Variable Length Subnet Masks (VLSM)

“Classful Route” Means if a route to a network starting with
1 - 126 is received, it is a class A => mask length is 255.0.0.0
128-191 => class B => 255.255.0.0
192-223 => Class C => 255.255.255.0

Classful interpretation of routes implies and requires guesswork. (Not explicitly told everything)

Classless routing advertises a mask along with each route.

VLSM addressing cannot be used with classful routing protocols. Old protocols like RIP version 1 are classful. Modern routing protocols (for example OSPF) are classless.

Variable length subnet masks: IP network is subdivided in unequal pieces, each having its own unique subnet mask thus “extended-network-prefixes” have different lengths.

VLSM allows size of subnets to reflect the number of required host addresses in each subdivision.

We desire to use smaller subnets (Longer Masks) where we have fewer end stations and larger subnets (Shorter Masks) where there are more endstations.

VLSM also allows for route aggregation. Network is first divided into subnets, some subnets are further divided into sub-subnets, etc. Allows routing information for one subnet group to be hidden from routers in another subnet group.

Source: IP Fundamentals by Maufer Chapter 4
Requirements For Using VLSM

1. Routing protocols must carry extended-network-prefix information with each route advertisement. OK to use: OSPF, RIPV2, IS-IS, CISCO’s E–IGRP they are all classless.

2. Routers must use a forwarding algorithm based on longest match.

EXAMPLE: IP packet destination IP address 10.1.2.5
Routing table has entries for: 10.1.0.0/24
                          10.1.2.0/24
                          10.1.0.0/16

DESTINATION
10.1.2.5 = 00001010.00000001.00000010.00000101

POSSIBLE ROUTES
  Route # 1
      10.1.0.0/24 = [00001010.00000001.00000000].00000000
  Route # 2
      10.1.2.0/24 = [00001010.00000001.00000010].00000000
  Route # 3
      10.1.0.0/16 = [00001010.00000001].00000000.00000000

  Route # 2 Has Longest Machine Prefix

3. Subnet clusters must share the same set of most significant bits. This allows clustering of subnets into one single route with a shorter mask.
Address allocation for private internets RFC - 1918. IANA has reserved:

- 10.0.0.0 - 10.255.255.255 (10.0.0.0/8 prefix)
- 172.16.0.0 - 172.31.255.255 (172.16.0.0/12 prefix)
- 192.168.0.0 - 192.168.255.255 (192.168.0.0/16 prefix)

- Private not routable on internet
- Can be used simultaneously by many organizations
VLSM EXAMPLE

An Organization has the “Private” network prefix 192.168.0.0/16 and plans to deploy VLSM. Here is their plan:

To have 16 equal size blocks $2^4 = 16 \Rightarrow 4$ bits are needed beyond /16 $\Rightarrow$ 20 extended-network-prefix
Each of these blocks has $2^{12} = 4096$ addresses below.

Here are those subnets:

Base Prefix: 11000000.10101000.00000000.00000000 = 192.168.0.0/16

Subnet # 0: 11000000.10101000.00000000.00000000 = 192.168.0.0/20
Subnet # 1: 11000000.10101000.00010000.00000000 = 192.168.16.0/20
Subnet # 2: 11000000.10101000.00100000.00000000 = 192.168.32.0/20
Subnet # 3: 11000000.10101000.00110000.00000000 = 192.168.48.0/20
Subnet # 4: 11000000.10101000.01000000.00000000 = 192.168.64.0/20
Subnet # 13: 11000000.10101000.11010000.00000000 = 192.168.208.0/20
Subnet # 14: 11000000.10101000.11100000.00000000 = 192.168.224.0/20
Subnet # 15: 11000000.10101000.11110000.00000000 = 192.168.240.0/20
While at this level in the hierarchical addressing plan look at the resulting host addresses Available for the subnet # 3 ( 190. 168.48. 0/20 )

Define the host addresses for Subnet # 3ₜ₄ ( 192.168.48.0/20 ).

Subnet # 3: 11000000.10101000.00110000.00000000 = 192.168.48.0/20

Host # 1: 11000000.10101000.00110000.00000001 = 192.168.48.1
Host # 2: 11000000.10101000.00110000.00000010 = 192.168.48.2
Host # 3: 11000000.10101000.00110000.00000011 = 192.168.48.3

Host # 4093: 11000000.10101000.00111111.11111101 = 192.168.63.253
Host # 4094: 11000000.10101000.00111111.11111110 = 192.168.63.254

The broadcast address for Subnet # 3ₜ₄ is found by setting the host-number field to the all-1s value, like so:

Broadcast : 11000000.10101000.00111111.11111111 = 192.168.63.255
ASIDE:

Notation
Given that we are working with a /16 base address

Subnet # 3₄ is the subnet with value 3 while using a 20 bit extended-network-prefix
(a 4 bit field has been added to the /16 base address)

Subnet # 14₄ - 14₄ is sub-subnet # 14 (while using a 4 bit sub-subnet field) under subnet #14
(which also in this example also uses a 4 bit subnet field added onto the /16 base address).
Thus the extended network prefix is now 24 bits long.
While still at this same level look at the 16 subnets we want on #14\(_4\) (199.168.224.0/20)

Define 16 sub-subnets for subnet #14\(_4\) (192.168.224.0/20)

- Subnet #14: \(11000000.10101000.11100000.00000000 = 192.168.224.0/20\)
- Subnet #14-0: \(11000000.10101000.11100000.00000000 = 192.168.224.0/24\)
- Subnet #14-1: \(11000000.10101000.11100001.00000000 = 192.168.225.0/24\)
- Subnet #14-2: \(11000000.10101000.11100010.00000000 = 192.168.226.0/24\)
- Subnet #14-3: \(11000000.10101000.11100011.00000000 = 192.168.227.0/24\)
- Subnet #14-4: \(11000000.10101000.11100100.00000000 = 192.168.228.0/24\)
- Subnet #14-14: \(11000000.10101000.11101110.00000000 = 192.168.238.0/24\)
- Subnet #14-15: \(11000000.10101000.11101111.00000000 = 192.168.239.0/24\)
While down “2 levels” look at the host addresses on one of these new sub–subnetworks, the # 14 – 3 (192.158.227.0/24)

Define the host addresses for subnet # 14 – 3 (192.168.227.0/24)

The host addresses for Subnet # 14 - 3 are listed below. The underlined portion of each address identifies the extended–network–prefix, while the bold digits identify the 8 bit host–number field:

Subnet # 14 - 3: 11000000.10101000.11100011.00000000 = 192.168.227.0/24

Host # 1 11000000.10101000.11100011.00000001 = 192.168.227.1
Host # 2 11000000.10101000.11100011.00000010 = 192.168.227.2
Host # 3 11000000.10101000.11100011.00000011 = 192.168.227.3
Host # 4 11000000.10101000.11100011.00000100 = 192.168.227.4
Host # 5 11000000.10101000.11100011.00000101 = 192.168.227.5
Host # 253 11000000.10101000.11100011.11111111 = 192.168.227.253
Host # 254 11000000.10101000.11100011.11111110 = 192.168.227.254

The broadcast address for Subnet # 14 – 3 is determined by setting all the bits in the host-number field to 1, which is:

Broadcast: 11000000.10101000.11100011.11111111 = 192.168.227.255
While down “2 levels” look at the sub-subnets for # 144 - 144 (192.168.238.0/24)

Define the sub-subnets for subnet # 144 - 144 (192.168.238.0/24)

Determine Eight Sub-sub Subnets for Subnet # 144 - 144 (192.168.238.0/24)

After Subnet # 14^4 was divided into 16 subnets, subnet # 14^4 - 14^4 was further subdivided into eight equal-sized address blocks, as shown above.

Since $8 = 2^3$, 3 more bits are required to identify each of eight subnets. This means that the extended-network-prefix length for this level of subnetting will be 27.

The eight subnets of the 192.168 238.0/24 address block are given below, numbered 0 through 7. The underlined portion of each sub-sub-subnet address identifies the extended-network-prefix, while the **bold** digits identify the 3 bits representing the sub-sub-subnet-number field:

Subnet # 14 - 14:

Subnet # 14 - 14 - 0:

Subnet # 14 - 14 - 1:

Subnet # 14 - 14 - 2:

Subnet # 14 - 14 - 3:

Subnet # 14 - 14 - 4:

Subnet # 14 - 14 - 5:

Subnet # 14 - 14 - 6:

Subnet # 14 - 14 - 7:
Going down “3 levels” look at the sub–sub–subnet of #14 - 2 (192.168.238.64/27)

Define the host addresses for subnet #14 - 2 (192.168.238.64/27)

Determine Host Addresses For Subnet #14 - 2 (192.168.238.64/27)

Let’s examine the host addresses that can be assigned to Subnet #14 - 2 (192.168.238.64/27).

Each of the subnets of Subnet #14 - 2 has 5 bits in the host-number field. This means that each subnet contains 30 valid host addresses ($2^5 - 2$). The valid host addresses for Subnet #14 - 2 are given below. The underlined portion of each address identifies the extended-network-prefix, while the bold digits identify the 5-bits host-number field:

Subnet #14 - 2:

- Host #1: 11000000.10101000.11101110.01000001 = 192.168.238.65
- Host #2: 11000000.10101000.11101110.01000010 = 192.168.238.66
- Host #3: 11000000.10101000.11101110.01000011 = 192.168.238.67
- Host #4: 11000000.10101000.11101110.01001000 = 192.168.238.68
- Host #5: 11000000.10101000.11101110.01001001 = 192.168.238.69
- Host #29: 11000000.10101000.11101110.01011110 = 192.168.238.93
- Host #30: 11000000.10101000.11101110.01011111 = 192.168.238.94

The broadcast address for Subnet #14 - 2 is the all-1’s host address, namely:

Broadcast 11000000.10101000.11101110.01011111 = 192.168.238.95
GOING THE OTHER WAY  ( SUPERNETTING )

(See Forouzan Chapter 5)

So far took fixed prefix and divided into a number of smaller subnets with longer prefix lengths

Now: How can we combine thirty two / 24’s to make a shorter prefix / 19 aggregate.

When are thirty two / 24’s not aggregatable into a / 19 ?

NOTE: / 24 mask 11111111.11111111.11111111.00000000

/ 19 mask 11111111.11111111.11100000.00000000

\[ 2^5 = 32 \]

Now days internet users are granted “blocks” of / 24’s when they need more than one / 24 but less than one / 16.

EXAMPLE:

Four Class C’s

192.168.66.0/24 through 192.168.69.0/24

Can we aggregate these 4 /24’s into a single advertisement of a / 22 ?

192.168.66.0  11000000 . 10101000. 010000  10 . 00000000
192.168.67.0  11000000 . 10101000. 010000  11 . 00000000
192.168.68.0  11000000 . 10101000. 010001  00 . 00000000
192.168.69.0  11000000 . 10101000. 010001  01 . 00000000

These 22 bits not always same => NO

REFERENCE: Chapter 5 “IP fundamentals ” By Maufer
Another Example:

Four Class C’s
192.168.68.0/24 through 192.168.71.0/24

Can we aggregate into single?

192.168.68.0 11000000.10101000.01000100.00000000
192.168.69.0 11000000.10101000.01000101.00000000
192.168.70.0 11000000.10101000.01000110.00000000
192.168.71.0 11000000.10101000.01000111.00000000

These 22 bits always same => YES
192.168.68 / 22
Supernetting

Subnetting divides a single IP address into multiple subnetworks. A supernet is the inverse of a subnetwork and is an aggregation of multiple class C networks into a single common address prefix.

1. Reduces size of routing tables by reducing number of separate class C network entries.

2. More efficient use of limited IP address space.
   - Class B ≈ 65,000 hosts
   - Class C only 254
   Instead of one B, use only as many C as needed.

Example
Suppose we are assigned a block of 16 class C addresses

192.18.0.0
192.18.1.0
192.18.2.0
192.18.15.0

Router

Advertise 192.18.0.0
With mask 0xfffff000

11111111 11111111 11110000 00000000

192 18 > 15
Must Must Will
Match Match Not
Match

...
CLASSLESS INTERDOMAIN ROUTING (CIDR)

CIDR removes concept of class A,B,C, network addresses and uses instead concept of network-prefix. Routers use network prefix instead of first 3 bits of IP address to determine dividing point between network number and host number.

CIDR supports arbitrary sized networks instead of standard 8,16, or 24 bit network numbers.
Constraint: address blocks must always be a power of 2

Advantages:
(1) Helps keep internet routing tables smaller ( 60,000 routes instead of 80,000 )

(2) Keeps internet from seeing every single network “route – flap” ( Net Up, Net Down, Up, Net Down….. ) by doing route aggregation.

In CIDR each route is advertised with a bit mask ( Prefix Length ) ; specifies number of left most bits in network portion. With CIDR a /20 prefix (for example) can be carved out of a traditional Class A, Class B, or Class C network number.

EXAMPLES:

Traditional A 10. 223. 208. 0 / 20 00001010. 11011111. 1101 0000 . 0000000
Traditional B 172. 16. 144. 0 / 20 10101100. 00010000. 1001 0000 . 0000000
Traditional C 192. 168. 64. 0 /20 11000000. 10101000. 0100 0000 . 0000000

2 12 Hosts 4096
CIDR Example # 1

An Internet service provider (ISP) has been given 200.25.0.0/16. A portion of this address space 200.25.16.0/20 has been allocated as follows:

ISP Single Advertisement!
Now what if organization “A” decides to change internet service providers to a provider that has been assigned addresses 199.30.0.0/16.
The exception route should be advertised by ISP #2. Since longest prefix match always takes precedence, this will work.
CIDR Example #2

An ISP has been assigned the address block 206.0.64.0/18
(Since 14 bits are left out of this block we have $2^{14} = 16,384$ addresses).
(Note a single /24 => $2^8 = 256$ addresses and thus a single /18 is equivalent to 64 class C’s)

New customer needs 800 host addresses
- A single /24 => $2^8 = 256$ addresses
  (A class C size block)

  A single Class C size block is **NOT ENOUGH**

- Single /16 wastes too many addresses!
- ISP decides to assign a /22 This has $2^{10} = 1024$ addresses and is equivalent to a block of four class C’s
  For Example Assign
  206.0.68.0/22

- This is at most one new route that must be advertised.
CIDR Example #3

Assume an ISP with 200.25.0.0/16. The ISP wants to allocate the 200.25.16.0/20 address block (which is $2^{12} = 4096$ IP addresses, which is classfully equivalent to 16/24’s)

First: In a classful environment how would this be done?

Second: In a classless environment how could this be done?

First: Must use the /20 as 16 individual /24’s by filling out all possible bit patterns.

<table>
<thead>
<tr>
<th>Network #</th>
<th>Bit Pattern</th>
<th>IPv4 Address</th>
<th>Subnet Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0000.00000000</td>
<td>200.25.16.0/24</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0001.00000000</td>
<td>200.25.17.0/24</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0010.00000000</td>
<td>200.25.18.0/24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1111.00000000</td>
<td>200.25.31.0/24</td>
<td></td>
</tr>
</tbody>
</table>

Changes

In classful environment **must cut into equal sizes in this example**

Second:

There are many possibilities. One possible solution is to take this block of addresses and cut it into two halves, one half may be assigned to organization “A”. The second half may be split again with one half of it going to organization “B”. The remaining half of the original half may be split again into halves and assigned to “C” and to organization “D”.
Can Do This By

Step 1: Divide address block 200.25.16.0/20 into two equal halves, each with $2^{11} = 2048$ addresses

Original ISP Block: $11001000.00011001.00010000.00000000$ 200.25.16.0/20

ORG A: $[11001000.00011001.00010000]00.00000000$ 200.25.16.0/21

Remaining: $[11001000.00011001.00010011]00.00000000$ 200.25.24.0/21

Step 2: Divide remaining block into two equal halves.

Remaining From

Step 1: $[11001000.00011001.00010011]00.00000000$ 200.25.24.0/21

ORG B: $[11001000.00011001.00010011]00.00000000$ 200.25.24.0/22

Remaining: $[11001000.00011001.00011101]00.00000000$ 200.25.28.0/22

Step 3: Divide remaining block from step1 into two equal sized blocks

Remaining From $[11001000.00011001.00011111]00.00000000$ 200.25.28.0/22

Step 2:

ORG C: $[11001000.00011001.00011111]00.00000000$ 200.25.28.0/23

ORG D: $[11001000.00011001.00011111]00.00000000$ 200.25.30.0/23
Cont.
WHAT IS THE DIFFERENCE BETWEEN CIDR AND VLSM?

CIDR and VLSM are essentially the same thing since they both allow a portion of the IP address space to be recursively divided into subsequently smaller pieces.

The difference is that with VLSM, the recursion is performed on the address space previously assigned to an organization and is invisible to the global Internet.

CIDR, on the other hand, permits the recursive allocation of an address block by an Internet Registry to a high-level ISP, to a mid-level ISP, to a low-level ISP, and finally to a private organization's network.

The key difference between VLSM and CIDR is a matter of where recursion is performed. In VLSM the subdivision of addresses (subnetting) is done after the address range is given to the user. In CIDR the subdivision of addresses (aggregation) is done by the Internet authorities and ISP before the user receives the addresses.