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Binary and IP Address Basics of Subnetting

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Introduction

The process of subnetting is both a mathematical process and a network design process. Mathematics drive how subnets are calculated, identified, and assigned.

The network design determines how many subnets are needed and how many hosts an individual subnet needs to support based on the requirements of the organization.

This paper focuses on the mathematics of binary numbering and IP address structure. It covers the following topics:

1. Construct and representation of an IPv4 address.
2. Binary numbering system.
3. Process to convert a decimal number to a binary number.
4. Process to convert a binary number to a decimal number.
5. Fundamental aspects of an IPv4 address.

Note: Throughout this document, the term IP address refers to an IPv4 address. This document does not include IPv6.

IP Address Construct and Representation

An IP address is a thirty-two-bit binary number. The thirty two bits are separated into four groups of eight bits called octets. However, an IP address is represented as a dotted decimal number (for example: 205.57.32.9). Since an IP address is a binary number represented in dotted decimal format, an examination of the binary numbering system is needed.

The Binary Numbering System

Numbering systems have a base, which indicates how many unique numbers they have. For example, humans use the decimal numbering system, which is a base ten numbering system. In the decimal numbering system there are only ten base numbers—zero through nine. All other numbers are created from these ten numbers. The position of a number determines its value. For example, the number 2,534 means the following: there are two thousands; five hundreds; three tens; and four ones. The table below shows each number, its position, and the value of the position.

Power ^{Exponent}	10^3	10^2	10^1	10^0
Place Value	1000	100	10	1
Name (Place)	Thousands	Hundreds	Tens	Ones
Example Number	2	5	3	4

Computers, routers, and switches use the binary numbering system. The binary numbering system is a base two numbering system, meaning there are only two base numbers—zero and one. All other numbers are created from these two numbers. Just like in the decimal numbering system, the location of the number determines its value. The table below shows the value of the first eight binary positions.

Base ^{Exponent}	2 ⁷	2 ⁶	2 ⁵	2 ⁴	2 ³	2 ²	2 ¹	2 ⁰
Place Value	128	64	32	16	8	4	2	1

For exponents above 7, double the previous place value. For example, 2⁸ = 256, 2⁹ = 512, 2¹⁰ = 1,024, and so on.

Decimal to Binary Conversion

Since IP addresses are a binary number represented in dotted decimal format, it is often necessary to convert a decimal number to a binary number.

Base ^{Exponent}	2 ⁷	2 ⁶	2 ⁵	2 ⁴	2 ³	2 ²	2 ¹	2 ⁰
Place Value	128	64	32	16	8	4	2	1
Example: Convert decimal 35 to binary	0	0	1	0	0	0	1	1
$35 = (2^7 * 0) + (2^6 * 0) + (2^5 * 1) + (2^4 * 0) + (2^3 * 0) + (2^2 * 0) + (2^1 * 1) + (2^0 * 1)$								
$35 = (32 * 1) + (2 * 1) + (1 * 1)$								
$35 = 0 + 0 + 1 + 0 + 0 + 0 + 1 + 1$								
$35 = \underline{00100011}$								

In the figure above, the decimal number 35 is converted to the binary number 00100011. The steps to perform this conversion are below.

1. Determine your decimal number. In this scenario, it is 35.
2. Write out the base number and its exponent. Since an IP address uses groups of eight binary bits, eight base two exponents are listed.
3. Below the base number and its exponent, write the place value. For example, 2⁰ has a value of 1; 2² has a value of 4; 2³ has a value of 8; etc.
4. Compare the value of the decimal number to the value of the highest bit position. If the value of the highest bit position is greater than the decimal number, place a 0 below the bit position. A 0 below the bit position means that position is not used.

However, if the value of the highest bit position is less than or equal to the decimal number, place a 1 below the bit position. A 1 below the bit position means that position is used.

In the figure, the value of the highest bit position is 128. It is greater than the decimal number 35, so a 0 is placed below the bit position of 2^7 .

1. Go to the next bit position to the right. Make the same comparison and apply the same rules. In the figure, the value of the next bit position to the right is 64. It is greater than the decimal number 35, so a 0 is placed below the bit position of 2^6 .
2. In the next bit position to the right, the value is 32. Thirty-two is less than 35, so a 1 is placed below the bit position of 2^5 .
3. Since the bit position of 2^5 (32) is used, that means 32 of 35 have been accounted for. To determine how much is not accounted for, subtract 32 from 35. The result is 3. ($35 - 32 = 3$)
4. Compare the remaining value against the value of the remaining bit positions, moving to the right one position at a time. Since the bit positions of 2^4 (16), 2^3 (8), and 2^2 (4) are all larger than 3, a 0 is placed below each of those bit positions.
5. The bit position of 2^1 (2) is less than 3, so a 1 is placed below that bit position. This means 2 of 3 have been accounted for, so subtract 2 from 3 to determine what value is not accounted for. The result is 1. ($3 - 2 = 1$)
6. The bit position of 2^0 (1) is the same as 1, so a 1 is placed below the bit position of 2^0 . This means 1 of 1 has been accounted for, so subtract 1 from 1 to determine what value is not accounted for. The result is 0. ($1 - 1 = 0$)
7. This means the number 00100011 is binary equivalent of the decimal number 35.
8. Whenever the amount remaining equals 0, then all remaining binary positions, if any, have a 0 placed below them. For example, the decimal number 160 is represented in binary by the number 1010000. The table below demonstrates the process.

Power ^{Exponent}	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	128	64	32	16	8	4	2	1
Convert Decimal 160 to Binary	1	0	1	0	0	0	0	0
Calculations	160 <u>-128</u> 32	64 > 32	32 <u>-32</u> 0					

Binary to Decimal Conversion

Since IP addresses are a binary number represented in dotted decimal format, it is often necessary to convert a binary number to a decimal number.

Base ^{Exponent}	2 ⁷	2 ⁶	2 ⁵	2 ⁴	2 ³	2 ²	2 ¹	2 ⁰
Place Value	128	64	32	16	8	4	2	1
Example: Binary Number	1	0	1	1	1	0	0	1
Decimal Number Total: 185	128	0	32	16	8	0	0	1

10111001 =	$(128*1)+(64*0)+(32*1)+(16*1)+(8*1)+(4*0)+(2*0)+(1*1)$							
10111001 =	128 + 0 + 32 + 16 + 8 + 0 + 0 + 1							
10111001 =	<u>185</u>							

In the figure above, the binary number 10111001 is converted to the decimal number 185. The steps to perform this conversion are below.

1. Write out the base number and its exponent. Since an IP address uses groups of eight binary bits, eight base 2 exponents are listed.
2. Below the base number and its exponent, write the place value. For example, 2⁰ has a value of 1; 2² has a value of 4; 2³ has a value of 8; etc.
3. Below the place value, write the binary number. To avoid placing the wrong number in the wrong position, start at the right and move to the left.
4. Add the value of all positions that contain 1 in the binary number. In the example, the positions with values of 128, 32, 16, 8, and 1 all have binary 1s, so these values are to be added. The total is 185.
5. $(128 + 32 = 160 + 16 = 176 + 8 = 184 + 1 = 185)$
6. This means 185 is the decimal equivalent of 10111001.
7. Here's another example. The binary number 11100010 is represented in decimal by the number 226. The table below demonstrates the process.

Base ^{Exponent}	2 ⁷	2 ⁶	2 ⁵	2 ⁴	2 ³	2 ²	2 ¹	2 ⁰
Place Value	128	64	32	16	8	4	2	1
Binary Number	1	1	1	0	0	0	1	0
Calculations	128	128 <u>+64</u> 192	192 <u>+32</u> 224	224 <u>+0</u> 224	224 <u>+0</u> 224	224 <u>+0</u> 224	224 <u>+2</u> 226	226 <u>+0</u> 226

The Fundamentals

Just like every physical location requires a unique address for the delivery of mail and packages, every device on a computer network requires a unique IP address for the delivery of data. Given the importance of IP addresses to the communications process, a good understanding of the fundamentals of IP addresses is crucial.

IP Address Construct and Representation

1. An IP address is a thirty-two-bit binary number.
2. The thirty-two bits are separated into four groups of eight bits. Each group is called an octet. Each bit has a value. The value of the bits in each octet are as follows:

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
128	64	32	16	8	4	2	1
3. The maximum value an octet can have is 255.
4. $(128 + 64 = 192 + 32 = 224 + 16 = 240 + 8 = 248 + 4 = 252 + 2 = 254 + 1 = 255)$
5. An IP address is represented in dotted decimal format. This means each octet is converted to a decimal number, and a dot (period) is placed between each octet. (Example: 192.168.5.3)
6. An IP address has a network portion and a host portion. The network portion is always to the left. The network portion describes the IP network or IP subnetwork (subnet) to which a host belongs. The host portion is always to the right. The host portion describes the individual device within the IP network or IP subnet.

Think of the network portion as a city, and think of the host portion as a specific location within the city. The network portion describes a group of devices in general terms; it is similar to referencing Atlanta or New York or Seattle. These cities are large and describe a general area. The host portion describes a specific device on the network; it is similar to referencing a specific location, such as Turner Field or the Empire State Building or the Space Needle. These are specific locations within a city.

The IP Address Classes

1. As per Request For Comment (RFC) 1700, there are five classes of IP addresses used for computer networks. This document focuses on the first three classes, as only the first three classes are assigned to computer networks. The other two classes are reserved for special purposes.

The class of an IP address is determined solely by the value in the first octet. The classes are listed below.

- a. **Class A** = 1-126 in the first octet. (Addresses with 127 in the first octet are reserved and cannot be assigned to hosts.)
 - b. **Class B** = 128-191 in the first octet.
 - c. **Class C** = 192-223 in the first octet.
2. The class of an IP address determines the default dividing point between the network portion and the host portion.
 - a. **Class A** = The first octet (the first 8 bits) is the network portion; the last three octets (the last 24 bits) are the host portion. This can be represented as N.H.H.H, where each letter represents 8 bits.

- b. **Class B** = The first two octets (the first 16 bits) are the network portion; the last two octets (the last 16 bits) are the host portion. This can be represented as N.N.H.H, where each letter represents 8 bits.
 - c. **Class C** = The first three octets (the first 24 bits) are the network portion; the last octet (the last 8 bits) is the host portion. This can be represented as N.N.H.H, where each letter represents 8 bits.
3. Each class of IP network has a default number of hosts it can support.
- a. **Class A** = 16,777,214 hosts ($2^{24} - 2$; the power of 24 is used because a class A network has 24 host bits by default.)
 - b. **Class B** = 65,534 ($2^{16} - 2$; the power of 16 is used because a class B network has 16 host bits by default.)
 - c. **Class C** = 254 hosts ($2^8 - 2$; the power of 8 is used because a Class C network has 8 host bits by default.)
4. An IP network is assigned to an organization (general area), and the host portion is assigned to a device (specific location) by the network administrator. For example, the Class B network 175.15.0.0 (N.N.H.H) is assigned to the Acme Co. Any IP address that has 175.15 in the first two octets are considered to be under the administrative control of the Acme Co. On the other hand, the Class B network 175.17.0.0 is assigned to WileE.Coyote Inc. Any IP address that has 175.17 in the first two octets is considered to be under the administrative control of WileE.Coyote Inc.

Subnet Mask

The subnet mask identifies the network bits and host bits of an IP address.

1. The subnet mask is a thirty-two-bit binary number. Like an IP address, the thirty-two bits are separated into four octets. The individual bit values and the maximum value of an octet are the same as an IP address. However, there are two methods to represent the subnet mask.
 - a. **Dotted Decimal Format**—This is the same format that is used for IP addresses. (Examples: 255.255.240.0 and 255.224.0.0)
 - b. **Prefix Notation**—When using prefix notation, the total number of network bits are represented by a slash and number following the IP address. For example, if given 156.14.253.198 /16, the /16 is the prefix length, meaning the first 16 bits are the network portion of the IP address.
2. In the subnet mask, a binary one represents a network bit; a binary zero represents a host bit. The tables below show examples:

Subnet Mask in Dotted Decimal Format	255.0.0.0
Subnet Mask in Binary	11111111.00000000.00000000.00000000
Prefix Notation	/8
Interpretation	The first eight bits are network bits (binary 1s); The last 24 bits are host bits (binary 0s).

Subnet Mask in Dotted Decimal Format	255.240.0.0
Subnet Mask in Binary	11111111.11110000.00000000.00000000
Prefix Notation	/12
Interpretation	The first 12 bits are network bits (binary 1s); The last 20 bits are host bits (binary 0s).

3. A subnet mask MUST start with a string of consecutive 1s and end with a string of consecutive 0s. This requirement means there is a limited set of valid values for an octet of a subnet mask. The figure below shows these valid values.

128	64	32	16	8	4	2	1		
0	0	0	0	0	0	0	0	=	0
1	0	0	0	0	0	0	0	=	128
1	1	0	0	0	0	0	0	=	192
1	1	1	0	0	0	0	0	=	224
1	1	1	1	0	0	0	0	=	240
1	1	1	1	1	0	0	0	=	248
1	1	1	1	1	1	0	0	=	252
1	1	1	1	1	1	1	0	=	254
1	1	1	1	1	1	1	1	=	255

- a. **Valid**—255.255.252.0 (11111111.11111111.11111100.00000000)
 - b. **Invalid**—255.255.192.240 (11111111.11111111.11000000.11110000) Mixing of 1s and 0s is not allowed in a subnet mask.
4. Every class of IP network has a default subnet mask. They are shown below.
- a. **Class A** = 255.0.0.0 (N.H.H.H)
 - b. **Class B** = 255.255.0.0 (N.N.H.H)
 - c. **Class C** = 255.255.255.0 (N.N.N.H)

- The tables below summarize the default subnet mask information for each class of IP address.

Class of Address	A
Default Subnet Mask in Dotted Decimal Format	255.0.0.0
Subnet Mask in Binary	11111111.00000000.00000000.00000000
Prefix Notation	/8

Class of Address	B
Default Subnet Mask in Dotted Decimal Format	255.255.0.0
Subnet Mask in Binary	11111111.11111111.00000000.00000000
Prefix Notation	/16

Class of Address	C
Default Subnet Mask in Dotted Decimal Format	255.255.255.0
Subnet Mask in Binary	11111111.11111111.11111111.00000000
Prefix Notation	/24

Reserved IP Addresses

There are several reserved IP addresses that cannot be assigned to host devices.

- Network Address:** The network address (often referred to as the network) represents an entire IP network or subnet. In a network address, all host bits are a binary 0. The table below shows example network addresses.

Class A	115.0.0.0
Class B	138.44.0.0
Class C	207.56.224.0

- Directed Broadcast Address:** The directed broadcast address (often referred to as the broadcast) is used to communicate with all hosts in a particular IP network or subnet. In a directed broadcast address, all host bits are a binary 1. The table below shows example directed broadcast addresses.

Class A	115.255.255.255
Class B	138.44.255.255
Class C	207.56.224.255

- Local Broadcast Address:** The local broadcast is used to communicate with all devices on the local network. A PC configured to use Dynamic Host Configuration Protocol (DHCP) sends a packet with the local broadcast address as the destination IP address in order to find a DHCP server. The local broadcast address is 255.255.255.255
- Local Loopback Address:** The local loopback address is used for by host for testing connectivity to its Network Interface Card (NIC). The IP address 127.0.0.1 is very commonly used as the local loopback address, but the entire Class A range of addresses that start with 127 in the first octet are reserved.

5. **All Zeros Address:** The all zeros address is used by an end host when it does not have an IP address. It is used as a source IP address only. A PC configured to use DHCP uses the all zeros address as the source address when it sends a message to locate a DHCP server. The all zeros address is 0.0.0.0.

Conclusion

The process of learning how to subnet IP addresses begins with understanding binary numbers and decimal conversions along with the basic structure of IPv4 addresses.

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Alan Thomas holds a Bachelor of Science degree in technical management and has been a network professional in several capacities for over 20 years. Alan is a Global Knowledge Instructor and has received the Quality Instructor Award.