You previously learned that when an organization chooses to use a certain number of bits for the subnet identifier, that choice determines the number of subnets throughout the organization, and the number of hosts per subnet for all subnets. That methodology works on the assumption that the organization uses the same length subnet mask throughout the organization, termed a *fixed length subnet mask (FLSM)*. Although fixed length subnet masks are straightforward conceptually, their use can result in many assignable addresses being wasted or unused by the organization. These wasted or unused addresses can lead to decreased routing performance, and can cause the organization to run out of subnets and/or addresses as their network grows.

In this lab, we explore a flexible methodology for assigning subnets in an organization's network that helps to address these issues, and that builds upon the methodology you have already learned. You learn how to create subnets that have different length subnet masks (and thus different length network identifiers) in the same organization, termed *variable length subnet masks (VLSM)*. With variable length subnet masks, an organization can create some subnets with a larger number of assignable addresses, and some subnets with a smaller number of assignable addresses, minimizing wasted addresses.

LAB OBJECTIVES

The objectives of this lab are:

- to learn how the use of fixed length subnet masks can leave many assignable addresses unused.
- to learn why re-allocating existing subnets is problematic.
- to learn what variable length subnet masks are conceptually.
- to learn to allocate subnets with VLSMs in limited scenarios.
- to learn how to calculate various important properties of subnets that use variable length subnet masks.

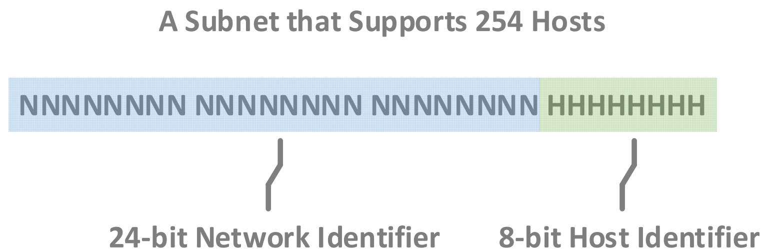
LAB SUBMISSION

Use the submission template provided in the assignment inbox to perform the steps requested by this lab. Return to the assignment inbox to submit your lab.

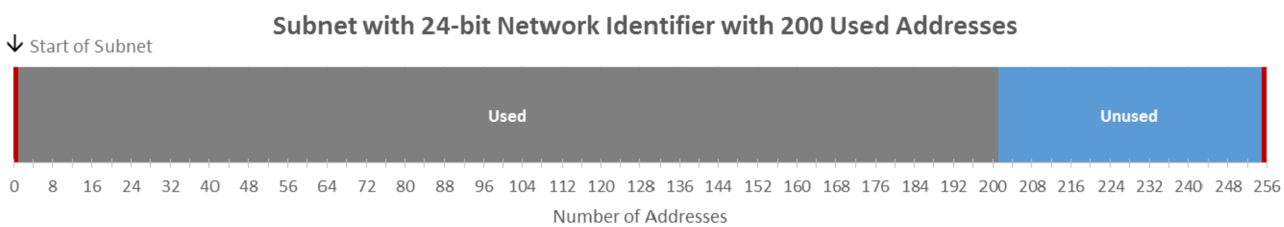
Section One – Variable Length Subnet Masks

OVERVIEW

Let us begin with an example to help us learn the limitations of using fixed length subnet masks. Imagine that an organization initially needs to allocate a single subnet to support 200 client machines, and therefore allocates 24 bits for the subnet's network identifier, leaving 8 bits for the host identifier, as illustrated in the following figure.



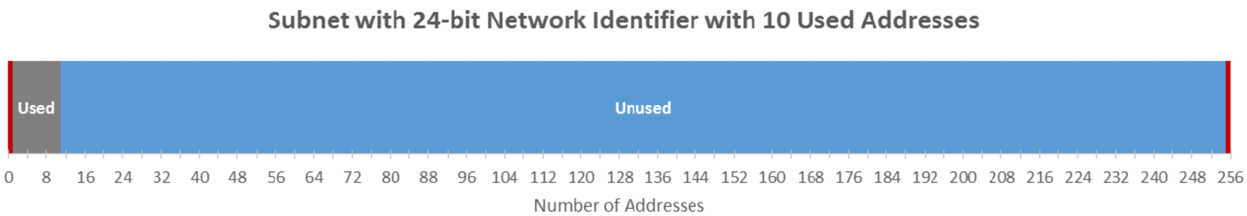
A subnet with an 8-bit host identifier supports 254 assignable addresses, which is the fewest number of assignable addresses that is a power of 2 and that supports the 200 client machines needed by the organization. Recall that we arrive at the number of assignable addresses by applying the number of host bits as the exponent of our binary base of 2. In this case, we have 8 host bits, and 2 to the 8^{th} power results in 256 total addresses. After subtracting out the network and broadcast addresses in the subnet, we know that there is a total of 254 assignable addresses. This allocation thus works as illustrated in the following figure.



We can see that the majority of the addresses are used on this subnet, and that the allocation is reasonable. In particular, if we had selected 7 host bits instead of 8 host bits, there would only be 126 assignable addresses, which would not be enough to support 200 client machines.

In the figure, the red bands that are one address long and that are located at the beginning and end of the subnet represent the network and broadcast addresses on the subnet. We know that these addresses cannot be assigned to any host, and the red bands are a simple indication of this fact. Some other figures in this lab make use of these red bands to indicate the unassignable network and broadcast addresses.

Imagine that after some time passes, the organization needs another subnet dedicated to supporting 10 servers. How will this organization allocate this subnet? From what we have learned thus far about subnet allocation, where the organization uses the same length subnet mask throughout the organization, the organization would allocate the new subnet with a different 24-bit network identifier. The subnet would support all 10 servers, but would also have 244 assignable addresses that are unused, as illustrated in the following figure.



We can see that almost all of the addresses on this subnet are left unused, which tells us that these addresses will most likely remain permanently unused, or wasted. If the organization's network substantially grows, these wasted addresses could cause the organization to run out of addresses, that is, to no longer be able to assign addresses to the new computers.

STEPS

1. In your own words, explain how the use of fixed length subnet masks (the use of same-length network identifiers throughout the organization) can cause issues of permanently unused, or wasted, addresses.

2. For each scenario below, indicate the number of assignable addresses and the number of unused addresses on the subnet. Make sure to show your work, but you do not need to draw a diagram unless it assists you in answering the question.

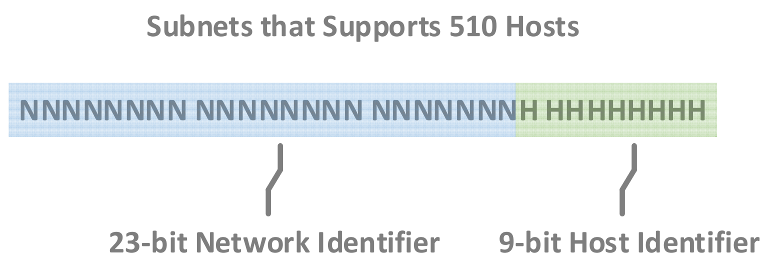
   Scenario A: Subnet 66.114.124.0/22 is used to support 217 hosts.

   Scenario B: Subnet 54.88.181.128/25 is used to support 119 hosts.

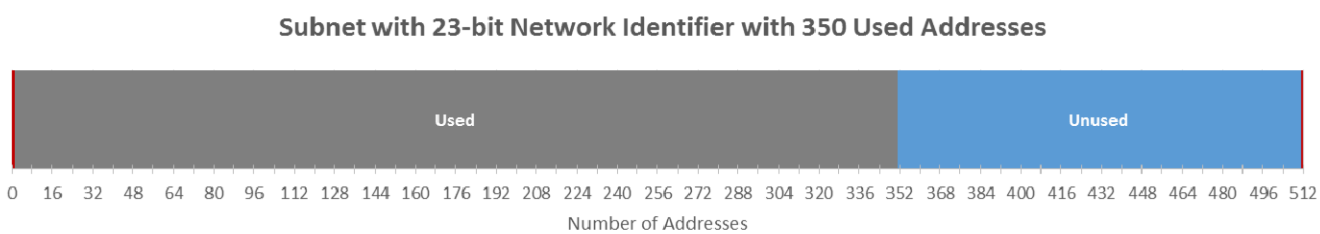
   Scenario C: Subnet 50.63.202.48/28 is used to support 1 host.

3. Now let us look at a perhaps even more serious problem that can occur in the example given in the introduction to this section. Imagine that after some time passes, the organization needs a third subnet that supports 350 hosts. We know that the use of an 8-bit host identifier limits the number of assignable addresses to 254, so 350 is beyond the capability of the existing allocation scheme. What options does the organization have when using the same length subnet identifiers throughout the

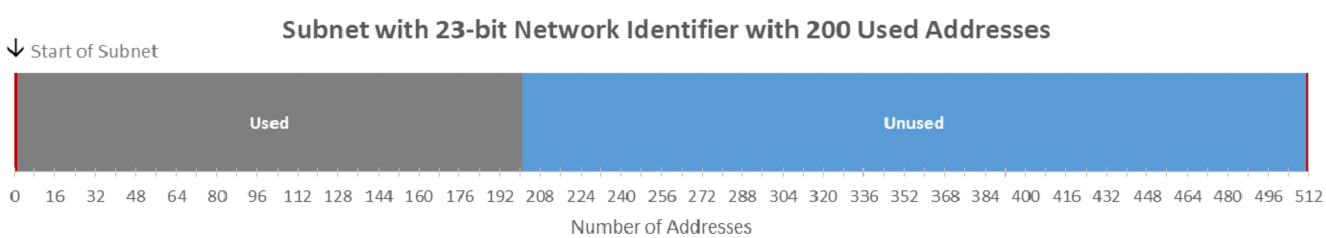
organization? One option is to re-allocate all existing subnets, and allocate the new subnet, with a 23-bit network identifier and a 9-bit host identifier, as illustrated in the following figure.

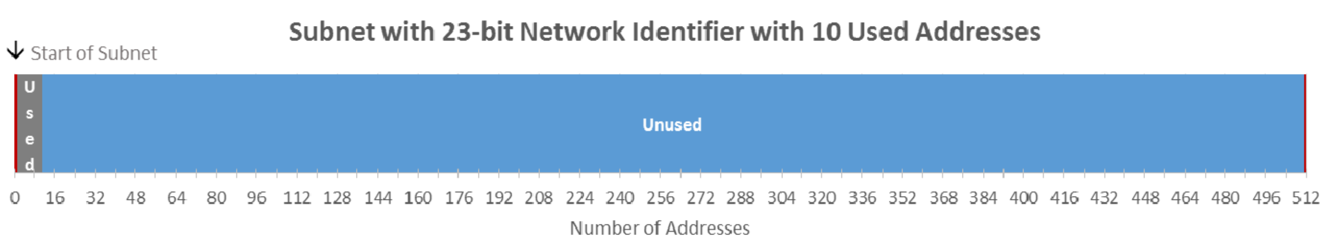


This re-allocation would ensure that all three subnets support the needed number of hosts. For example, the new subnet with 350 hosts would be allocated as follows.



This is a reasonable allocation because 510 is the least number of assignable addresses in a subnet that can support 350 hosts. However, what about the other two existing subnets? Many addresses would be wasted in each, as illustrated in the following figures.





Notice in particular how many addresses are wasted with the subnet that supports only the 10 servers. Practically the entire subnet is filled with unused addresses!

Wasted addresses are not the only problem with re-allocation. Re-allocating subnets is usually a major effort for an organization, because the addresses and other configurations for all client computers on the network must be re-configured and re-assigned. Re-allocation also requires changes to existing routers, DHCP servers, switches, firewalls, and other network devices and controls. So in summary, while re-allocation is a possible solution, it is oftentimes impractical, and also does not solve the problem of wasted addresses.

Another option for the organization is to simply make a requirement that no subnet can exceed 254 hosts. In this case, the organization would subdivide the new subnet into two subnets, each with fewer than 254 hosts. This requirement may or may not be viable, depending upon the requirements of the new subnet. And, just as with the re-allocation option, this requirement does not address the problem of existing wasted addresses.

4. Explain in your own words why re-allocating existing subnets to accommodate a new subnet is problematic.

5. At its core, the concept of variable length subnet masks (VLSMs) is subdividing subnets into additional subnets, which can be casually described as subnetting the subnets. Recall that the term “network” is often associated with a single overarching entity that belongs to an organization and represents the organization’s entire network, and the term “subnet” often refers to a specific sub-network within the organization’s overall network. Further recall that this distinction is somewhat arbitrary, because there is nothing to stop an organization from subdividing its overall network into multiple networks, and subnetting those smaller networks. To state this idea plainly, if we have a subnet, it is also by definition a network, and as such, additional subnets can be created from that original subnet.

   Let us take a look at an example use of VLSMs. Imagine that an organization is assigned the network specified by CIDR entry 198.105.0.0/16. The network identifier in binary for the organization’s network is thus **`11000110 01101001`**.

   Needing a subnet that supports 220 computers, they opt to create a subnet with a 24-bit network identifier, leaving addresses for up to 254 hosts. Recall that a 24-bit subnet identifier leaves 8 bits for the host identifier, and that 2 to the 8^{th} power, minus 2, brings the total number of assignable addresses to 254.

   The organization simply selects the first available network identifier for the subnet, which results in a CIDR entry for the subnet of 198.105.0.0/24. The subnet’s network identifier is illustrated in binary below.

```
First Subnet:  11000110 01101001 00000000
```

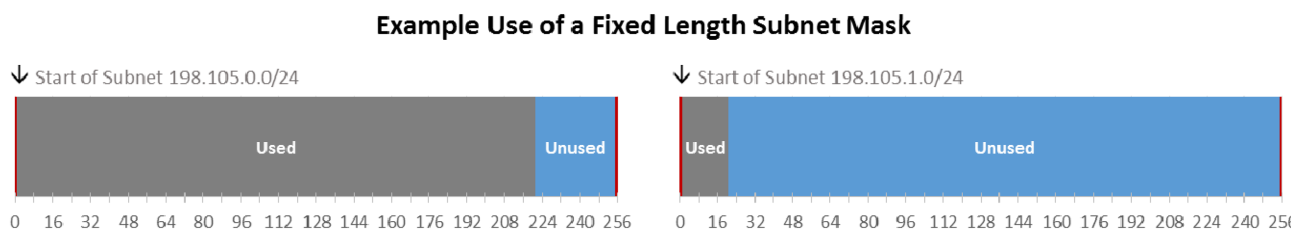
Notice that the first subnet's network identifier begins with the overarching network's network identifier, **11000110 01101001**. All subnets on that network must begin with the same 16-bit sequence, so that they remain on the same network. For the last 8 bits of the first subnet's network identifier, **00000000** is selected because **00000000** is the first (lowest) available number on the network.

Imagine that the organization needs another subnet which must support 20 computers. If the organization uses fixed length subnet masks, it would simply select the next subnet available, which has a CIDR entry of 198.105.1.0/24. In binary, the second subnet identifier would look as follows.

Second Subnet: 11000110 01101001 00000001

Notice that the first 16 bits, **11000110 01101001**, are the overarching network's network identifier, as is the case with all subnets on the network, and that the last 8 bits are **00000001**, because **00000000** is already used by the first subnet's network identifier. The bit sequence **00000001** is one higher than **00000000** and so is the next available choice.

The organization's use of fixed length subnet masks is illustrated diagrammatically in the following figure.



Notice that the two subnets are allocated sequentially and have the same length network identifier. Also notice that the second subnet has 234 unused addresses, which is undesirable.

Now let us take a look at allocating the second subnet using VLSMs instead of fixed length subnet masks. The organization may opt to do this to minimize the number of unused addresses. The organization would not change the allocation for the first subnet, because the minimum number of host bits, 8, are used in that allocation to support the 200 hosts. The change in allocation occurs with the second subnet.

The organization *begins* the process of subnet selection with the next available subnet, which we determined to be 198.105.1.0/24, but the organization does not end the selection there. Rather, the organization breaks that subnet into smaller subnets, or subnets the subnet. Since support for 20 hosts is needed, the organization only needs 5 bits for the host identifier, and thus 27 bits for the network identifier. Therefore the organization selects 198.105.1.0/27 as the next subnet instead of 198.105.1.0/24. In binary, this choice looks as follows.

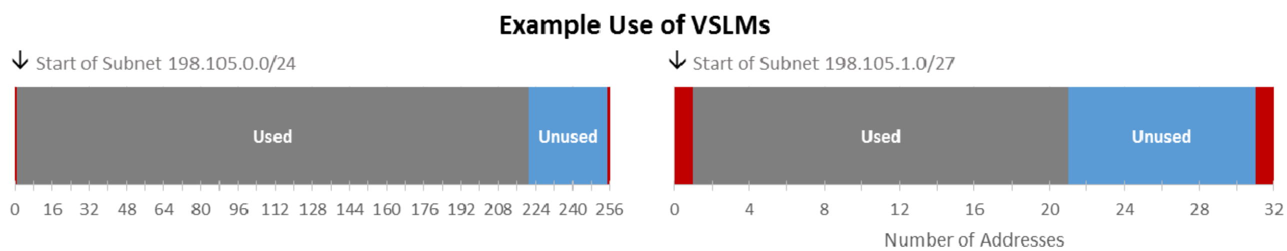
```
Second Subnet (using VLSMs): 11000110 01101001 00000001 000
```

Notice that this choice, when compared to the second subnet's network identifier, has an additional three 0 bits, **`000`**, at the end, as illustrated below.

```
Second Subnet (fixed length): 11000110 01101001 00000001
Second Subnet (VLSMs):        11000110 01101001 00000001 000
```

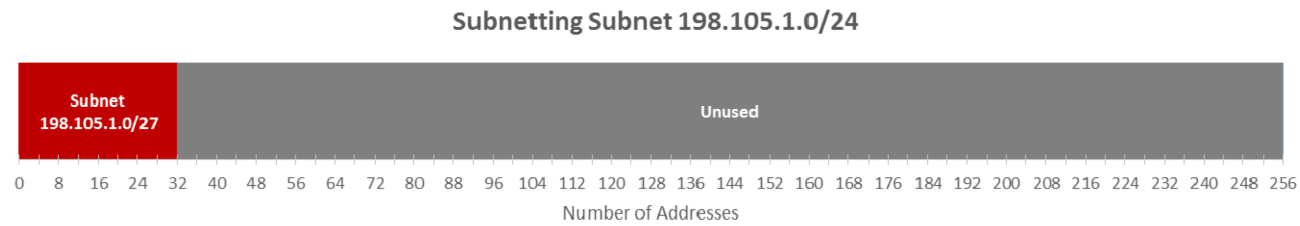
In effect this choice to use VLSMs to allocate the second subnet reduces the number of host bits available, and increases the number of bits available in the subnet identifier. The unused host bits can now be used in additional subnets.

The two subnet allocation is illustrated diagrammatically in the following figure.



Notice that the subnets allocated using VLSMs are allocated sequentially, the same as with the fixed length subnet mask scenario, but that the second subnet only has 10 unused addresses from a total 30 assignable addresses. We see that this use of VLSMs has significantly reduced the number of unused addresses.

Let us review the difference again. The organization *could* have selected subnet 198.105.1.0/24, but instead selected 198.105.1.0/27. The only difference between these two entries at first glance is the length of the subnet's network identifier. They have, in essence, *started with* 198.105.1.0/24, treated it as a network in its own right, then subnetted that subnet. This is illustrated in the following figure.

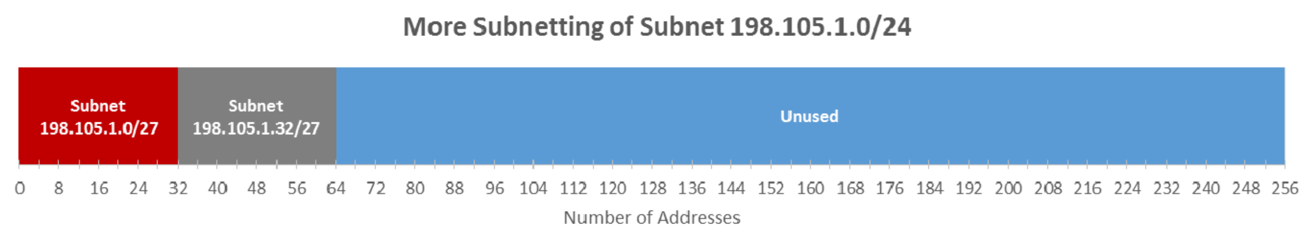


Notice that *would be* subnet 198.105.1.0/24 has been subnetted, and the first sub-subnet is 198.105.1.0/27.

What if the organization needs another subnet of the same size? They could simply choose the next one available with a 27-bit network identifier, and this would have CIDR entry 198.105.1.32/27. That subnet's network identifier would be **`11000110 01101001 00000001 001`** in binary. If we take a look at the network identifiers of the sub-subnets, they are sequential, as illustrated below.

```
First Sub-subnet:  11000110 01101001 00000001 000
Second Sub-subnet: 11000110 01101001 00000001 001
```

The subdivision of would be subnet 198.105.1.0/24 is illustrated in the following figure.



Notice that the second subnet is allocated immediately following the first subnet, and that two subnets have been allocated inside of a would be subnet 198.105.1.0/24. If the organization needed additional subnets of the same size, they would use the same method to allocate them.

Do you see how VLSMs work? The organization has the choice of either leaving the top-level subnets alone, or subnetting them into smaller subnets. If the organization always assigns hosts to top-level subnets directly, it is by definition opting to use fixed length subnet masks. If the organization opts to subnet one or more top-level subnets, it is by definition using VLSMs.

6. Below is a list of IPv4 address allocation scenarios, and you have a chance to exercise your knowledge based upon what you have learned in the previous step. Answer the series of questions for each scenario. Make sure to show your work.

Scenario A: The organization is assigned the network described by CIDR entry 172.226.0.0/16. The organization needs two subnets, the first to support 45 hosts, and the second to support 27 hosts. The organization allocates the first subnet as 172.226.0.0/26.

a. If the organization opts to use fixed length subnet masks to allocate its subnets, what is the CIDR entry for the second subnet, and what is the second subnet's network identifier in binary? Assume that the organization allocates the second subnet immediately adjacent to the first subnet.

b. If the organization opts to use VLSMs to allocate its subnets, what is the CIDR entry for the second subnet, and what is its network identifier in binary? Assume that the organization allocates the second subnet immediately adjacent to the first subnet, and creates it to be as small as possible whilst still supporting the needed number of hosts. It is not necessary to draw a diagram unless you feel it will help you answer this question.

c. Calculate the number of assignable addresses and the number of unused addresses for the second subnet for your allocation selections in part a and in part b.

Scenario B: The organization is assigned the network described by CIDR entry 64.91.224.0/22. The organization needs two subnets, the first to support 390 hosts, and the second to support 75 hosts. The organization allocates the first subnet as 64.91.224.0/23.

a. If the organization opts to use fixed length subnet masks to allocate its subnets, what is the CIDR entry for the second subnet, and what is the second subnet's network identifier in binary? Assume that the organization allocates the second subnet immediately adjacent to the first subnet.

b. If the organization opts to use VLSMs to allocate its subnets, what is the CIDR entry for the second subnet, and what is its network identifier in binary? Assume that the organization allocates the second subnet immediately adjacent to the first subnet, and creates it to be as small as possible whilst still supporting the needed number of hosts. It is not necessary to draw a diagram unless you feel it will help you answer this question.

c. Calculate the number of assignable addresses and the number of unused addresses for the second subnet for your allocation selections in part a and in part b.

Scenario C: The organization is assigned the network described by CIDR entry 98.136.241.128/25. The organization needs two subnets, the first to support 25 hosts, and the second to support 18 hosts. The organization allocates the first subnet as 98.136.241.128/27.

a. If the organization opts to use fixed length subnet masks to allocate its subnets, what is the CIDR entry for the second subnet, and what is the second subnet's network identifier in binary? Assume that the organization allocates the second subnet immediately adjacent to the first subnet.

b. If the organization opts to use VLSMs to allocate its subnets, what is the CIDR entry for the second subnet, and what is its network identifier in binary? Assume that the organization allocates the second subnet immediately adjacent to the first subnet, and creates it to be as small as possible whilst still supporting the needed number of hosts. It is not necessary to draw a diagram unless you feel it will help you answer this question.

c. Calculate the number of assignable addresses and the number of unused addresses for the second subnet for your allocation selections in part a and in part b.

7. For scenarios A, B, and C in step 6, does use of VLSMs significantly reduce the number of unused addresses in the second subnet? Explain for each scenario.

8. The last significant item to learn about VLSMs in this lab is to calculate various properties of subnets that use VLSMs. Calculating these properties is similar to calculating the properties of subnets that use a fixed length subnet mask.

   Let us take a look at an example. Imagine that an organization is assigned the block of addresses defined by 99.216.0.0/13. The organization initially must support 100 hosts on the first subnet, and 13 hosts on the second subnet. Using VLSMs, it creates the network identifiers as follows.

```
First Subnet:  01100011 11011000 00000000 0
Second Subnet: 01100011 11011000 00000000 1000
```

   After some time passes, the organization needs a third subnet that supports 100 hosts, and a fourth subnet that supports 29 hosts, which the organization allocates. The four subnets' network identifiers are as follows:

```
First Subnet:  01100011 11011000 00000000 0
Second Subnet: 01100011 11011000 00000000 1000
Third Subnet:  01100011 11011000 00000001 0
Fourth Subnet: 01100011 11011000 00000000 101
```

   We can now answer the following series of questions about the fourth subnet allocated. Though we focus on the fourth subnet, these questions can be answered for any of the subnets following the same methodology.

   a) How many bits are used by the subnet identifier of the fourth subnet?

14 bits are used.

b) What is the subnet mask for the fourth subnet in binary and in dotted decimal notation?
Since the network identifier spans 13 bits, and the subnet identifier spans 14 bits, the subnet mask is filled with 27 1 bits and 5 0 bits, like so:

11111111 11111111 11111111 11100000

In dotted decimal, this is 255.255.255.224.

c) How many hosts could the fourth subnet support?
Because the network identifier spans 27 bits, the host identifier spans 5 bits. Therefore the fourth subnet could support 30 hosts, because 2^5 = 32, and we subtract 2 because of the network and the broadcast addresses.

d) What is the fourth subnet's network address in dotted decimal notation?
The fourth subnet's network address is 01100011 11011000 00000000 10100000 in binary, and 99.216.0.160 in dotted decimal notation.

e) What is the broadcast address for the fourth subnet, in binary and dotted decimal notation?
We know that the network identifier is 01100011 11011000 00000000 101 in binary, and that the host identifier spans 5 bits. We simply fill the host identifier with all 1 bits to arrive at the broadcast address, which is 01100011 11011000 00000000 10111111 in binary, and 99.216.0.191 in dotted decimal notation.

f) What is the range of assignable IP addresses for the fourth subnet in dotted decimal notation?
We increment the network address by 1 to start the range, and we decrement the broadcast address by 1 to end the range. Therefore the range of assignable IP addresses are 99.216.0.161 through 99.216.0.190.

9. Now it is your turn to calculate the properties of subnets that are allocated using VLSMs.

Imagine that an organization is assigned the IP address block defined by 237.118.0.0/15, and that the organization needs one subnet that supports 400 hosts, and another that supports 77 hosts. The organization allocates the subnets' network identifiers as follows:

```
First subnet:  11101101 01110110 0000000
Second subnet: 11101101 01110110 00000010 0
```

Answer the following series of questions about *both* subnets.

a) How many bits are used by each subnet identifier?

b) What are the subnet masks of each subnet in binary and in dotted decimal notation?

c) How many hosts could each subnet support?

d) What are the network addresses of each subnet in dotted decimal notation?

e) What are the broadcast addresses of each subnet in binary and dotted decimal notation?

f) What are the ranges of assignable IP addresses for each subnet, in dotted decimal notation?

We will learn even more about VLSMs in the next lab, but you are already half way through the material on this subject. Congratulations!