Introduction to Computer Networks: Essay Assignment #1

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The sixties were a time of great change and great turmoil across the entire world. In the United States, the Civil Rights Movement brought an end to the racial segregation which had plagued the country for a century after the abolition of slavery. In the Caribbean, a confrontation between fleets of the Soviet Union and the United States nearly engulfed the world in nuclear war. In China, countless intellectuals and elements of capitalism and traditional culture were purged throughout the country. In Vietnam, American soldiers began arriving in the hundreds of thousands to resist the ever-dreaded communists. In Czechoslovakia, the liberalizations of the Prague Spring were crushed by its ostensible allies in the communist Warsaw Pact. On the Moon, a man's one small step heralded a giant leap for mankind. And deep down in the dark, unfathomable world of the United States Department of Defence, ARPANET was brought to life.

With the Cold War growing hotter and hotter, and nuclear weapons technology growing more and more sophisticated, the U.S. military sought more and more sophisticated computing and communications technology to match and counter the growing threats. The answer was ARPANET, a network utilizing packet-switching technology, which broke messages into small packets which could travel individually through any open route between networked computers to be reassembled at the destination, giving it great resistance to sabotage, a highly valuable property for military communication technology. It employed the newly developed protocol suite known as TCP/IP (Transmission Control Protocol/Internet Protocol). Much like Star Wars franchise, which began life with Episode IV, emerging in world cinemas in 1977, so too it was that the Internet Protocol began life with version 4, which was deployed to ARPANET in 1983.

The Internet Protocol version 4, more commonly abbreviated to IPv4, is still the most common protocol of its kind in use today, to the point that virtually everybody who has interacted with a computer, from computer specialists to complete laymen, has heard the term "IP address" (or a translation of it) at some point. Of course, most laymen may not have the slightest clue of what an IP address actually *is*, except that it has "something to do with the Internet", a crude description that nevertheless makes up in accuracy for what it lacks in precision, as suggested by its full name "Internet Protocol address". Indeed, just as postal addresses are crucial to the operation of the postal system, and as email addresses are crucial to the operation of email, and as residential addresses are crucial to holding wild parties in one's house while one's parents are away, IP addresses are likewise crucial to the operation of the entire Internet as we know it.

Despite their momentous importance, the structure of IPv4 addresses is deceptively simple. They are made up of 32 bits, logically divided into 4 bytes. Such a structure naturally and perfectly lends itself to a hexadecimal representation, and so of course they are instead typically written as four dot-separated decimal values with leading zeroes removed; for example, a typical (and completely randomly chosen) IP address may be written: "140.112.42.158". An IP address can be divided into two main parts: the left (higher-order) group of bits is the *network identifier* (also called *network ID*, *network prefix* or just *prefix*), while the right (lower-order) group is the *host identifier* (*host ID*). A network of hosts with the same network ID is called a *subnet*. Subnets do not have a set number of bits, and so additional subnets within a subnet can be created by assigning extra bits from the host ID - e.g. a subnet with a 16-bit prefix could be divided into 256 subnets with 24-bit prefixes. In theory, a prefix can be as small as 1 bit, but in practice, the smallest are 8 bits, as each possible 8-bit prefix is allocated to various registries by the Internet Assigned Numbers Authority (IANA), the department of the Internet Corporation for Assigned Names and Numbers (ICANN) responsible for global allocation of IP addresses, or reserved for special use.

However, IPv4, for all its magnificence, has a fatal oversight: there are not enough IPv4 addresses. Perhaps the engineers who developed IPv4 in the 1980s did not expect the Internet to grow as large as it has today. Perhaps they expected that IPv4 would quickly be replaced by a new version. Or perhaps they simply figured that a nuclear apocalypse would soon break out, well before the limited number of addresses could become an issue. In any case, most IPv4 addresses have now been exhausted. The issue was not unpredictable, and was in fact predicted as early as the 80s; with 32 bits, there are 2^{32} mathematically possible IP addresses, or about 4.3 billion. The savvy reader will notice that this is significantly less than the current world population of some 7.5 billion, and the even savvier reader will notice that this is also less than the world population of about 5 billion in 1983, the year in which IPv4 was introduced. And 4.3 billion is only the theoretical maximum; in practice, many address blocks are reserved for special use, and large blocks are restricted to certain companies or geographical regions (for instance, the nearly 17 million addresses beginning with "17." are assigned to Apple Inc.) and thus may not be fully utilized, making the total number of IP addresses that can actually be used much lower.

The solution is IPv6. (We do not speak of IPv5.) IPv6 surpasses its predecessor by using a massive 128-bit address, allowing 2^{128} or approximately 3.4×10^{38} addresses. For comparison, this is more than the number of grains of sand on all the world's beaches and deserts, *squared*, and probably a fair bit more than the number of IP addresses that will be needed in the foreseeable future. The unnecessarily large number of possible addresses is by design, as it ensures that there will never, in virtually any network or environment, be a shortage of IP addresses, thus rendering obsolete Network Address Translation (NAT), introduced to help stave off the impending IPv4 exhaustion.

By far the biggest advantage of IPv6 over IPv4 in my opinion, however, is that its standard representation uses hexadecimal rather than decimal. The 128 bits are logically divided into 8 groups of 16 bits (or 4 hexadecimal digits), and are separated by colons with leading zeroes removed, so that a typical address looks like: "2015:bag:1a4f:3cab:1319:8a2e:370:1234". Like IPv4 addresses, IPv6 addresses are allocated by IANA, also in large blocks. However, whereas in the early days of IPv4 massive blocks were assigned to single companies such as Apple, large IPv6 blocks are allocated almost exclusively to regional Internet registries (RIRs), which in turn allocate to other registries and ISPs.

Unfortunately, IPv6 adoption has been quite slow despite the decades of preparation time, partly due to the lack of backwards compatibility between IPv6 and IPv4. Most domains still lack IPv6 address records, and global Internet traffic is still dominated by IPv4. Nevertheless, all major operating systems nowadays have full support for IPv6, most top-level domains (TLDs) support IPv6 access to their domain name servers, and governments have increasingly pushed towards IPv6 adoption, through projects such as the China Next Generation Internet, initiated to gain China a technological advantage through the early adoption of IPv6. Eventually, as the Internet grows larger and larger and IPv4 is stretched thinner and thinner, it is inevitable that IPv6 will eventually come to dominate. The question is not one of if but when.

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