Designing IP Addresses for Large Networks
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Introduction

In numerous Cisco/Global Knowledge classes, students learn about IPv4 and IPv6 address subetting, complex subnetting, variable length subnet masking (VLSM), summarization, prefix routing, and address aggregation. These are valuable skills.

In order to apply these skills efficiently, a network designer should possess one additional skill. Planning the IP address space for a Class A or B IPv4 address is necessary to apply the complex skills listed above properly. Complex subnetting, VLSM, and IP address summarization can be implemented simply and efficiently with proper planning.

The purpose of this paper is to provide a simple-to-use tool for the IP address planning process. To begin, the 32-bit IPv4 address space is shown below:

<table>
<thead>
<tr>
<th>NETWORK BITS</th>
<th>SUBNET BITS</th>
<th>HOST BITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>32</td>
</tr>
</tbody>
</table>

Figure 1. The 32-bit IPv4 Address Space

Subnet bits are derived from “borrowing” bits from the host bits portion of the address so that additional networks can be identified. This process divides the 32 bits into three portions - network, subnet, and host - as shown in the figure above. Since a Class A address provides 24 host bits to work with, and a Class B address provides 16, the focus for planning is on Class A. The demarcation between the network portion of the address (network plus subnet bits) and the host portion of the address is called a bit boundary. The Class C address only allows the manipulation of eight host bits. This requires a minimum amount of planning for proper address administration. Several facts about the address space are:

1. The default network portion of the IP address will remain constant and be defined as Class A, B, or C, and be 8, 16, or 24 bits in length, respectively.

2. The number of host bits will be dictated by the application of the address (sometimes called role-based address assignment). For example, a VLAN may require up to 254 hosts, a smaller branch office may require up to 36 hosts, and a point-to-point line between two routers or a point-to-point Ethernet LAN link only require two hosts. For planning, the worst case need for host bits is identified first. In other words, what application is likely to require the highest number of host bits? This, of course, is the VLAN. And, the plan must include a provision for additional subetting of a /24 subnet as needed using VLSM to accommodate the need for a lesser number of hosts per network.
3. Planning the use of the subnet bit space is the critical part of the process, because summarization bit boundaries can be identified ahead of time in the planning process.

In most enterprises, the class A and B addresses that will be used are "private" as identified by RFC 1918, 10.0.0.0 for the Class A, and 172.16.0.0 through 172.31.0.0 for the Class Bs. Address planning for a Class A address such as 10.0.0.0/8 is used as an example.

First, the "worst case" number of host bits required by the users in any location for any application in the enterprise must be identified. To do that the following question must be answered. "What is the largest number of users in any one VLAN (broadcast domain)?" There are several variables to consider in order to answer this question.

**VLANS** - Client/Server applications were originally designed to comply with the 80-20 rule, which means that 80 percent of the data transferred remains in the same broadcast domain. To support this, end-to-end (organizational) VLANs were designed on the campus utilizing LAN switches that could extend the VLANs across Ethernet trunks using VTP (VLAN Trunking Protocol) and IEEE 802.1Q tagging or ISL (InterSwitch Link). These types of VLANs were common in the era of fast switches and slow routers. Modern network designs support the new rule for network traffic with data centers and the Internet being the target of most traffic, and no more than 254 hosts per VLAN is recommended, with routing between VLANs across the campus core.

<table>
<thead>
<tr>
<th>/8</th>
<th>/24</th>
<th>/32</th>
</tr>
</thead>
<tbody>
<tr>
<td>NETWORK BITS = 8</td>
<td>SUBNET BITS = 16</td>
<td>HOST BITS = 8</td>
</tr>
</tbody>
</table>

*Figure 2. Adding Subnets to the IPv4 Class A address space*

Eight host bits allow 254 hosts to be identified and leave 16 bits in the subnet space to be allocated to complete the plan. In addition, Cisco and Industry best practices recommend one IP subnet per VLAN for efficient routing between VLANs and across the enterprise.

**KEY POINT** - At this time in the planning, it is not necessary to deal with smaller VLANs requiring fewer host bits, non-VLAN environments requiring fewer host bits, or point-to-point links requiring only two host bits. With proper planning of the subnet space, these requirements will be met later in the process utilizing VLSM.

So, the first step in the plan is completed by identifying the number of host bits to be utilized for the initial network/host bit boundary. In our example, that would be a /24 network.
Planning the Subnet Space

Cisco network design guidelines refers to this process as “bit-splitting the subnet space.” The objective is to identify IP address summarization points before addresses are assigned to support hierarchical routing in the enterprise network (OSPF, EIGRP, and IS-IS). To do this, the following information is required about the enterprise (remember the maximum number of host bits needed is previously identified):

1. Number of countries where the company has locations.
2. Number of locations in each country (total number of locations).
3. Number of buildings and/or departments in each location/campus.
4. Number of VLANs per building, department, or region. Typically this will be number of VLANs per building submodule. Data, Voice, Wireless, and Management VLANs must be identified.
5. Growth factor to be added. This is estimated increases in number of locations, regions, buildings, VLANs, etc., which translates to additional bits required for each category. When in doubt, Cisco Network Designers typically use a minimum of 20 percent.
6. Number and location of smaller VLANs and non-VLAN environments (small offices, etc.).
7. Location and number of point-to-point links (two hosts).

 Armed with this information, a designer can plan the subnet bit space from the left to the right. As a rule of thumb, the bit space is allocated from left to right, and assigned from right to left. Figure 3 shows a plan that identifies countries, locations within countries, buildings within locations, and subnets (VLANs) for the buildings.

<table>
<thead>
<tr>
<th>NET=8</th>
<th>CCC</th>
<th>LLLL</th>
<th>BBB</th>
<th>SSSSSS</th>
<th>HOST=8</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>L</td>
<td>B</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Location</td>
<td>Building</td>
<td>Subnet in building (VLAN)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3. Summarization Points**

In the figure above, CCC means three bits used, LLLL means four bits used, etc. With this plan, up to eight countries can be identified, 16 locations within a country, eight buildings at each location, and 64 subnets for each building. Automatic summarization points are:

- All subnets in a building - /18
- All subnets at a specific location - /15
- All subnets in a specific country - /11

**KEY POINT** - The subnet space per building (SSSSSS) must be large enough to accommodate VLSM for point-to-point links, small offices, etc.
To accommodate point-to-point lines in a location or in the campus core, as well as small offices and non-VLAN applications requiring a small number of hosts, VLSM is used.

In the example above, The WAN core (if there is one) could be treated as one location within a country or one building within one of the existing locations. Any of the identified subnets (either /15 or /19) could be resubnetted to /30, which would provide many network numbers for point-to-point links.

The same process can be utilized for small offices or non-VLAN applications.
- If one of the locations in the previous example has 50 small branch offices, with 20 users in each office, 50 /27 addresses are required.
- Each building has 64 /24 subnets available. Any building’s address space can be used and for each /24 resubnetted to /27, eight more branch offices will have addresses.
- So, to do 50 branch offices would require seven of the 64 /24 subnets that are available. If there are point-to-point links going to each of the small offices, each /24 resubnetted to /30 will provide 64 additional subnets for them.

Obviously, proper planning during the design process makes VLSM, route summarization, and overall address administration simple.

A similar process can be used for planning IPv6 addresses.

A practical working example would be ACME Corporation. The relevant facts about ACME follow:
- There are locations in three countries, USA, Canada, and Mexico and a data center in the USA with a back-up data center in Canada.
- In each country, there are a maximum of six locations with ten branch offices at each location.
- Each branch office has a maximum of 20 users with a requirement for voice, data, and wireless.
- There are a maximum of five buildings at each location with the largest having 16 floors and the users have a requirement for voice, data, and wireless.
- The campus core will use Layer 3 point-to-point Ethernet links and each branch will also be connected to the campus core with point-to-point links.
- Growth will be minimal with no planned expansion to more countries, and possibly an additional location or building in the future, but no current plans are in place.
### Figure 4. A Way to Allocate the Address Space for Acme Corporation Using the Private Address 10.0.0.0/8

The reserved bit (R) can be used to expand either the location or building space.

The two data centers are assigned a country summary:

- USA – 000 – 10.0.0.0/11
- Mexico – 001 – 10.32.0.0/11
- Canada – 010 – 10.64.0.0/11
- Data Center 1 – 011 – 10.96.0.0/11
- Data Center 2 – 100 – 10.128.0.0/11

**NOTE:** The data center address assignment detail is not part of this example.

#### Figure 5. Breakdown of the Address Assignment for One Location in the US for Acme Corporation
All of the VLSM for the point-to-point links and device loopbacks will be done from the Core address space.

The subnetwork allocations for buildings are assigned in “first available” order.

For the core, the highest possible subnet is selected to begin the VLSM process (10.1.255.0/24). The core is also assigned the highest possible value in the building (B) field (1111) or 10.1.224.0/19. This is done to avoid possible address overlap as new VLAN subnets are assigned “bottoms-up” in the buildings by going “top-down” in the core.

The Management VLAN space in the core will be used for the management addresses for the core switches, the loopback interface addresses for the branch and headquarters routers, and the loopback interfaces for routers connecting to the Internet. More VLANs may be needed, but there are lots of extra addresses.

### Acme Corporation
#### Location 1 Details

<table>
<thead>
<tr>
<th>Building Branch, Core</th>
<th>Range</th>
<th># V:AMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>10.0.0.0/19 - 10.0.31.0/19</td>
<td>32</td>
</tr>
<tr>
<td>Building 2</td>
<td>10.0.32.0/19 - 10.0.63.0/19</td>
<td>32</td>
</tr>
<tr>
<td>Building 3</td>
<td>10.0.64.0/19 - 10.0.95.0/19</td>
<td>32</td>
</tr>
<tr>
<td>Building 4</td>
<td>10.0.96.0/19 - 10.0.127.0/19</td>
<td>32</td>
</tr>
<tr>
<td>Building 5</td>
<td>10.0.128.0/19 - 10.0.159.0/19</td>
<td>32</td>
</tr>
<tr>
<td>Branch VLANs</td>
<td>10.1.253.0/27 - 10.1.253.96/27</td>
<td>32 - Need 30</td>
</tr>
<tr>
<td>Campus Core Management VLAN</td>
<td>10.2.224.0/24</td>
<td>1</td>
</tr>
<tr>
<td>Campus Core Point-to-Point</td>
<td>10.1.225.0/30 - 10.1.255.64/30</td>
<td>16 Links</td>
</tr>
<tr>
<td>Branch Point-to-Point</td>
<td>10.0.0.0/19 - 10.1.254.40/30</td>
<td>10 Links</td>
</tr>
</tbody>
</table>

**Figure 6. Details of the Address Assignments for Location 1 of the Acme Corporation**

For IPv6 address planning, the simple approach is to simply obtain a number of /48 addresses from the addressing authorities and overcome the problem with “brute force.” However, there are still 16 bits that can be allocated using the methodology described here. The address is 128 bits long encoded in hexadecimal.

The first 48 bits (/48) are assigned by the authority or the ISP. The last 64 bits are assigned either manually, by the device, or DHCP. That leaves the space from /48 to /64 (16 bits).
Based on the previous example, the 16-bit field could be allocated as shown.

**Summary**

Great care must be taken to complete the IP address planning process accurately to accommodate current needs and growth. A bad address plan fouls up the routing and troubleshooting processes in the network. The following skills are needed:

- Basic and advanced Cisco network design
- Subnetting IP addresses
- VLSM
- Summarizing IP addresses
- IP Routing and Routing Protocols

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About the Author

Ray Dooley, BS, MBA, CCSI, CCNA, CCNP, CCDA, CCDP, SE, FE, has been a network professional in several capacities for over 30 years. He is a Global Knowledge Course Director for CCDA, ARCH, SWITCH, ROUTE, TSHOOT, and ICMI. He has done course development for Global Knowledge, Cisco Systems, and GE.