IPv4 Addressing Simplified

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January 23, 2011

The concept of **IP Addressing** is foundational to overall **routing** in general. Without a clear grasp of this concept, more issues related to complex routing will not make sense later. This paper assumes you have a basic understanding of the concept of IP packets in the context of passing information between two points. In order to break the concept of IP Addressing down we will use a metaphor of a courier and a package delivery at an office complex to introduce these concepts.

Think of an IP Address as the address label on a package. This label provides clues as to where to send the contents within a physical location contained in a large office complex (Figure 1). There are many buildings; each with several floors containing many offices; these offices can contain hundreds to thousands of people inside. Locating a specific person at a specific desk would be very difficult without some way to narrow down the search. In this case their unique Address (**IP**).

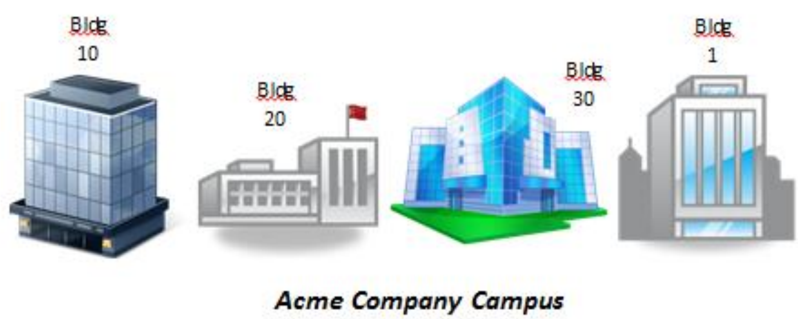

Figure 1. Campus Site overview

You are the messenger and have a time-sensitive important delivery to make (**packet**). Once you pick up that packet from the sender (**source**), you need to determine the recipients' location on the campus (**destination**). To do this, you look at the address label (IP) of the package. The address is broken down into a logical location which is represented as a **four Dot Notation** address. Each portion of the address is called an octet. In this addressing system octets can range from 0 – 255. Refering to the deliver label we see our destination address is **10.2.15.35**, Attn: Sally, Accounting Department.

Since Acme campus has several buildings, we need to narrow our search to first determine which building on this large campus Sally from Accounting might work. Looking at the building numbers (figure 1) on campus map, we see that buildings are numbered, 1,10,20 and 30. When you compare the IP address of **10**.2.15.35 to the buildings, we see that the first octet is "10"; there is a building 10 on campus. It would be logical that the recipient would be located somewhere in building 10, so we will drive to that location to continue our search.

When we arrive at the building, we discover there are many floors within this building (figure 2). The building is large and we have never visited this building before. We do not know if all the floors are occupied or how many people work on each floor. What we need a method to narrow our search down further. If we refer back to the IP address for clues, we see that the next octet of the IP address 10.**2**.15.35, is a "2". There are several floors in this building. It would make sense that the second octet represents the floor within the building. We decide to take the elevator to the second floor in search of Sally.

Figure 2. The 10 Network represented as a multi-floor building

Arriving at the second floor we discover there are many offices on the floor (figure 3). Each office has a door and we can't see inside. Our next challenge is to determine which office to visit. We notice that each door to each office has a number, beginning at 1 and ranging to 255. These offices represent logical groupings of workers that perform a similar function (e.g. Legal, Accounting, etc…) but may not work for the same company. If we refer back to the IP address for clues, we see that the third octet of the IP address 10.2.**15**.35, is a "15". It would make sense that the accounting department would be in office 15, so we enter this office.

Figure 3. Second Floor Hallway

When entering this office we find that there are hundreds of workers within this office. Fortunately we notice that each worker has an inbox on their desk. Each inbox has a number that ranges between 1 and 254. If we refer back to the IP address for clues, we see that the fourth octet of the IP address 10.2.15.**35**, is a "35". So it would make sense that Sally sits at the desk with Inbox 35.

Converting the metaphor to learning.

That was a fairly simplified example of how IP addressing works. It follows a logical hierarchical route to a specified destination. So now that we have determined where the package has to be delivered, we simply have to take a logical route to the location. This is accomplished through advertised routes. Suffice it to say, in its simplest form, it's a road map to a specified IP space which routers share among themselves. This topic is covered in more detail later on in this series. So an IPv4 address is a four-dot notated logical address. To better understand this, let's examine the address space itself. An IPv4 address is a thirty-two bit space that uses what is called **quad-dotted notation** to separate each of the four octets in the address IP space. An **Octet** is a decimal representation of an 8 bit binary address. The valid numerical range for any octet is between 0-255. For example, our fictitious IP address of 10.2.15.35 we used earlier becomes 1010.10.1111.100011 in binary. Using the quad-dotted notation, we can direct address packets between a **Source** and **Destination** location. There is however one other type of packet we must understand; the IP **Broadcast Packet**. A broadcast is not targeted at a specific destination, rather the entire address space identified in the Subnet mask. We will discuss subnetting a little later on in this paper. A computer sends a broadcast because they require the **Media Access Control (MAC) Address** of an unknown resource on the segment. For example, a computer might broadcast a 'DHCP Hello message' as a method to obtain an IP address from the DHCP server. Broadcasts are sent to a specified subnet mask of 255.255.255.255, which is interpreted as a destination of MAC address (FF:FF:FF:FF:FF:FF). All network cards are set to additionally access packets as this address. When the DHCP server responds, it provides its actual MAC address, which allows the requesting computer to target future packets in the handshake to that responding system, reducing the broadcast traffic to all other hosts.

Understanding Classes of Networking Address Space.

There are five basic address classes in IPv4. The primary classes are A,B, and C in regards to IP address space allocation. Class D is used for **Multi-casting** and exclusively uses the address space of 224.0.0.0; while Class E is an experimental class identified in RFC 997 and not currently used. Classes D and E are not further addressed in this overview. The **Class A Network** uses eight bits for the network identity and twenty-four bits for the host identity. This provides for a total of 126 possible usable networks and 16,277,214 possible usable hosts. A usable host address is defined as addresses not consumed by the reserved network or broadcast address for each subnet. The **Class B Network** uses sixteen bits for the network identity and sixteen bits for the host identity. This provides for a total of 16,384 possible usable networks and 65,534 possible usable hosts. In this hierarchy, several Class B sized networks are logically allocated as part of the larger Class A but retain their Class A network address spacing. The **Class C Network** uses twenty-four bits for the network identity and eight bits for the host identity. The fourth octet identifies the specific host. This provides for a total of 21 possible usable networks and 254 possible usable hosts.

Sub-allocated Network (Subnet) Mask Basics.

As you can probably imagine, in the larger networks, if a host has to search for a resource among 16,277,214 possible targets, the system time out would have to be quite large to allow enough time for the target to receive and respond to the request. One way we improve network performance is by narrowing down the total number of possible hosts on a network segment using a process called a subnet mask. The **Subnet Mask** provides a mathematical filter that tells the system how many hosts are within the systems network. For example, if you have a network of sixteen total IP addresses, there is no need to scan all 255 hosts of a Class C for a response. By not scanning unused or allocated network segments, your network performance improves. Depending on the type of device, a subnet can be annotated as either a four-dot notated logical address (e.g. 255.255.255.0) or in Classless Inter Domain Routing (**CIDR**) (e.g. /24). In CIDR notation, the number following the slash is the number of bits allocated to represent the network, with the remaining (from a total of 32 possible bits) representing the hosts. We will not delve any deeper into CIDR in this paper. Just like CIDR a subnet Mask helps the system determine how many possible hosts exist on its network. This may be arbitrarily determined by the administrator (e.g. using Private IP address spacing) or dictated as part of an addressable range provided by the upstream service provider (Roadrunner, Comcast, AT&T, etc…). Regardless, using the correct IP subnet mask is important. For the purposes of the following, we will focus on a Class C sized network. However this applies to Class A,B, and C Networks.

Let's go back to our scenario from earlier. If you remember, you found the right building, right floor, and right office. However, when you walked inside the office you discovered that it was quite large and contained 255 desks in a series of cubical work spaces (figure 4).

Figure 4. Room fifteen Cubical Farm

In order to narrow down your search, you need something else to help you further define where Sally sits. As we look more closely we realize that the room is divided into four cubical farms, each with 64 desks (figure 5). We don't know if all the desks belong to this company as many offices are shared. If we knew which quad to search, it would speed up our delivery. In addition to the address, there is an internal reference number (subnet mask). This reference number groups the desks based on the inbox numbers (fourth octet of the IP address) into logical clusters. In this case, we know that there are four cubical groups; each containing 64 desks; and each desk contains a single inbox. By looking at the IP address we see that the fourth Octet is "35". Using simple deductive reasoning surmise that the internal routing number of one most likely corresponds to cubical group one within this office. This means we would only need to search for Sally in the first quarter of the office, within cubical farm one. Walking into the cube grouping one, you see the inbox numbers and walk down the aisle to the desk with inbox 35. As you approach the desk with inbox 35 you find a woman smiling who greets you by saying “Ah a see you found me”.

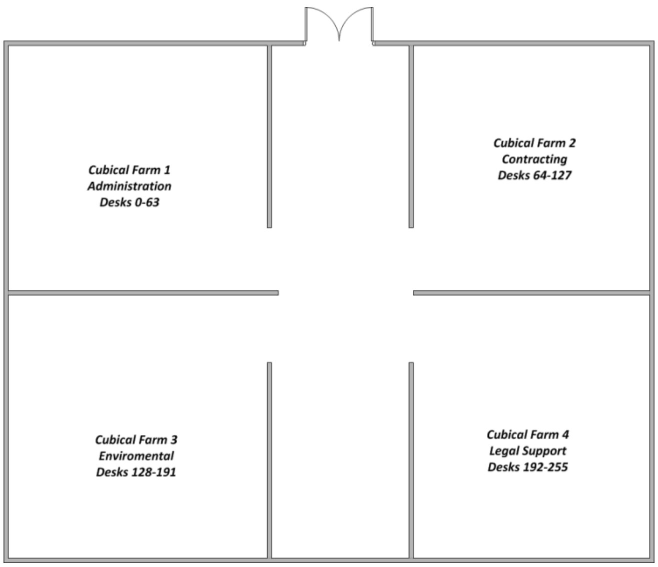

Figure 5. 2ND Floor, Room 15 office layout

<u>Converting the metaphor to learning.</u>

In this case, rather than physically searching through all 255 possible hosts (desks) in the destination network (office), we can narrow the search because we do not own the entire Class C (255 address space). In this case we only control the first 64 addresses (desks). Searching beyond the 64th IP is a waste of time and degrades performance. By using a subnet mask of 255.255.255.192, we tell the host to only search in blocks of 64 total IP’s.

# Hosts	Network Address	Broadcast Address	Usable IP’s	Subnet Mask	CIDR Notation
254	192.168.0.0	192.168.0.255	254	255.255.255.0	/24
126	192.168.0.0	192.168.0.127	126	255.255.255.128	/25
	192.168.0.128	192.168.1.254	126		/25
64	192.168.0.0	192.168.0.63	64	255.255.255.192	/26
	192.168.0.64	192.168.0.127	64		/26
	192.168.0.128	192.168.0.191	64		/26
	192.168.0.192	192.168.0.255	64		/26

Figure 6. Partial Class C Network Subnet Breakdown Sample

Since we know the IP address fourth octet is “35” then the computer can ascertain that if the host in that 64 block IP range does not respond, then to stop searching. As we can see, this filter can improve performance and it can also cause problems. If you inadvertently seek an IP address outside the confines of the set subnet mask, it will not be found.

For example:

Scenario: You have been issued a block of 64 IP addresses from your Internet Provider (/26 CIDR) using the below information. You have just been tasked to statically add a new workstation to the network using a previously unassigned IP address:

IP Range: 10.168.0.128 - 10.168.0.191
Subnet Mask: 255.255.255.192

Task: Trouble shoot why the statically assigned Host of 10.168.0.204 can't connect to the network printer at 10.168.0.189 or the internet.

Using figure 6 above, you can see this is the third segment of possible networks within the .192 subnet mask range. This tells us that we must set our **Network Gateway Address** IP to 10.168.0.128 and we must reserve 10.168.0.191 as the network broadcast address. If we assign a client system an IP of 10.168.0.204, it's not on the same network as our space allocation. Even if we provide it our correct gateway address of 10.168.0.128 and connect it to our switch, the traffic will not be able to pass to the gateway because the subnet mask filters the search to only logical hosts in its defined segment. Changing the IP address to one of the usable address within the 10.168.0.129 – 10.168.0.190 range that is not previously allocated will resolve the issue.

Terms:

Broadcast Packet: A specially crafted packet that is addressed not to a specific system, but to a universal MAC address on a network segment that all assigned hosts listen. This MAC address is FF:FF:FF:FF:FF:FF,, which equates to 255.255.255.255. These packets normally are used for discovery and service requests (e.g. DHCP discovery, host searching, etc…).

CIDR (Classless Inter Domain Routing): divides the total possible address space into two segments. The first segment is the Most Significant Part or network address segment. This segment identifies a whole network or sub-allocated network space. The second part segment is the Least Significant portion, which identifies the number of hosts, or the remaining bits in a 32-bit address space.

Class A Network: Logical network address space consisting of a total of 126 possible usable networks and 16,277,214 possible usable hosts.

Class B Network: Logical network address space consisting of a total of 16,384 possible usable networks and 65,534 possible usable hosts.

Class C Network: Logical network address space consisting of a total of 21 possible usable networks and 254 possible usable hosts.

Class D Network: used for Multi-casting and exclusively uses the address space of 224.0.0.0.

Destination: The end point that an IP packet is targeted.

IPv4 Address: A 32-bit network address consisting of four octets which follow classfull network hierarchy.

Media Access Control (MAC) address: A unique 64-bit identifier assigned to network interface hardware (both physical and virtual) for communications on the physical network segment. For physical hardware, this burned into the chip as the time of manufacture and not duplicated, providing a unique hardware address. The MAC address is a combination of the manufactures assigned hardware address code and the unique device ID number assigned by the manufacture.

Multi-casting: A process that allows for a system to steam the same content to more than one host simultaneously. This is often used for multi-media content. Examples include one-to-many audio conferences and one-to-many video streams.

Network Gateway: The Router address that points to the upstream content provider or next hop beyond the connected LAN.

Octet: an eight digit binary address that is displayed in decimal notation for ease of viewing. Used in networking, see the quad-dotted notation standard below.

Packet: A basic unit of allocation related to digital communications. Dependent upon the method of communication, this may also be referred to as a datagram, segment, or frame. Data in transmission that exceeds the MTU size for a given host and destination is segmented into packets and transmitted. Once received at the destination, it is reassembled and consumed by the assigned application.

Quad-dotted Notation: A decimal-based addressing notation that separates the binary address into four octets (segments). These segments have a valid numerical range each octet between 0-255.

Routing: The transmission of datagrams between a source and destination using agreed upon protocols.

Source: The host system attempting to initiate communications with a destination system.

Subnetting is the allocation of logical network addresses, using a hierarchical distribution system that provides a traversable flow for packets that travel the network between source and destination.

Subnet Mask: The logical filtering of packet within a classful network.