# Notes: Networks, Subnets, and CIDR



## About

There are networks known as classful and classless. The first plan adopted and used widely by the Internet community were classful networks. So named because three address classes: A, B, and C were defined with assignable IP address space. These classes, however, disproportionately distributed the number of available IP addresses. A new method to identify networks and allocate IP addresses was needed to support the continued growth of the Internet. The new method is named classless because it does away with the idea of classes altogether. It is commonly known as Classless Inter-Domain Routing (CIDR). It is much more flexible than classful networks and is what the Internet uses today. Classful networks are still used by many devices, so it is important to understand both classful and classless networking.

### IPv4 Overview

An IPv4 address contains 32-bits. It is usually represented in dotted decimal quad notation so it is easier to read and communicate. Computers, of course, read this information in binary form. And in order to calculate subnet masks, network addresses, and broadcast addresses, the binary value must be known.

Converting a dotted decimal IP address to binary is simple. Given that there are 4 numbers, each decimal number is represented in binary as an octet. The high order bits in binary are always the leftmost ones.

Counting in Binary

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Binary** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Powers of 2** | $2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ |
| **Decimal** | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |

The largest single value an IP address may have in decimal is 255 since this is the sum when all of the bits are added together, i.e. $2^7 + 2^6 + 2^5 + 2^4 + 2^3 + 2^2 + 2^1 + 2^0$. When all of the bits are turned off, the number is 0. The range of an IP address is therefore 0 - 255, 256 values.

The following is how the IP address 68.125.16.250 would be converted and represented in binary form.

| | Decimal | Broken Down | Binary Addition | Binary |
|---|---|---|---|---|
| **First Octet** | 68 | 64 + 4 | $2^6 + 2^2$ | 01000100 |
| **Second Octet** | 125 | 64 + 32 + 16 + 8 + 4 + 1 | $2^6 + 2^5 + 2^4 + 2^3 + 2^2 + 2^0$ | 01111101 |
| **Third Octet** | 16 | 16 | $2^4$ | 00010000 |
| **Fourth Octet** | 250 | 128 + 64 + 32 + 16 + 8 + 2 | $2^7 + 2^6 + 2^5 + 2^4 + 2^3 + 2^1$ | 11111010 |

The end result looks like 01000100011111010001000011111010.

## Classful Networks

Once an IP address is represented in binary format, the class of network can be determined rather easily. Beginning from the left of the IP address, the first bit that is not a "1" indicates whether it is a Class A, Class B, Class C, Class D, or Class E network.

For class A networks, the high order (leftmost) bit is always a "0". For class B networks, the high order bits are always a "1" followed by a "0". For class C networks, the high order bits are always a "1" followed by a

"1" followed by a "0".

| | First Bit | Start Address | End Address |
|---|---|---|---|
| **Class A** | 0 | 0.0.0.0 | 127.255.255.255 |
| **Class B** | 10 | 128.0.0.0 | 191.255.255.255 |
| **Class C** | 110 | 192.0.0.0 | 223.255.255.255 |
| **Class D** | 1110 | 224.0.0.0 | 239.255.255.255 |
| **Class E** | 1111 | 240.0.0.0 | 255.255.255.255 |

Not all of the address ranges in the above table are assignable. The IANA has reserved several address spaces for special or private use. Some of the most well-known reserved address spaces are listed in the table below.

### Subnet Masks

Subnet masks represent what part of an IP address is used to determine network information versus host information. For a class B network, the subnet mask uses 16 bits, allowing the remaining 16 bits to be used for host information.

| | Subnet Mask | Binary Format | Decimal Format |
|---|---|---|---|
| **Class A** | 8-bit | 11111111.00000000.00000000.00000000 | 255.0.0.0 |
| **Class B** | 16-bit | 11111111.11111111.00000000.00000000 | 255.255.0.0 |
| **Class C** | 24-bit | 11111111.11111111.11111111.00000000 | 255.255.255.0 |

The total number of available hosts on a network can be determined from it's subnet mask. Since a class B network uses 16 bits for its subnet mask, it leaves 16 bits available for host information. $2^{16}$ = 65,536. All hosts need a network address and a broadcast address. The network and broadcast addresses are indicated by either all 1s or all 0s in the host information part of an IP address. With those two addresses always reserved, the total number of assignable hosts for a class B network is $2^{16} - 2$ = 65,534.

| | Host Bits | Host Formula | Available Hosts |
|---|---|---|---|
| **Class A** | 24-bit | $2^{24} - 2$ | 16,777,214 |
| **Class B** | 16-bit | $2^{16} - 2$ | 65,534 |
| **Class C** | 8-bit | $2^{8} - 2$ | 254 |

The total number of networks a class address may have is calculated by subtracting the number of bits in the subnet mask from the number of bits used to determine which class of network it is. For example, a class A network has an 8-bit subnet mask. Only 1 bit is used to determine that it is a class A network. Subtract 8 from 1 and that leaves 7 bits available for networks. $2^{7}$ is 128. So, there is only room for 128 class A networks.

| | Subnet Mask | Network ID | Network Formula | Available Networks |
|---|---|---|---|---|
| **Class A** | 8-bit | 1-bit | $2^{8-1}$ | 128 |
| **Class B** | 16-bit | 2-bit | $2^{16-2}$ | 16,384 |
| **Class C** | 24-bit | 3-bit | $2^{24-3}$ | 2,097,152 |

### Classless Networks

Forget class A, B, and C now. Classless networks don't use it at all, hence the name. Instead, CIDR networks are identified with a trailing "/" slash and a number that indicates how many bits are used to identify the network portion of the address. Like a class C address in classful networking, a /24 would indicate that 24-bits are used to identify the network and the remaining 8-bits are used to identify the host. Unlike classful networking, CIDR provides much more flexibility than 8, 16, and 24-bit network masks. Under CIDR, the number of bits used to indicate the network portion of the address can be from /8 to /30 although more commonly only /13 to /29 are used. This gives network administrators the flexibility to assign addresses from 6 - 524,286 to match the needs of an organization.

### CIDR Available Hosts

The formula to calculate the number of assignable IP address to CIDR networks is similar to classful networking. Subtract the number of network bits from 32. Raise 2 to that power and subtract 2 for the network and broadcast addresses. For example, a /24 network has $2^{32-24} - 2$ addresses available for host assignment.

| CIDR Notation | Host Formula | Available Hosts |
|---|---|---|
| /8 | $2^{32-8} - 2$ | 16,777,214 |
| /9 | $2^{32-9} - 2$ | 8,388,606 |
| /10 | $2^{32-10} - 2$ | 4,194,302 |
| /11 | $2^{32-11} - 2$ | 2,097,150 |
| /12 | $2^{32-12} - 2$ | 1,048,574 |
| /13 | $2^{32-13} - 2$ | 524,286 |
| /14 | $2^{32-14} - 2$ | 262,142 |
| /15 | $2^{32-15} - 2$ | 131,070 |
| /16 | $2^{32-16} - 2$ | 65,534 |
| /17 | $2^{32-17} - 2$ | 32,766 |
| /18 | $2^{32-18} - 2$ | 16,382 |
| /19 | $2^{32-19} - 2$ | 8,190 |
| /20 | $2^{32-20} - 2$ | 4,094 |
| /21 | $2^{32-21} - 2$ | 2,046 |
| /22 | $2^{32-22} - 2$ | 1,022 |
| /23 | $2^{32-23} - 2$ | 510 |
| /24 | $2^{32-24} - 2$ | 254 |
| /25 | $2^{32-25} - 2$ | 126 |
| /26 | $2^{32-26} - 2$ | 62 |
| /27 | $2^{32-27} - 2$ | 30 |
| /28 | $2^{32-28} - 2$ | 14 |
| /29 | $2^{32-29} - 2$ | 6 |
| /30 | $2^{32-30} - 2$ | 2 |

As the table indicates, two /29 networks equals a /28 network. Two /28 networks equals a /27 network. Two /27 networks equals a /26 network. And so on, and so on. The notion of combining two smaller networks into a larger one is another benefit of classless networks named *supernetting*. In order to create a supernet the smaller networks must be contiguous. For example, 192.0.2.240/29 and 192.0.2.248/29 can form a supernet 192.0.2.240/28, but 192.0.2.240/29 and 192.0.2.8/29 could not.

### CIDR Available Networks (subnetting)

How many /29 networks can fit into a /24 network? Or how many /21 networks can fit into a /17 network? The best way to explain the formula is to show it. The following illustrates how many /21 networks can fit into a /17 network.

1. Subtract the network bits from 32.
   ***/17 = 32-17 and /21 = 32-21***
2. Raise 2 to that power.
   $\boldsymbol{2^{32-17}}$ ***and*** $\boldsymbol{2^{32-21}}$
3. Divide the larger network by the smaller one.
   $\boldsymbol{2^{32-17} / 2^{32-21} = 2^{15} / 2^{11} = 2^{15-11} = 2^4 = 16}$

As the example shows, a /17 network could be divided into sixteen /21 networks. Spot the shortcut in the steps? How many /29 networks in a /24?

$$2^{8-3} = 2^5 = 32$$

### CIDR Networks

Since CIDR address spaces can overlap byte boundaries, the method to tell which address is a part of which network is a little trickier than with classful networking. Everything that needs to be known is indicated by the "/" number, however. Given a network address 172.16.0.0/21, it is known that the first 21 bits of that address represent the network portion. That leaves 11 bits for host information, about 2,000 host addresses. To easier see what that range looks like, convert 172.16.0.0 into binary. In binary, the number looks like **10101100.00010000.00000**000.00000000. The bold numbers show the /21 network mask. No modification can be done to network portion of the address. The remaining 11 bits are available for host assignment on the network. After the bold section, the remaining 3 bits in the third octet can be added up for a maximum value of decimal 7 ($2^2 + 2^1 + 2^0$). All of the bits in the last octet are available and when converted to decimal equal 255. With all of the bits turned on (all 1s), the decimal number turns out to be 172.16.7.255. This is the end range of the 172.16/21 network, 172.16.0.0 - 172.16.7.255.

### CIDR Subnet Mask

The process to determine the subnet mask for a CIDR address is straight forward. The number of bits in the network portion of the address are converted to 1s and right padded with 0s until there are 32 numbers. The sequence of numbers is then divided into 4 octets. From then, it is a matter of converting the 4 octets from binary to decimal.

| CIDR Notation | Convert to 1s and Right Pad | Subnet Mask |
|---|---|---|
| /8 | 11111111.00000000.00000000.00000000 | 255.0.0.0 |
| /9 | 11111111.10000000.00000000.00000000 | 255.128.0.0 |
| /10 | 11111111.11000000.00000000.00000000 | 255.192.0.0 |
| /11 | 11111111.11100000.00000000.00000000 | 255.224.0.0 |
| /12 | 11111111.11110000.00000000.00000000 | 255.240.0.0 |
| /13 | 11111111.11111000.00000000.00000000 | 255.248.0.0 |
| /14 | 11111111.11111100.00000000.00000000 | 255.252.0.0 |
| /15 | 11111111.11111110.00000000.00000000 | 255.254.0.0 |
| /16 | 11111111.11111111.00000000.00000000 | 255.255.0.0 |
| /17 | 11111111.11111111.10000000.00000000 | 255.255.128.0 |
| /18 | 11111111.11111111.11000000.00000000 | 255.255.192.0 |
| /19 | 11111111.11111111.11100000.00000000 | 255.255.224.0 |
| /20 | 11111111.11111111.11110000.00000000 | 255.255.240.0 |
| /21 | 11111111.11111111.11111000.00000000 | 255.255.248.0 |
| /22 | 11111111.11111111.11111100.00000000 | 255.255.252.0 |
| /23 | 11111111.11111111.11111110.00000000 | 255.255.254.0 |
| /24 | 11111111.11111111.11111111.00000000 | 255.255.255.0 |
| /25 | 11111111.11111111.11111111.10000000 | 255.255.255.128 |
| /26 | 11111111.11111111.11111111.11000000 | 255.255.255.192 |
| /27 | 11111111.11111111.11111111.11100000 | 255.255.255.224 |
| /28 | 11111111.11111111.11111111.11110000 | 255.255.255.240 |
| /29 | 11111111.11111111.11111111.11111000 | 255.255.255.248 |
| /30 | 11111111.11111111.11111111.11111100 | 255.255.255.252 |

## Reserved IPv4 Address Spaces

The IANA is "dedicated to preserving the central coordinating functions of the global Internet for the public good." Among their other tasks, they coordinate and allocate IP address space.

This table represents the most common reserved or special use address spaces for IPv4. A full list of IPv4 classifications can be found on the IANA website.

| Network | Description |
|---|---|
| 10.0.0.0/8 | For private internal networks. IP addresses from this space should never be seen on the public Internet. |
| 127.0.0.0/8 | This address range is reserved for the loopback address of a host, commonly implemented as 127.0.0.1. No addresses from this space should appear on the public Internet. |
| 169.254.0.0/16 | This address space is used for communication on a single host. It is most often seen when a host is trying to obtain an IP-address but is unable to reach a DHCP server. |
| 172.16.0.0/12 | For private internal networks. IP addresses from this space should never be seen on the public Internet. |
| 192.0.2.0/24 | This address range is set aside to be used with example code and documentation. The common "example.com" used frequently in technical books is most often associated with an IP address in this range. IP addresses from this space should never be seen on the public Internet. |
| 192.168.0.0/16 | For private internal networks. IP addresses from this space should never be seen on the public Internet. |

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