Redes de Computadores (RCOMP)

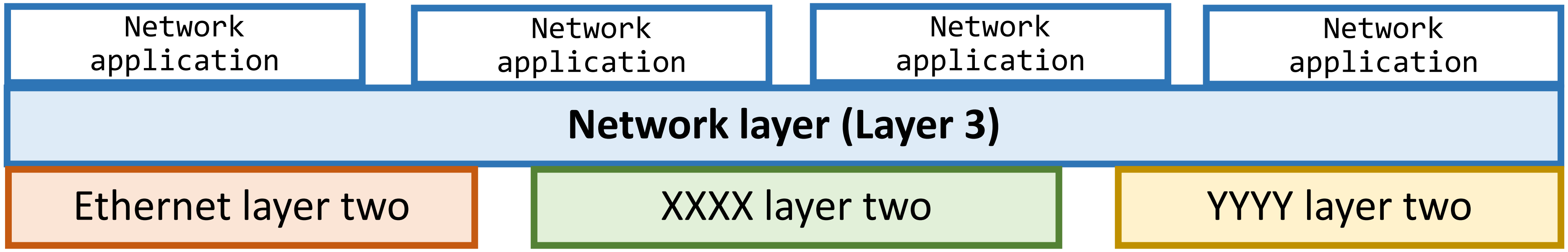
Theoretical-Practical (TP) Lesson 04

2017/2018

- Introduction to IPv4 operation.
- IPv4 addressing and network masks.

Network layer (layer three)

End user network applications are not supposed to have direct interaction with layer two technologies like Ethernet. The network layer (layer three) has the important role of creating a communications abstraction level.



Without a Network Layer, applications would have to be developed for specific layer two types, therefore they could only communicate with other applications developed for the same layer two type. Moreover, the layer two implementation would have to be the same (the same local network).

The network layer (layer three) has the ability to adapt itself and use different layer two types. By doing so it will be able to transfer data from one layer two type network to another layer two type network.

Internet Protocol (IP)

Although in the past several different network layer types did exist, nowadays everybody recognizes the total domain of the internet protocol (IP).

Having a single alternative for layer three is good news. This means everybody is using the same language at layer three (IP), therefore all nodes using this layer can communicate with each other. IP protocol is used globally at the internet and unites all nodes around the planet (and beyond).

Yet, there are two IP versions, the currently most widely used is still version four (IPv4), but version six (IPv6) is gradually being globally introduced.

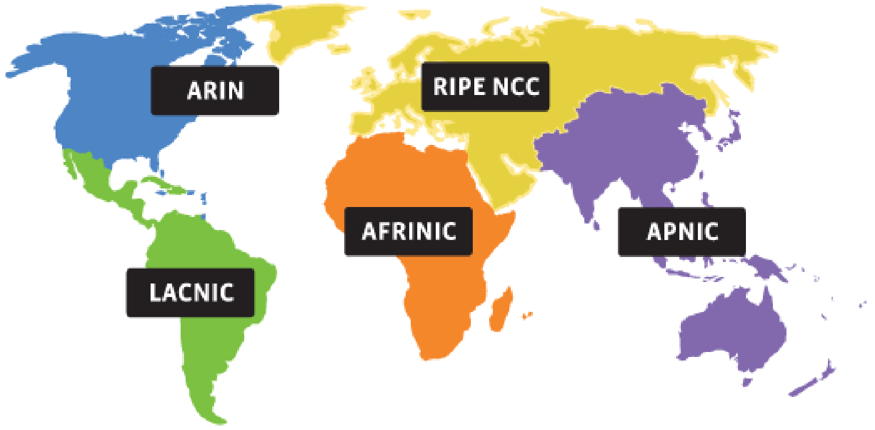
The main motivation for IPv6 is overcoming IPv4 limitations on the maximum number of supported nodes. On IPv4, nodes are identified by unique 32-bits numbers, whereas on IPv6 nodes are identified by unique 128-bits numbers.

O node using IPv4 will not be able to communicate with another node using IPv6. Yet, nowadays, most networks nodes are dual-stack, this means they have both IPv4 and IPv6, so they can communicate with other nodes using either IPv4 or IPv6.

IP node addresses assignment

In IPv4, network nodes are identified by unique 32-bits numbers. To ensure each node has a unique 32-bits address, they are assigned by a global entity called the **Internet Assigned Numbers Authority** (IANA).

IANA manages the 32-bits address space globally, but not directly, the address space is divided by IANA into blocks and each block management is delegated to an RIR (Regional Internet Registries), each for a different part of the world.



(http://www.iana.org/_img/2013.1/rir-map.svg)

Registry	Area Covered
AFRINIC	Africa Region
APNIC	Asia/Pacific Region
ARIN	Canada, USA, and some Caribbean Islands
LACNIC	Latin America and some Caribbean Islands
RIPE NCC	Europe, the Middle East, and Central Asia

Each RIR manages the address space assigned to it by IANA. In turn, one RIR can divide its address space and delegate parts of it to a National Internet Registry (NIR) or a Local Internet Registry (LIR).

Routers

Network layer operates by using a layer two implementation, however, each layer two network has a limited size (the broadcast domain). This represents how far can a communication can reach by using only the layer two and nothing else.

To go beyond the layer two network limits, devices called **routers** operate at the layer three, they use the internet protocol to transfer data from one layer two network to another layer two network.

Routers are the network layer (layer three) intermediate nodes, they receive layer three packets that are not intended to them and retransmit those packets to other routers to ultimately reach the required destination node address.

Routers do this by taking routeing decisions (to where retransmit a packet). Routeing decisions are taken by searching the **packet destination node address** in a table, pretty much like an Ethernet switch does with the MAC table. For routers, though, the task is simpler because at layer three the network concept exists, and thus the network address concept.

The network address identifies a network (containing many nodes). The advantage is that now routeing decisions can be taken network by network and not node by node as it happens on an Ethernet layer two switch.

IP network addresses

A **network address** is a unique identifier for a network. **Each different layer two network needs a different network address at layer three**, this is crucial because:

- Routers only retransmit IP packets between networks with different addresses (otherwise they are not different networks).
- When a node is sending a packet, it must know if the destination address is on its own network, if so, the IP packet can be **sent directly using the layer two**, otherwise, the IP packet must be **sent to a router**.

At layer three, any node address must include in itself the network address, meaning the node belongs to that network.

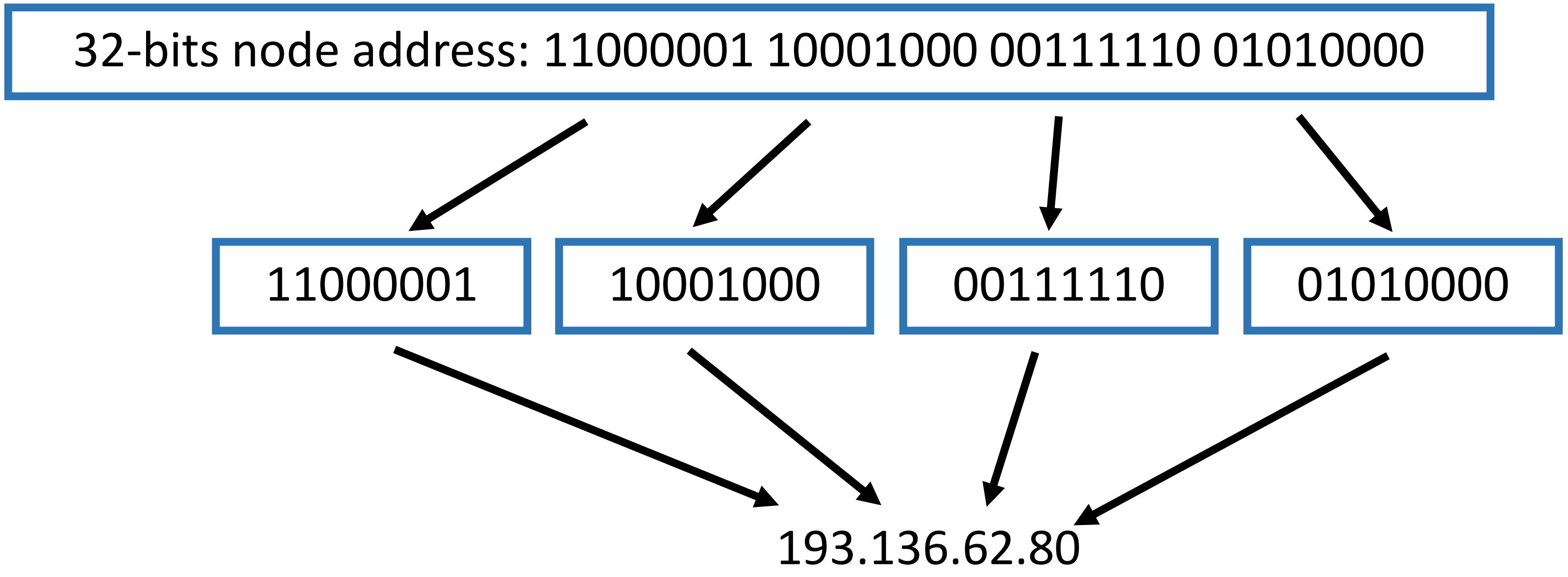
In IPv4 (and also IPv6) the most significant bits of the node address are in fact the network address, the remaining bits represent the address of the node within that network.

Of course two nodes belong to the same network if the network address bits are exactly the same, also, the remaining bits must be different because each node address must be unique.

IPv4 address representation

The usual human readable representation for IPv4 addresses consists in dividing the 32-bits address into four 8-bits sets and represent each as a decimal number, separated by a dot (**Dot-decimal** notation).

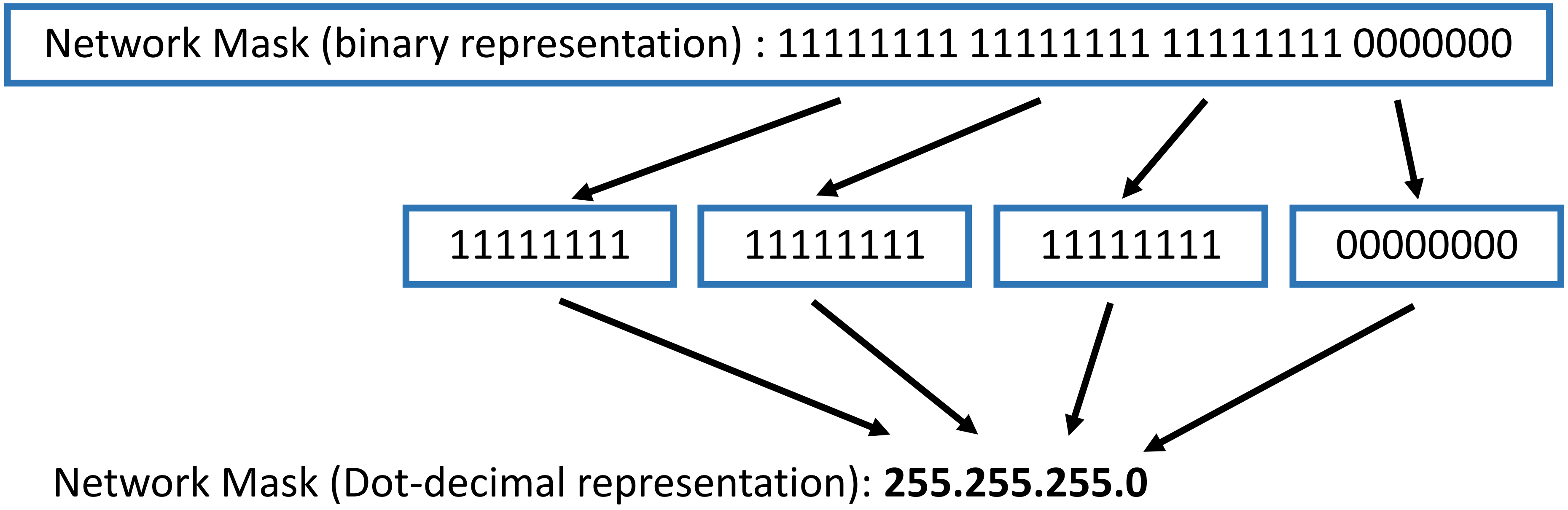
Example:



Thus, each of these four numbers can go from 0 to 255. We already know any IPv4 **node address** also contains a **network address** (the network the node belongs to). We also know the network address is the most significant bits of the node address, the doubt is how many bits are used for that purpose.

The network mask

The number most significant bits of the node address that represent the network address is determined by the **network mask**. A network mask is also a 32-bits number but is always made of a sequence on 1-bits corresponding to the most significant bits that are used to represent the network, followed by the remaining bits with value zero. Example:



Network Mask (binary representation) : 11111111 11111111 11111111 0000000

Network Mask (Dot-decimal representation): **255.255.255.0**

In this example, the network mask tells us the 24 most significant bits are used to identify the network. This network mask can also be referred to as a 24 bits **network prefix-length** or a 24 bits network mask.

IPv4 network address

An IPv4 **network address** is also represented as a 32-bits number, nevertheless, only the most significant bits are used to identify the network, therefore by convention, the remaining bits are represented as zero.

Yet, representing an IPv4 network address by just a 32-bits number is not enough because it says almost nothing about how many are the most significant bits being used to identify the network. The network address requires an associated network mask or prefix-length for proper interpretation.

Take as example network address 160.0.0.0, because 160 value is 1010 0000 in a binary representation, this network address could make sense for any network mask of three bits or more (prefix-length greater than 3). With a network mask of less than three bits, the third bit at the network address can never be 1 (by convention must be represented as zero on the network address).

To identify an IPv4 network, two values are required: the **network address** and the **network mask**

IPv4 networks – maximum supported nodes

The network mask defines how many most significant bits are being used to identify the network (**network bits**) and therefore how many bits are left to identify hosts within the network (**host bits**).

If the network mask defines **N** network bits, then **32-N** bits are left for host bits. The number of possible different addresses is $\mathbf{2^{(32-N)}}$, this is also called the addresses block size for an **N** bits prefix-length.

Not all addresses in a block are valid IPv4 node addresses. When an address block is used for a network, the first address (all host bits zero) and the last address (all host bits one) are reserved. The first represents the network address itself, the second is reserved for broadcasting.

Therefore, the maximum number of IPv4 nodes in a network with prefix-length **N** is: $\mathbf{2^{(32-N)} - 2}$

The biggest useable network prefix-length in IPv4 is 30 bits, resulting in a network capable of holding a maximum of only two hosts.

Some examples to clarify

Network address 201.201.0.0 with network mask 255.255.0.0

The network mask has sixteen bits, this network can also be represented as **201.201.0.0/16**, know as CIDR (Classless Inter-Domain Routing) notation.

First of all, we can say the network address is consistent with the mask because, for all zero bits at the mask, the corresponding bits are also zero at the network address. If this was not so, then something was wrong, either the network address or the network mask.

Addresses within this network go from 201.201.0.0 to 201.201.255.255, the number of addresses is 2^{16} = 65536, however, the first (network address) and the last (network broadcast address) are reserved and cannot be used as node addresses.

This leaves 2^{16}-2 = 65534 valid node addresses in this network, valid node addresses go from 201.201.0.1 up to 201.201.255.254.

Network address 192.168.100.0 with network mask 255.255.255.0

The network mask has twenty-four bits, this network can also be represented as **192.168.100.0/24** (CIDR notation).

Again, we can say the network address is consistent with the mask because, for all zero bits at the network mask, the corresponding bits are also zero at the network address.

Addresses within this network go from 192.168.100.0 to 192.168.100.255, the number of addresses is 2^8 = 256, once more, the first (network address) and the last (network broadcast address) are reserved and cannot be used as node addresses. This leaves 2^8-2 = 254 valid node addresses in this network, valid node addresses go from 192.168.100.1 to 192.168.100.254.

The **network address** together with the **network mask** defines the network. They also provide a fast method to check if a given node address belongs to a network: by performing a bit to bit **and logical operation** between the **given address** and the **network mask**, we will obtain the **network address**. Examples:

[**192.168.10.3**] .AND. [255.255.255.0] = [**192.168.10.0**] (different network)

[**192.168.100.9**] .AND. [255.255.255.0] = [**192.168.100.0**] (same network)

[**193.16.100.1**] .AND. [255.255.255.0] = [**193.16.100.0**] (different network)

Classful and classless addresses

In early days, only three network masks were used: 8, 16 and 24 bits, on those times **network masks were not required because they were implicit**, the most significant bits of the address were used to identify the prefix-length.

Any address starting by bit 0 was supposed to use a 8-bits mask (255.0.0.0) and they were called **class A**. Addresses starting by 10 bits would use a 16-bits mask (255.255.0.0), they were called **class B**. Addresses starting by 110 bits would use a 24-bits mask (255.255.255.0), they were called **class C**. This is **classful addressing**. There is also class D, for addresses starting by 1110 bits and reserved for multicast addresses. Class E, addresses starting by 1111 bits are reserved for other uses.

Due to IPv4 address space exhaustion, classful addressing has been replaced by **classless** addressing (CIDR). Classless addressing means any network mask can be used. However, because the mask is no longer implicit, it must now be specified together with the network address.

Classless addressing allows a much more precise adjustment of the mask to the real needs under de point of view of maximum nodes to support in a network, and therefore saves a lot of addresses.

Classful versus classless addressing

Using classful addressing results in severe address wasting because there are only three alternatives for the maximum nodes supported by a network.

On internet backbones, many networks consist of dedicated connections between routers, these networks only require two node addresses (the connected routers), in classful addressing the best-adjusted mask for this purpose is 24-bits class C (255.255.255.0) which supports 254 nodes, thus 252 addresses are unused. The same network using classless addressing can be coped with a 30-bits mask which supports exactly two nodes ($2^{(32-30)} - 2 = 2$).

Another example: imagine we want a network to support up to 500 hosts, in classful addressing the best-adjusted mask for this purpose is 16-bits class B (255.255.0.0) which supports $2^{(32-16)} - 2 = 65534$ nodes, thus 65034 are unused. The same network using classless addressing can be coped with a 23-bits mask which supports $2^{(32-23)} - 2 = 510$ nodes, leaving only 10 unused addresses.

Using classless addressing presents, though, some challenges for human handling because the dot-decimal notation is no longer convenient. Every address assignment and validation will now require a binary representation for addresses, at least for the octet where the network mask is placed.

Classless networks examples

Representing IPv4 addresses in dot-decimal notation is most convenient for network masks of 8/16/24 bits, but otherwise, the mask will not match the octet division. A hexadecimal representation may help in some cases because each hexadecimal symbol will correspond to a set of four bits, so if the network mask is 4/8/16/20/24/28 we will be able to see it clearly. The general solution, however, is **binary representation**.

Example 1: Network 192.168.100.192/29

It's valid because all bits with zero value at the network mask also have zero value at the network address, to check that we must represent both in binary. There is no point in representing all four octets in binary, our analysis will be only on the octet where the mask is located:

Network address:	192.168.100.$(1100\ 0\mathbf{000})_2$
Network mask:	255.255.255.$(1111\ 1\mathbf{000})_2$

(this network mask represented in dot-decimal comes as 255.255.255.248)

This network has $2^{(32-29)}$ = 8 addresses, thus 6 valid node addresses.

Getting the first valid node address is always easy, we can get it simply by adding one to the network address, thus it's **192.168.100.193**.

Getting the broadcast address can be achieved by analyzing the network address and mask in a binary representation, and then placing bits with value one on the host bits. Only the octet where the mask is placed really matters:

Network address:	192.168.100.$(1100\ 0\mathbf{000})_2$
Network mask:	255.255.255.$(1111\ 1\mathbf{000})_2$
So, the broadcast address is	192.168.100.$(1100\ 0\mathbf{111})_2$ = **192.168.100.199**

As always, the last valid node address may be obtained by subtracting one unit to the broadcast address, it is, therefore: **192.168.100.198**.

Some more pragmatic approaches can also be used, once we know the size of the address space (eight addresses in this sample) we can determine **the next network address** by adding it to our network address:

192.168.100.192 + 8 = **192.168.100.200**.

Our network broadcast address can be obtained by subtracting one unit to the next network address: **192.168.100.199**.

The last valid node address in our network can then be obtained, as before, by subtracting one unit to the broadcast address: **192.168.100.198**.

This pragmatic approach can be used in any case: if we know the **network address space size** (from the network mask) and the **network address** we can get everything:

First valid node address = (**Network address + 1)**

Next network address = (**Network address + Network address space size)**

Broadcast address = (**Next network address – 1)**

Last valid node address = (**Broadcast address – 1)**

Knowing the next network address is very important, because it tells us where to place additional networks. Remember however that this **next network** is **valid only for a network with an identical prefix**.

Calculating the **next network address** by adding the **network address space size** may be harder if the number to be added is greater than 256 (network prefix shorter than 24 bits). To make adding easier the ideal is expressing these big numbers in 8-bits sets as well.

Also calculating big powers of two to determine the **network address space size** may be hard. Nevertheless, the sequential determination of the powers of two is simple because each doubles the predecessor. Thus we can quickly build a simple table with possible **network masks** and the corresponding **network address space sizes**.

To build this table we can use as reference the maximum possible prefix (30-bits in IPv4) or a reference value like the 24-bits prefix, each time we reduce one bit to the mask, the **network address space size** doubles.

Network prefix (mask)	**Network address space size**	**Network address space size** (split in octets)
30	4	0.0.0.4
29	8	0.0.0.8
28	16	0.0.0.16
27	32	0.0.0.32
26	64	0.0.0.64
25	128	0.0.0.128
24	**256**	**0.0.1.0**
23	512	0.0.2.0
22	1024	0.0.4.0
21	2048	0.0.8.0
20	4096	0.0.16.0
19	8192	0.0.32.0
18	16384	0.0.64.0
17	32768	0.0.128.0
16	**65536**	**0.1.0.0**

Example 2: Network 10.16.64.0/18

It’s valid because all bits with zero value at the network mask also have the zero value at the network address, to check it we must represent both in binary. There is no point in representing all four octets in binary, our analysis will be only on the octet where the mask is placed:

Network address: 10.16.$(01\mathbf{00\ 0000})_2$.**0**

Network mask: 255.255.$(11\mathbf{00\ 0000})_2$.**0**

(this network mask represented in dot-decimal comes as 255.255.192.0)

This network has $2^{(32-18)}$ = 16384 addresses. As we can see in the previous table.

Getting the first valid node address is always easy, we can get it simply by adding one to the network address, thus it is **10.16.64.1**.

As we can see on the table, an eighteen bits prefix will correspond to a 16384 network address space size, it can also be represented as 0.0.64.0 (split in octets). Obtaining the next network address by adding this to our network address is now simple, it will be 10.16.(64+64).0: **10.16.128.0**.

Now, by removing one unit we get **our network broadcast address**: **10.16.127.255**

By removing another unit we get **our network last valid node address**: **10.16.127.254**

Defining IPv4 networks – step one

This is a common problem network administrators face in real-world. They have an available address space (a network address and a prefix-length) and they are required to fit within that address space a set of networks, each supporting a given maximum number of hosts.

The **first step** is easy, determining the required prefix-length for each network. We can do that just by looking at the previously drawn table, remembering that the number of valid nodes is the network address space size minus two reserved addresses, also that these valid nodes must include all IPv4 devices, including routers and printers for instance. The result from this first step is a network mask or prefix-length for each network.

Example: create one network able to hold up to 20 nodes, another network able to hold up to 1000 nodes, and yet another network able to hold up to 63 nodes. By looking at the table we come to:

- 20 nodes	-> network prefix = 27	(up to 30 valid nodes)
- 1000 nodes	-> network prefix = 22	(up to 1022 valid nodes)
- 63 nodes	-> network prefix = 25	(up to 126 valid nodes)

Notice that for 63 nodes the 26-bits prefix is not enough as it only provides up to 62 valid nodes.

Defining IPv4 networks – step two

The **second step** is more tricky, we must now assign network addresses to each network without overlapping, all within the provided address space.

We can start by checking if there is a solution, we can do this by summing the address space size of each network we want to create and check whether the result is less or equal to the size of the provided address space. Picking the example at the previous page, we have as required address space: 32 + 1024 + 128 = 1184. To solve the problem the provided address space must be at least 2048 (21-bits prefix), this is the biggest prefix (smallest address space) where 1184 addresses can be fitted.

Having checked the problem has a solution, now we can assign network addresses to each network.

One thing is important to understand: each address space (defined by a prefix) can always be split in two by increasing one bit on the prefix.

This means: **wherever a network starts with given prefix, at that same point (same network address) also starts a network with a bigger prefix (smaller address space).**

The reverse, however may not be true: given two networks with the same prefix, by reducing the prefix-length in one bit we may not get a valid network containing the address spaces of the two original networks.

Defining IPv4 networks – step two

To assign addresses to each network we can take advantage of what was highlighted. First of all, we could place any of our networks at the start of the provided address space, because all our networks will have a bigger prefixes than the provided address space, they could start there.

As we have seen before, after assigning the first network we will know where the next network with an identical prefix starts, and bigger prefixes networks also can start there, so if we start by assigning shorter prefixes first and then bigger prefixes we can guarantee all addresses will be correct.

By using this technique, once a network is assigned we immediately know where to place the next network, remember however that **this is valid only if the next network prefix is equal or bigger**.

So to assign addresses to our networks we start by sorting them accordingly to the prefix size, smaller prefixes (bigger address spaces) first. Then we can sequentially assign them addresses in the given address space.

Summarizing, the whole problem can be solved just by calculating some powers of two (building the table by doubling values) and performing some add operations.

This is not the only method to solve this kind of problem, but undoubtedly it’s one that does not require significant resources.

Defining IPv4 networks – example

Lets pick an extensive example and solve the problem:

- We have the address block **120.20.32.0/20** to assign network addresses.
- We must provide address within this block to the following networks:
    - 2 networks with up to 300 nodes
    - 2 networks with up to 1000 nodes
    - 8 networks with up to 100 nodes

First step: networks' prefix-lengths

- 2 networks with up to 300 nodes	prefix-length: 23-bits (512 addresses)
- 2 networks with up to 1000 nodes	prefix-length: 22-bits (1024 addresses)
- 8 networks with up to 100 nodes	prefix-length: 25-bits (128 addresses)

Provided addresses: 20-bits prefix-length means: 4096 addresses

Required addresses: 2 x 512 + 2 x 1024 + 8 x 128 = 4096 **(it's just enough)**

Defining IPv4 networks – example

Second step: assign addresses sequentially <u>starting by smaller prefixes</u>

up to 1000 nodes network 1 -	**120.20.32.0/22**	(next network: 120.20.36.0)
up to 1000 nodes network 2 -	**120.20.36.0/22**	(next network: 120.20.40.0)
up to 300 nodes network 1 -	**120.20.40.0/23**	(next network: 120.20.42.0)
up to 300 nodes network 2 -	**120.20.42.0/23**	(next network: 120.20.44.0)
up to 100 nodes network 1 -	**120.20.44.0/25**	(next network: 120.20.44.128)
up to 100 nodes network 2 -	**120.20.44.128/25**	(next network: 120.20.45.0)
up to 100 nodes network 3 -	**120.20.45.0/25**	(next network: 120.20.45.128)
up to 100 nodes network 4 -	**120.20.45.128/25**	(next network: 120.20.46.0)
up to 100 nodes network 5 -	**120.20.46.0/25**	(next network: 120.20.46.128)
up to 100 nodes network 6 -	**120.20.46.128/25**	(next network: 120.20.47.0)
up to 100 nodes network 7 -	**120.20.47.0/25**	(next network: 120.20.47.128)
up to 100 nodes network 8 -	**120.20.47.128/25**	(next network: 120.20.48.0)

Network 120.20.48.0 is out of the provided address space, that's ok, as we had already seen we exhausted all the provided address space.

Private IPv4 addresses

Every node on the internet must have a unique IPv4 node address, they are assigned directly or indirectly by IANA. However, some addresses were reserved for arbitrary and experimental local use, they are known as private addresses.

Private addresses are not recognized over the internet, so a node using a private IPv4 address cannot communicate directly using the internet. Yet, later we will see, Network Address Translation (NAT) can be used to hide private addresses and allow these nodes to communicate with the internet.

IPv4 private addresses are:

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

These addresses are intended for local communications and experimental networks and should never reach the internet. A node using one of these addresses could send requests to the internet, but no reply will ever be received. Under the internet point of view, these are always unknown addresses.