Analyzing the Competition Between Internet Protocol Versions 4 and 6

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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STS Paper

Introduction

Over the last 40 years, the internet has interconnected the world in a way that was unimaginable less than a century ago. Of all of humanity's technological advancements, the internet stands up there as one of the most impactful innovations we have yet to see, as it enables communication in ways and at a scale never before possible. It's estimated that over 5 billion people around the world use the internet each day, all using this shared technology that has fundamentally changed how we live (DataReportal, 2023). But despite that, how many people actually understand what makes the internet tick?

Way before the mass adoption of the internet, the United States government was working on developing a technology to enable digital communication between computers over long distances. As computers were getting faster and more powerful, we knew that the future hid somewhere in digital computing, so DARPA, the Defense Advanced Research Projects Agency, started work on designing the early protocols that would become the heart of today's internet (Zimmerman & Emspak, 2022). Little did they know that these protocols they were creating would be adopted widely beyond the original scope they were intended for.

The first predominant protocol in the history of the internet is Internet Protocol version 4 (IPv4), which was created in the early 1980s. In order for devices to communicate with each other using IPv4, each device had a unique ID or address. That way, when trying to communicate with another computer, a device could just use the address of the other machine to send data to it, and network devices (i.e. routers) in between the computer would know how to send it to that machine. While networks like this existed before, IPv4 made it possible for the network to scale internationally, which is why it quickly caught on as the backbone protocol used widely when communicating digitally (Prefixx, 2020).

Unfortunately, as it became clear that IPv4 was going to start being used all over the world, it had one glaring issue. As IPv4 expects every device to have a unique address, those addresses have to be allocated somehow to ensure that two people don't try to have the same address. As IPv4 addresses are represented digitally, there are a finite number of unique addresses that are possible due to how the addresses are stored and looked at by computers. The exact number of unique IPv4 addresses is a bit over 4 billion, which seemed like a lot until it became clear that the internet would take over the entire world (Internet Society, n.d.).

In order to address this problem, a new protocol, Internet Protocol version 6 or IPv6, came out with the intention of replacing IPv4. IPv6's main draw was that it had an immense pool of unique addresses that we won't be able to run out of for the foreseeable future, making it easier for the internet to scale beyond the pool of 4 billion addresses. Unfortunately, IPv6 has still not served its purpose of replacing IPv4, despite the ongoing push towards IPv6 since its creation in 1995 (Internet Society, n.d.). While IPv6 is slowly becoming more and more utilized, still over 75% of internet websites in the world use IPv4 instead of the newer and better IPv6 (Internet Society, 2018). Why is that?

In the rest of this paper, I will analyze the reasons for the competition between IPv4 and its successor IPv6. I will start by providing some background information on the technology, then examine the relationship between different actors who are closely tied into the two competing protocols. Finally, I will argue that IPv6 has failed to be a suitable replacement for IPv4 as it had no proper solution to address the difficulties of transitioning off of IPv4.

Background

When talking about the internet, the term protocol is one of the most widely utilized words in the industry. In any sort of communication, at least two parties involved need to be involved: a sender of the information and a receiver of the information. Beyond that, though, both parties need to agree on some form of communication that they can both understand. For example, when talking to another person, you and the other person have an agreed on language that the two of you speak in. Without that agreed on language, the two parties might struggle to communicate and not properly understand each other. While humans are smart enough to be able to distinguish languages and intelligently respond to different forms of communication, digital computers don't have that ability. Instead, they heavily rely on their own languages, or protocols, to communicate with each other (Cloudflare, n.d.). Computer hardware and software designers build in the logic that allows the computer to understand and respond to protocols so that it can communicate with other computers. And just like with human language, nobody actually enforces that these protocols are used in any particular way. Instead, it is in everyone's collective benefit to agree on the languages and protocols we use so that our communication is as consistent as possible.

Today there are two primary protocols that people use to connect to the internet, Internet Protocol version 4 (IPv4) and Internet Protocol version 6 (IPv6). These two protocols serve similar functions, but IPv6 was specifically designed to address flaws identified in IPv4 with the hope that it would replace it eventually. While we have made progress since then, the IETF originally published IPv6 in 1995 and despite that Google still only sees IPv6 connectivity from around 40% of its clients (Google, n.d.). In the last two and a half decades, the size of the internet has grown considerably, but a significant portion of that growth still has been with the older IPv4 protocol (Wilhelm, 2022).

The most significant factor for IPv6's lack of adoption is that IPv6 doesn't have backwards compatibility with IPv4. This means that a machine using IPv4 can only talk to other machines using IPv4, while a machine talking IPv6 can only communicate with machines using IPv6. So in the early adoption of IPv6, you couldn't just build an IPv6 network and have it work with the rest of the internet that used IPv4. Instead, network engineers had to upgrade old networks to support both versions of the protocol so that they could support connections with both types of protocols. Still, any new networks built had to include IPv4 support in order to connect to the old networks that hadn't transitioned. And for many old networks, network operators had little incentive to upgrade their support as the benefits were greatly diminished by the costs and complications associated with the process of upgrading (Internet Society, n.d.).

On the other hand, IPv6 fixed a fundamental flaw in the internet that necessitated the creation of a brand new protocol. The main issue with IPv4 is that it only had support for a 32-bit address, which limited the total number of addresses to around 4 billion. In theory, every device on the internet should have a unique address that identifies it in order for other devices to connect to it. So when it became clear that 4 billion addresses was not going to be nearly enough for all of the devices that would one day connect to the internet, IPv6 started development to address that issue. IPv6 has a 128-bit address, meaning that it has an inconceivably large number of addresses that will be difficult to run dry for the foreseeable future (Internet Society, n.d.). While the cost of an IPv4 address is relatively expensive, IPv6 addresses have such high supply that they can essentially just be handed out (Pinto, n.d.). This main feature is why IPv6 is seen as the future of the internet and why so many people want to push towards that future.

Methods for Research

In order to analyze the competition between IPv4 and IPv6, I will use Actor Network Theory to look at the relationship between different actors and how they influenced the adoption of the different protocols. The two core actors of the network are the competing protocols, IPv4 and IPv6, with external actors creating the relationship between the two that we see today. The main external actors identified influencing the two protocols are the Internet Engineering Task Force (IETF), Device/Software Developers, Application Service Providers (ASPs), and Internet Service Providers (ISPs).

The majority of the research used for this analysis was collected from reading digital sources and books online. Some of the sources I utilized focused heavily on the overall history of the internet, starting with DARPA's involvement in the early creation of IPv4, then progressing through its more widespread adoption over the next decades. These readings gave me an overview of the progression of the internet, especially up to the beginning of IPv6 adoption. They also provided a better understanding of the extremely decentralized nature of the internet that is hard to compare to most other technologies.

In addition to sources outlining the history of the internet, I used a number of articles and reports that outline the specific differences and advantages of IPv6 over IPv4. Some of these sources came from specific actors in the network, such as articles from the IETF's parent organization, the Internet Society, describing in depth the reasons they recommend transitioning to IPv6. There are also plenty of Application Service Providers, like Cloudflare, that publish information to educate the public about IPv6 with the hopes of lighting the way in its adoption.

In addition, I utilized a few reports that document individual actors' actual experiences transitioning to IPv6 to see the actual data on the progress of transitioning. One of the most useful sources was the United States's Department of Defense report on their attempts to transition from IPv4 to IPv6, but plenty of other sources help paint the picture of exactly why it is difficult to work through the transition.

Identifying the Actors at Play

Looking at the history of the internet over the last 30 years, there are many actors that have played a significant role in its evolution. Given the scale of the internet however, many of the individual actors are grouped together for simplicity's sake in order to make the network easier to understand.

Within the Actor Network, IPv4 and IPv6 are the two inanimate actors at the center of the network. These two artifacts are very closely related, as they serve functionally identical purposes, with IPv6 directly drawing much of its design from IPv4. At the same time, these two actors are not identical and their coexistence comes with competition. IPv6's main benefit, a larger address space, also came with some added complexity that makes using IPv6 slightly harder than IPv4. IPv6's lack of backwards compatibility also made it impossible to completely transition from IPv4, and instead both versions often run side by side. (Internet Society, n.d.) Unlike a lot of other competition between technology, the decentralized nature of the internet means that the success of these technologies isn't primarily driven by the goal of financial gain. Nobody owns IPv4 or IPv6, and while there are certainly financial motivations that influence the other actors, no actor directly benefits financially from the success of one or the other. Still, many other external actors have contributed to the competition between the protocols for other reasons.

Designers of the Protocols

Perhaps the most important "human" actor involved in the competition between IPv4 and IPv6 is the IETF. The IETF is a nonprofit organization that relies on internet engineering talent from around the world to help design protocols for the internet. They are the group responsible for originally designing and releasing IPv6 into the world in order to address some of the issues seen with IPv4 (ARIN, n.d.). Aside from just developing IPv6, the IETF has done a tremendous amount over the last three decades to solidify their reputation as an organization devoted to the betterment of the internet by promoting large-scale collaboration. The IETFs efforts have created many internet "standards" which are essentially rules or protocols for devices to follow when communicating with each other. The IETF doesn't have any way to enforce these rules, however. Instead people agree to follow these standards so that programmers and device manufacturers can all design independent technology that can still communicate with each other (Rouse, 2018). The IETFs successful work maintaining and developing so many widely used protocols has given them a large amount of authority in the field. On top of creating and maintaining the standards for IPv6, the IETF has also taken on maintaining the standards for IPv4 in order to implement improvements to it. (Rouse, 2018) The IETF's primary goal as they put it is "to make the Internet work better" (IETF), so rather than encourage the transition to IPv6 by letting IPv4 out to dry, they've worked to support both versions for as long as possible to ease transitioning.

Another group of actors are the device manufacturers and software developers who provided the necessary support in their products for IPv6 alongside IPv4. Hardware manufacturers like Cisco were the ones who actually had to take the IPv6 standards designed by the IETF into their hardware and configuration software in order to allow companies to actually build networks that supported IPv6 (Cisco, 2012). Alongside the hardware developments made, software developers had to also rewrite their code to allow support for both internet protocols. For example, the early Windows operating systems had support for IPv4, but full official support for IPv6 wasn't added in a service pack for Windows XP until September of 2002 (Tulloch, 2006). Other software, like web browsers/servers, also had to be updated in the same way. After the creation of the standards of IPv6 by the IETF, these designers had to lay the groundwork by making sure that companies and ISPs had the tools they needed to build the networks with the new internet standard. At this point, IPv6 is now almost universally supported in new devices.

Implementers of the Protocols

A rather broad group of actors in the network consists of all of the large companies that provide the applications, such as web site sites, to the Internet. Today that includes companies like Google, Microsoft, Facebook, Amazon, etc. that run internet services that millions if not billions of people rely on every day. These make up a group of companies called Application Service Providers (ASPs) (GeeksForGeeks, 2021). While many of these companies are easily recognizable, there are also actors like Cloudflare or Akamai, a large content provider, who's services people use every day without realizing it. All of these ASPs and their products are the predominant way that individuals use the internet in their day to day lives (NCTA, 2019). This gives them a tremendous amount of influence in how people use the technology. In the case of

IPv4 and IPv6, it was up to these companies to start the wave of transitioning their services to the newer protocol back in the late 90s and early 2000s, otherwise end users would have no services to connect to on the IPv6 internet. For many of these ASPs, however, the cost of adding support for IPv6 was simply not worth it, as all of their customers were still using the older protocol, especially up until recently (Internet Society, n.d.). This gave them little incentive to break ground into the “new and improved” internet that IPv6 supposedly offered, slowing down the transition tremendously.

Aside from the companies that provide the applications that users connect to, the Internet Service Providers (ISPs) are the ones that actually design and connect the end users to the internet. It is up to these ISPs to give their customers access to the IPv4 and/or IPv6 internet. On one hand, the ISPs are the ones who benefit the most from IPv6’s main draw, which is the much larger address space. ISPs typically have to assign one or several IP addresses to each customer, but first in order to do that they need to purchase the rights to that address. With IPv4, the much smaller pool of possible addresses makes each one more valuable, making it cheaper for ISPs to purchase IPv6 addresses for their clients. This also makes it easier to consolidate IP addresses, as companies easily can purchase blocks of IPv6 addresses that are larger than the entirety of the current internet (Samantha, 2020). The problem, however, is that just as with the companies providing the end applications, the ISPs had little reason to quickly offer IPv6 support because all of their clients still required IPv4 in order to connect to the vast majority of the internet’s services.

Understanding the Network Relationships

Analyzing the actor network surrounding the different IP versions sheds some more light on why the competition between the versions has gotten so drawn out.

First, the IETF has been one of the most ardent supporters of IPv6, especially given their involvement developing it. Despite that, the IETF doesn't have any legitimate authority that they can use to make people transition between versions. Instead all they have been able to do is continue to write standards to improve various protocols while also educating the public on the benefits of the newer IPv6. In efforts to help the world as it transitions between IPv4 and IPv6, the IETF has also written standards that help enable some compatibility between the two protocols, although these solutions only apply at a limited scale (IETF, 2022). These new standards have helped network operators reap the benefits of IPv6 while still keeping the IPv4 internet accessible. While these compatibility standards are necessary to ease the transition, these compatibility layers also make it so that legacy IPv4 networks continue to function normally, sparking little urgency to actually set up IPv6 support. So even though the IETF has done a lot to encourage the upgrade to IPv6, IPv4 can only become obsolete once the entirety of the world collectively moves off of it, which the IETF ultimately has no control over.

In a very closely related way, device manufacturers work with the IETF and their standards to create products that are capable of communicating with other devices utilizing those agreed upon rules. Just like with the IETF, device manufacturers want to see the success of IPv6 for the sake of creating a better internet, but primarily care about addressing the needs of their customers. Especially when working for profit, they don't care whether their customers use IPv4 or IPv6, as long as they use their products. In a similar vein to the IETF, this has meant that manufacturers have helped in some way to prolong the existence of IPv4 by continuing to give their customers the choice over which to use. And again just like with the IETF, by manufacturers trying to make either the IPv4 or IPv6 option as easy as possible, users of these products have little urgency to up and move onto IPv6 if their IPv4 solution just works.

The bulk of the competitiveness between IPv4 and IPv6 comes from the way that both Application and Internet Service Providers treat IPv6. For the IETF, their mission is to improve the internet as a whole across the world, and with the benefits IPv6 offers, they believe it is part of that solution. As with device manufacturers, their primary customers are the ASPs and ISPs that buy massive amounts of servers, routers, firewalls and other high-end networking equipment. They know that the benefits of IPv6 most directly benefit the ASPs and ISPs who are actually setting up and using the protocol, so they want to create a product that supports IPv6 better than any of their competitors. Device manufacturers also know that those customers have the technical expertise to make the decision over which protocol to use themselves. For both the IETF and device manufacturers, their goal is to give their consumers the best options possible and let the customer work out the details.

On the other hand, for both ASPs and ISPs, their typical customer (the everyday users of the internet) doesn't want to work out the details. Their typical customer doesn't have the technical expertise to understand whether they should use IPv4 or IPv6 and doesn't want to, they just want to "use the internet". For that reason, ASPs and ISPs have been the two groups of actors primarily responsible for the competitiveness between IPv4 and IPv6 we see today, as they are the actors actually making the decision for who uses which protocol. There are thousands of individual ISPs and ASPs that each have to weigh their own decisions over which protocols to use. Starting in the early 2000s, device and software developers finally had the tools ready for these providers to start deploying IPv6 networks, but there was no real incentive for existing networks to hurry to switch over. Some large organizations, such the US Department of Defense, hurried to set an example by switching over to IPv6, but found it was way more complicated than they bargained for. After initially setting the goal that the DOD would be fully transitioned by 2008, a report given in 2020 to the US Congress demonstrates that they have still failed to meet most of the goals necessary for transitioning, 12 years after the initial deadline (D'Souza, 2020). At the same time, because so few of the other providers on IPv4 were also on IPv6, the content available was extremely limited, so once setup, an IPv6 network was hardly used. This meant that there was little practical benefit to an IPv6 network until everyone had set one up, creating this kind of bystander effect where each provider was waiting for the rest to take action first. Every year, more and more of the world starts using IPv6 over IPv4, but the slow initial start has left us still very much unfinished.

IPv6's Failure

Still the most glaring issue with Internet Protocol Version 6 is that it contains no backwards compatibility with existing Version 4 infrastructure. While device manufacturers and operating systems quickly started supporting both versions of the protocol, all of the infrastructure in between two devices talking over the internet needed to support whichever version of the protocol they were using. So these two different internets, two different networks now span across the Earth, one for each version. Today, when a network administrator goes to set up a new network, many opt to build their network to utilize both IPv4 and IPv6, ensuring that the users of the network have complete access to both versions of the internet.

The problem with this decision in the long term is that by maintaining both IPv4 and IPv6, it perpetuates the growth of both versions of the internet rather than working towards a single unified network. On the other hand, if a network administrator wanted to build their network with a single version, even today there are so many popular sites online that only support IPv4, they often find it easier and simpler to build a pure IPv4 network. Especially in the United States, more and more services are supporting IPv6, making it more viable to work off of a pure IPv6 network. But for many end users of the internet, even a single website not working on a pure IPv6 network can be a dealbreaker. For example, as of early 2023, Disney Plus is just one of the services that doesn't support IPv6 and wouldn't function on an IPv6 network (Mcgree, 2021).

The creation of IPv6 back in the mid 90s left us in a sort of stalemate that is only now showing signs of breaking. On the one hand, IPv6 offers features that make it easier for everyone in the world to connect to the internet. This feature, however, is greatly stunted by IPv6's lack of backwards compatibility. As good of a protocol as IPv6 might be, its design failed to address how it would replace its predecessor. As no actor in the network has the true authority to enforce how and when protocols are used by other actors, individual ASPs or ISPs needed another incentive to use IPv6 over IPv4. But especially in the early days of adoption, there was essentially no incentive to use IPv6 other than a promise that it would one day be the future. And if the last quarter century has proved anything, that promise was not nearly enough.

At the end of the day, the internet doesn't belong to anyone. Nobody has any true authority over what people connect to or how people connect to it, at least at the global scale of the internet. As much as actors like the IETF and device manufacturers can develop advancements in the protocols we use, they cannot force anyone to use it. At least for the case of IPv4/IPv6, this left it to the ISPs and ASPs to actually build out the promised future of IPv6. And understanding the motivations, or lack thereof, that these actors had for utilizing IPv6 shows us why this transition shows no signs of ending soon.

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