of cost 10. R1 is the BGP speaker. Router and network addresses are as follows:

N0: 128.92.20
N1: 128.92.21
N2: 128.92.22
R0: 128.92.20.70

R1: 128.92.21.3
R2: 128.92.22.10

AS3 consists of a single network and a single router. Address of the network is 128.92.0.0 and the router is 128.92.0.14.

AS4 consists of three routers—R1, R2, and R3, and three networks—N1, N2, and N3. R1 is connected to R2 via a link of cost 1, R2 is connected to R3 via a link of cost 4, and R3 is connected to R1 via a link of cost 4. R2 is the BGP speaker. Router and network addresses are as follows:

N1: 128.92.64
N2: 128.92.65
N3: 128.92.66
R1: 128.92.64.7
R2: 128.92.65.3
R3: 128.92.66.16

Finally AS5 consists of two routers—R1 and R2, and two networks—N1 and N2. R1 and R2 are directly connected by a link of cost 10. R1 is the BGP speaker. Addresses of the routers and networks are as follows:
N1: 128.92.16
N2: 128.92.17
R1: 128.92.16.25
R2: 128.92.17.30

For this assignment, assume that there are 20 hosts with the following IP addresses: 128.92.32.100, 128.92.33.100, 128.92.34.100, 128.92.35.100, 128.92.36.100, 128.92.37.100, 128.92.38.100, 128.92.38.101, 128.92.80.100, 128.92.81.100, 128.92.82.100, 128.92.20.100, 128.92.21.100, 128.92.22.100, 128.92.0.100, 128.92.64.100, 128.92.65.100, 128.92.66.100, 128.92.16.100, and 128.92.17.100.

Routing for the internetwork consists of (1) BGP among BGP speakers to share reachability information, (2) BGP speakers sharing the information they have learned with other border routers in their AS, and (3) distance vector routing protocol with in each AS.

Recall that as a part of BGP, a BGP speaker advertises complete paths for various networks (network address prefixes) it knows about to the BGP speakers of one or more other AS. The paths it advertises are a sequence of AS ids. In addition, a BGP speaker also advertises withdrawn paths when it learns that a path it advertised earlier no longer exists. For simplicity, assume that each BGP speaker knows the AS ids and IP addresses of the BGP speakers to whom it advertises paths.

Assume that AS0 BGP speaker advertises paths to AS1, AS2, and AS3 BGP speakers, AS1 BGP speaker advertises paths to AS0 and AS4 BGP speakers, AS2 BGP speaker advertises paths to AS0 and AS5 BGP speakers, AS3 BGP speaker advertises paths to AS0 BGP speaker, AS4 BGP speaker advertises paths to AS0, AS1, and AS5 BGP speakers, and AS5 BGP speaker advertises paths to AS2 and AS4 BGP speaker. A BGP speaker advertises paths every 10 seconds, and when it notices a change.

To share reachability information with other border routers in its AS, a BGP speaker simply sends the reachability information it has learned to all border routers via intradomain routing. Assume that each BGP speaker knows the IP addresses of all border routers in its

AS. A BGP speaker shares reachability information every 10 seconds.

Finally, border routers include in the distance vector, that they send to their neighbors in their AS, any information about the networks (network prefixes) they can reach that they learned from the BGP speaker by assigning an appropriate link cost. For this assignment, assume that the cost assigned to reach a network is the number AS traversed to reach that network. Routers send their distance vectors to their neighbors every 5 seconds, and when they notice a change.

Organize your program as follows. Each AS is implemented as a separate Unix process. Each router and host is implemented as a separate thread (use Pthreads). All communication is simulated by using UDP. Each router and host creates and binds a UDP socket through which it communicates with its neighbors. A host can communicate with its default router. A router can communicate with all other routers that it is directly connected to and all hosts in its interfaces.

To initialize and manage your program, implement a coordinator process. The coordinator process creates and binds a UDP socket. It first receives the UDP addresses (IP address, port number) of all hosts and routers, and then responds to queries from hosts or routers, and from standard input. All hosts and routers learn the UDP addresses of all hosts and routers with whom they can directly communicate by send a query (UDP message) to the coordinator. Queries that the coordinator reads from the standard input have the following format:

- C <AS id> <router id1> <router id2> <new cost> : Change the cost of the link between routers with router ids id1 and id2 in AS id to new cost. Assume that the link cost is always an integer less than or equal to 20, except when it is down. On reading this query, the coordinator send an appropriate message to the two end routers of the link.

- D <AS id> <router id1> <router id2> : The link between routers with router ids id1 and id2 in AS id is down. Again on reading this query, the coordinator send an appropriate message to the two end routers of the link.

- F <AS id1> <router id1> <AS id2> <router id2> : The link between router ids id1 in AS id1 and id2 in AS id2 is down. On reading this query, the coordinator send an appropriate message to the two end routers of the link.

- U <AS id1> <router id1> <AS id2> <router id2> : The link between router ids id1 in AS id1 and id2 in AS id2 is up. On reading this query, the coordinator send an appropriate message to the two end routers of the link.

- S <msg> <h1> <h2> : Send a message msg (an integer) from host with IP address h1 to host with IP address h2. On reading this query, the coordinator sends an appropriate message to host h1. As this message is routed through various intermediate routers, each router appends its id in the message. When the message reaches h2, h2 prints the message (integer value) and the sequence of intermediate routers that the message passed through.

- P <AS id> <router id> : Print the forwarding table of the router. The coordinator sends an appropriate information to the router.