WHAT IS THE ADOPTION RATE AND USAGE PATTERNS OF IPV6 AMONG DIFFERENT COUNTRIES AND REGIONS?

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ABSTRACT

IPv6 is a modern Internet protocol to provide larger address space for every atom on the earth. This study aims to understand the current IPv6 adoption and usage patterns worldwide. We use literature review and publicly available live dashboards to synthesize usage patterns in different regions. France, Germany, and India run most of their traffic to Google on IPv6. Russia and China are running on less than 10% IPv6 traffic. Sudan and Turkmenistan are at less than 1%. We use Alexa's top 1 million website data to analyze the IPv6 connections. We use traceroute, nslookup, and other tools on the top 25 sites [1] in some selected categories, including government, streaming content, social networks, defense, online grocers, airlines, defense, news media, and universities. Our results exhibit slow adoption rates in general, but some categories, such as government and defense, show high IPv6 connections. Overall, adoption rates are highly variable per category, with some with over 50% adoption, others closer to 30%, and some slow adoptions with less than 8%. From Alexa's top 500 websites, only 167 sites (33%) responded on IPv6 connections.

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1. INTRODUCTION

IPv6 is a cutting-edge new addressing protocol of the internet stack [41]. Nevertheless, it has a few disadvantages, such as long addresses with letters and numbers that are hard for network administrators to type, resulting in some potential system issues. It needs system upgrades to support the IPv6 scheme. IPv6 provides many benefits, including larger address space, built-in security features, and greater communication flexibility [42][30]. Despite these advantages, IPv6 adoption rates have been relatively low, and there are significant variations in adoption rates among different countries and regions.

Understanding the adoption rate and usage patterns of IPv6 is essential for several reasons. For one, it allows identifying areas where additional support or resources may be needed to promote the adoption of IPv6 [43]. It can also help inform decisions about network architecture, design, and investment in new infrastructure. In this study, we aim to explore the adoption rate and usage patterns of IPv6 among different countries and regions. First, we present the adoption pace of IPv6, then we investigate aspects that facilitate or hamper the upgrade to IPv6, and finally, we analyze the typical usage patterns of IPv6 worldwide using publicly available dashboards and datasets.

2. BACKGROUND

During the early 1990s, the Internet Engineering Task Force (IETF) recognized the rapid increase in the number of internet users and the resulting growth in the size of the internet routing table. To address this, discussions were initiated to develop a new network layer protocol that could overcome the limitations of IPv4 and support the network's future growth. The IETF introduced the protocol suite known as IPv6, which became an IETF Draft Standard in December 1998. In 1999, the Regional Internet Registries were assigned the first public IPv6 address blocks by the Internet Assigned Numbers Authority (IANA) [46]. IPv6 provides a larger address space and improved security features. The adoption of IPv6 has been relatively slow compared to IPv4 due to a variety of factors, including the complexity of transitioning to a new protocol and the entrenched use of IPv4 in existing network infrastructure.

Different countries and regions have different IPv6 adoption rates and usage patterns. Some countries and regions have made significant progress in transitioning to IPv6 and have high levels of IPv6 adoption, while others are still primarily using IPv4. Measuring the adoption rate and usage patterns of IPv6 can be challenging, as it involves tracking a wide range of metrics, such as the number of IPv6 addresses allocated, the percentage of internet traffic using IPv6, and the level of IPv6 readiness among network operators and service providers. Despite these challenges, the adoption of IPv6 is gradually gaining momentum, and many countries and regions are making progress in transitioning to the new protocol.

3. METHODOLOGY

We have employed a Python program to do a litmus test to see what websites are IPv6-capable today. Our methodology consists of 4 steps:

- We study the public IPv6 deployment datasets to determine the global promotion pace of IPv6 adoption

and the overall adoption rate among different countries and regions.
- ❖ We analyze recent examples of rapid deployment efforts in Ukraine and Mongolia.
- ❖ We explore why some parts see more or less IPv6 deployments.
- ❖ We study and analyze the usage patterns of the top 25 websites in some selected categories worldwide.

A detailed explanation is furnished in the next few sections.
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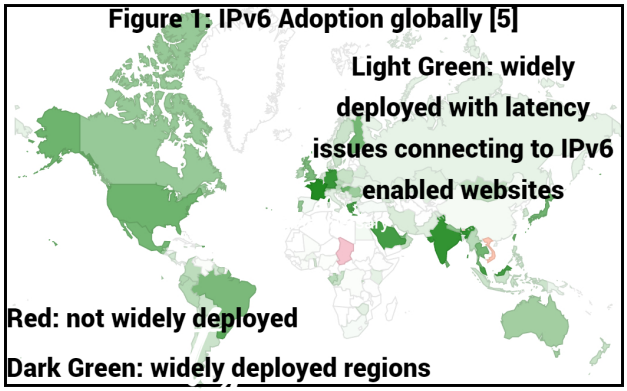
3.1 GLOBAL DEPLOYMENT PATTERN

The global deployment pattern of IPv6 is an essential topic of study in networking. While IPv6 has been available since 1998, adoption has been slow, with many organizations and individuals still relying on IPv4 [39]. However, in recent years, there has been increasing interest in IPv6 as the depletion of IPv4 addresses and the growth of the Internet of Things (IoT) have made IPv6 more relevant [40]. The deployment of IPv6 varies significantly across different countries and regions, with some areas leading the way in adoption and others lagging. In this section, we will explore the global deployment pattern of IPv6, examining which regions are leading the way in adoption and what factors are driving or hindering deployment in different parts of the world.

Figure 1 pertains to the current status of IPv6 adoption across different world regions [5]. The map shows the availability of IPv6 connectivity across the globe, with darker shades of green indicating a more significant deployment of IPv6. Regions where IPv6 is more widely deployed typically have fewer issues when connecting to IPv6-enabled websites, indicating that the technology is more established and reliable in these areas. Light green shades denote regions where IPv6 is less widely deployed with notable network latency problems when connecting to IPv6-enabled websites. The red shades of the region suggest that IPv6 is not widely deployed.

Figure 2 relates to the percentage of networks or Autonomous Systems (ASes) that have announced an IPv6 prefix, broken down by country or group of countries. Figure 2 shows the rate of IPv6-enabled networks over time for four different categories: Advanced Economies (the seven largest nations based on the GDP include Canada, France, Germany, Italy, Japan, UK, and the US), the United States, all nations, and all countries except advanced economies as defined by the International Monetary Fund (IMF). The ASes are mapped to a country using the statistics files maintained by Regional Internet Registry (RIR). The statistics files outline the current state of assignments of Internet number resources [8]. The accuracy of this mapping is assessed by comparing it to geolocating all announced IPv4 space for an AS using the MaxMind geolocation database [15].

Figure 2 highlights the varying levels of IPv6 adoption across various geographic regions and groups. Some countries have a higher percentage of IPv6-enabled networks than others, reflecting the extent to which organizations in those regions have transitioned to IPv6. Figure 2 also shows how IPv6 adoption has increased, with more networks announcing IPv6 prefixes in recent years.



Several countries have witnessed an increase in IPv6 adoption thanks to the efforts of major mobile networks. For instance, in Japan, NTT has an IPv6 deployment rate of 7%, while KDDI and Softbank have rates of 42% and 34%, respectively. In India, Reliance JIO boasts an impressive rate of 87%. In the USA, Verizon Wireless, Sprint, T-Mobile USA, and AT&T Wireless have high levels of IPv6 deployment, with rates of 84%, 70%, 93%, and 57%, respectively. Some mobile networks have even run IPv6-only to simplify network operations and reduce costs [16]. Table 1 shows the measurements of network operator participants in the World IPv6 Launch based on data from significant website participants [9].

3.2 RAPID DEPLOYMENT EXAMPLES

3.2.1 UKRAINE

The rapid deployment of IPv6 to Ukrainian internet users during the conflict is a notable achievement. Kyivstar, Ukraine's largest mobile operator and broadband internet provider, has over 26 million users and over a million broadband internet mobile users. The company's significant deployment of IPv6 marks a milestone as the first Ukrainian ISP to roll out IPv6 at scale. Despite the challenges faced by everyone in Ukraine, Kyivstar's commitment to engineering improvements for internet users is genuinely inspiring. IPv6 adoption began to grow in September 2022 and has since taken off, with approximately one-third of all Kyivstar subscribers now use IPv6 [10]. Figure 3 depicts the surge in IPv6 deployment in Ukraine [15].

3.2.2 MONGOLIA

Figure 4 shows a noticeable increase in IPv6 traffic from Mongolia earlier this year through Unitel, Mongolia's most prominent digital service provider. Unitel initiated its IPv6 project in 2016, as projections suggested that IPv6 would soon become a critical technology. Unitel followed a phased deployment approach to ensure a smooth transition, beginning with its core network elements in 2018 and gradually enabling IPv6 on all its network infrastructure [18]. APNIC, responsible for managing IP

address allocation in the Asia-Pacific region, has been actively promoting the adoption of IPv6 and providing technical training to Internet operators in Mongolia for several years.

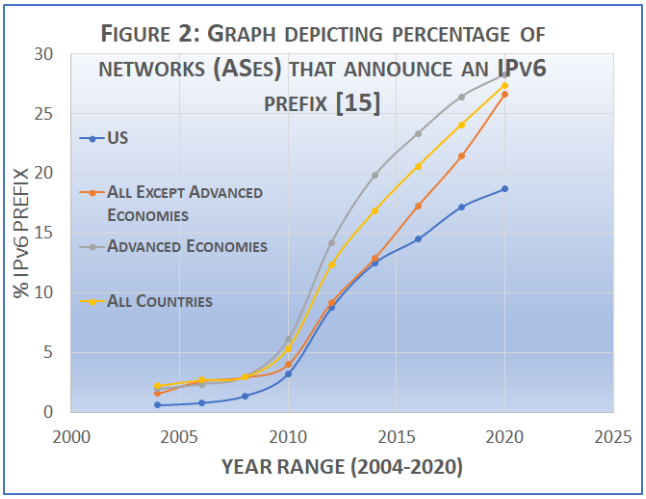
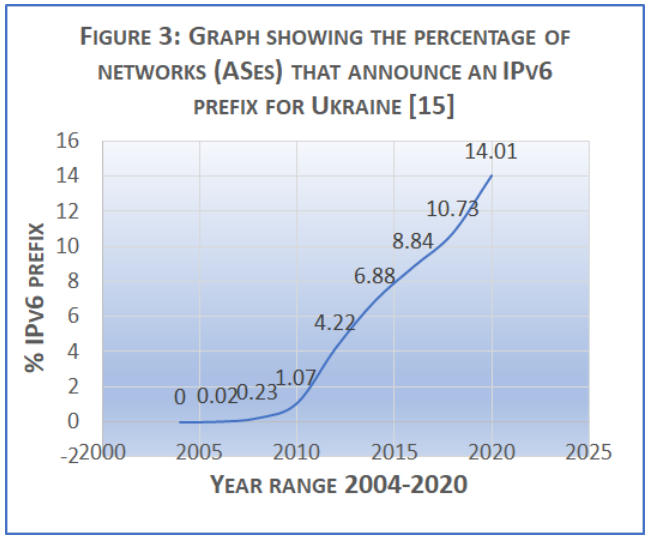
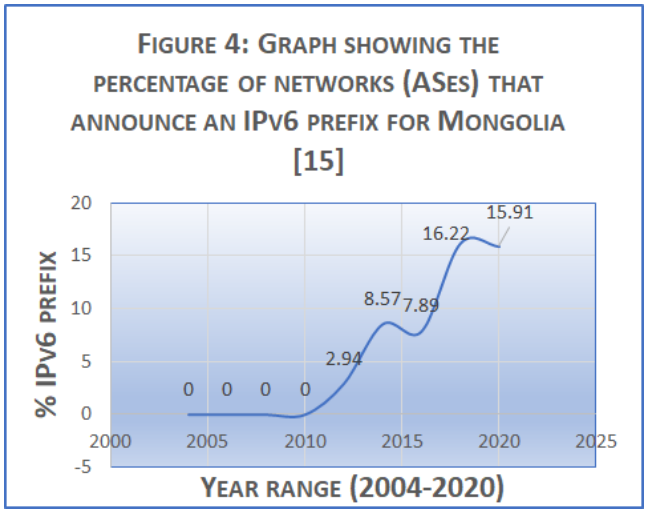


Table 1: Network operator measurements (8th June 2022) [9]

RANK	PARTICIPATING NETWORK	IPv6 DEPLOYMENT
1	Reliance Jio InfoComm Ltd	92.58%
2	Comcast	73.62%
3	Combined US Mobile Carriers	87.74%
4	Charter Communications	56.41%
5	ATT	72.32%



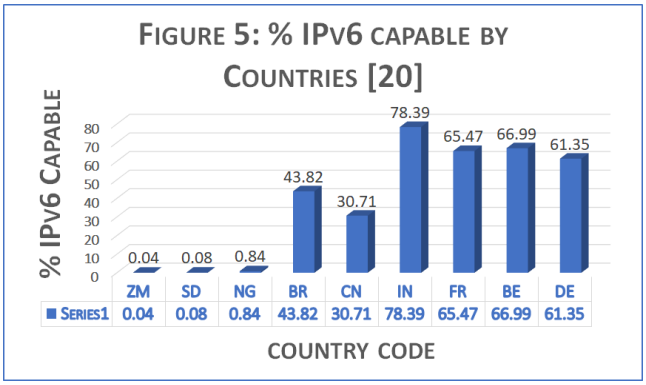


3.3 REGIONAL VARIATIONS

Low IPv4 per capita is directly proportional to high IPv6 adoption. For instance, countries like Brazil, China [44], and India have demonstrated an evident inclination towards adopting IPv6, as per local regulations and market-driven actions, besides the lack of IPv4 addresses. It is depicted in Figure 5 [20]. Even with IPv4 address scarcity, the move towards IPv6 is still unclear in several countries, especially in Africa, which still has low IPv6 adoption [21]. Figure 5 and Table 2 show the same in different views. African countries such as Nigeria, Zambia, and Sudan offer a low IPv6 capable connection.

Countries like Belgium, France, and Germany have made significant progress in IPv6 adoption in the European Union through government regulations or market incentives. For instance, Belgium provides an excellent example where Carrier-Grade NAT (CGN) systems and public IPv4 address use were restricted for legal examinations. It mandated one IPv4 per

16 customers on a NAT, lowering the ISP's economic burden by not using the performant deficient use of NAT [11]. This shift to IPv6 has led to increased protocol adoption in recent years.



France introduced its mobile carriers to use IPv6 compatible connections for its 5G frequencies in metropolitan cities. It ensured that services were interoperable, removing dependencies where services could operate only in IPv6 [24].

Public and industry actions helped increase IPv6 adoption in Germany. The Federal Office for Information Technology has issued the latest guidelines of 2022 [22] that outline the high-level roadmap for compulsory IPv6 adoption in its national networks.

The Office of Management and Budget urges IPv6 adoption in the United States, with 80% of US Federal networks migrated by 2025. In India, there is a country-wide increase in IPv6 adoption. The Reliance Jo move to IPv6 triggered high adoption in India. The Department of Telecommunications released a progressive adoption of IPv6 guidelines on Sep 2022 [23]. From Figure 5 and Table 2, we see that African countries have a shallow adoption while Brazil and China are in the middle, and European Countries and India are leading the IPv6 adoption.

3.4 IPv6 DEPLOYMENT IN AFRICA

It's more of a need for more understanding than reluctance for Africa's slow transition rate from IPv4 to IPv6 [45]. The African countries have an IPv6 adoption rate of less than 5%, with deployment still low in most countries, resulting in regional deployment well below the world average. Western Asia is at 13.92% and 1.36% in Africa (as of April 2022) [20]. A joint white paper released by ATU (African Telecommunications Union), AU (African Union), and Huawei describes that IPv6 is the most crucial choice for the internet in the future [17].

The primary goal of the white paper is to expedite the establishment of digital network infrastructure and encourage the development of the digital economy on the continent.

The reason why IPv6 deployment in Africa (and possibly other continents) is not reaching customers and services are as follows [19]:

- Lack of resources, including time, skills, and funding.
- Other perceived priorities often overshadow IPv6 deployment.
- There need to be more reliable indicators to track weekly progress.
- It is challenging to sustain engagement in a project whose results may not be visible for over a year.
- Maintaining individual accountability can be challenging, as teams may not prioritize specific tasks that contribute to project delivery.

Figure 6 shows that African countries are at a shallow adoption of IPv6.

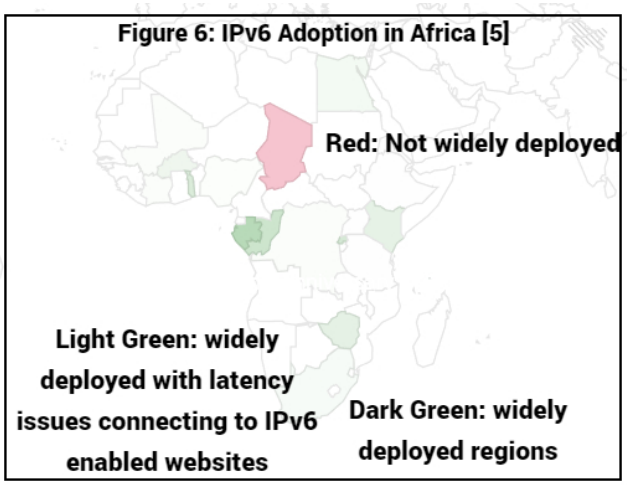
Table 2: IPv6 capability by region (11 Apr 2023)

COUNTRY CODE	COUNTRY	IPv6 CAPABLE
ZM	Zambia, Africa	0.04
SD	Sudan, Africa	0.08
NG	Nigeria, Africa	0.84
BR	Brazil, South America	43.82
CN	China, Asia	30.71
IN	India, Asia	78.39
FR	France, Europe	65.47
BE	Belgium, Europe	66.99
DE	Germany, Europe	61.35

3.5 TOP WEBSITES RUNNING IPv6

First, we collected data from various public datasets mentioned in the datasets section. We also collected the top 25 websites visited frequently in multiple categories, such as streaming media, fashion, air travel, national defense, government, grocery, news media, social networks, colleges, and universities [1], and the top 25 websites [2] in all categories combined to study the IPv6 usage patterns. The data collected in the top 25 websites in various categories were cleaned to run through the program that would run traceroute and nslookup tools. We scoured the data to remove inconsistencies in the URL pattern or errors in the URL, such as some government domains not responding due to timeout. So we had to remove such domains from the analysis and select an alternative domain for our top 25 website list. The program also indicated the presence of an AAAA record (for IPv6) and A record (for IPv4) for the domains selected. Our data was based worldwide, as the top 25 websites also had similar patterns per region [1]. We used statistical analysis of the data to understand IPv6 usage worldwide in the categories mentioned above. Based on the analysis, we have provided data visualization to present the

results using graphs and charts. Finally, we have provided the interpretation of the analysis of the results to conclude on IPv6 usage patterns worldwide.



3.5.1 AIR TRAVEL

The adoption is around 8% in our dataset. Airlines that provide domestic flights are only keen on reaching some users around the globe. They recognize this and are acceptable to support only some users and the slow roadmap to IPv6 adoption.

3.5.2 NATIONAL DEFENSE

National defense organizations in different countries want to utilize IPv6 immediately. Our program execution showed the migration rate as close to 50%. It shows the importance of IPv6 usage and its security features and perhaps performance playing an essential role in the decision to have IPv6 connections in this category.

3.5.3 STREAMING

The adoption rate is around 52% in this category. Since streaming is a bandwidth-intensive data transmission, IPv6 is better suited in such cases as IPv6 supports multicast addressing enabling multimedia streams to be sent to several destinations simultaneously. It could be the prime reason streaming sites run IPv6 connections.

3.5.4 FASHION

The adoption rate is around 20% which might be attributed to users wanting to have the in-person shopping experience hence fashion and retail stores still need to prepare to invest in IPv6 adoption.

3.5.5 GOVERNMENT

Government organizations show a reasonable adoption rate of around 48%. It is promising to see government organizations in the rise of IPv6 usage. It mainly shows that IPv6 is critical to Governmental agencies to use the performance and advanced security protocol offered in IPv6.

3.5.6 ONLINE GROCERS

Online grocers are at around a 12% adoption rate, which reveals the slow adoption. It would be interesting to see how this category's adoption rate will increase, making online grocers' presence necessary.

3.5.7 NEWS MEDIA

News media websites show a reasonable adoption rate of around 44%. Users could be on an IPv6-only connection. News media channels are moving towards IPv6 to reach most users.

3.5.8 COLLEGES & UNIVERSITIES

Colleges and Universities are almost at a 36% adoption rate. In this category, the knowledge to migrate to IPv6 is there. It could be due to other factors such as budget, resources, and other constraints that are making the usage pattern below 50% adoption rate. Charles [6] points out that at Washington University's transition to IPv6 was delayed due to the fear of the unknown. The conferences paint a scary picture that IPv6 is complicated, and the change would greatly impact the current infrastructure.

3.5.9 SOCIAL NETWORKS

Social Networks are also at a 36% adoption rate, like colleges and universities. Social media websites want their websites accessible to every user. Also, the number of users on IPv6-only connections is slowly increasing, and to be accessible to such users, websites in this category show improved adoption.

3.5.10 TOP 25 in ALL CATEGORIES

In Alexa's Top 1 Million Sites [2], we took the top 25 from the list. We ran the program to see the IPv6 usage. 56% are using IPv6 connection which may be attributed to the popularity of the website and the need to provide performance and security features for the average visit duration and pages visited on these websites.

4. DATASETS

This section will introduce the datasets to study IPv6 adoption in different regions.

4.1 GOOGLE IPv6 ADOPTION STATISTICS

Google provides a public dashboard that displays the ratio of users on their Google services connecting over IPv6 [5]. The dashboard manages continuous data collection as gradual IPv6 deployments occur. It provides color-coded maps of the deployment by regions. We have used this data to compare the deployments worldwide, Africa, Europe, United States, Brazil, Japan, Russia, China, Sudan and Turkmenistan.

4.2 APNIC LABS DEPLOYMENT STATS

APNIC Labs publishes IPv6 deployment statistics for Asia-Pacific region [20]. We have used to collect and analyze Asia specific IPv6 deployment measurements.

4.3 RIPE IPv6 DEPLOYMENT DASHBOARD

RIPE NCC is the regional Internet registry [7] [15]. They provide a public dashboard that shows the percentage of networks that have deployed IPv6 in their service region. We have used this to analyze the adoption trends in the groupings they provide such as Advanced economies (IMF), United States, All countries, All except advanced economies.

4.4 INTERNET SOCIETY IPv6 DEPLOYMENT MONITORING

The Internet Society provides a public dashboard showing the percentage of networks deployed IPv6 [8]. We use this to get the mapping of ASes to a country.

4.5 WORLD IPv6 LAUNCH MEASUREMENTS

The World IPv6 Launch collaborates with network operators, content providers, and equipment vendors to promote IPv6 adoption [9]. They provide public measurements of IPv6 deployment for different countries and regions. We use this to show the measurements of network operator participants in the world IPv6 launch based on data from significant website participants.

4.6 INTERNET SOCIETY PULSE

It provides examples of rapid deployment data within the last six months [10]. We have used this to illustrate two recent rapid deployments in key organizations (Ukrainian & Mongolian ISP).

4.7 ALEXA'S TOP 1 MILLION WEBSITES

It is a public dataset listing the top one million most visited websites in the world [2]. We analyzed the top 500 sites in this list to analyze the current percentage of IPv6 connections.

4.8 TOP WEBSITES RANKING - MOST VISITED in MARCH 2023

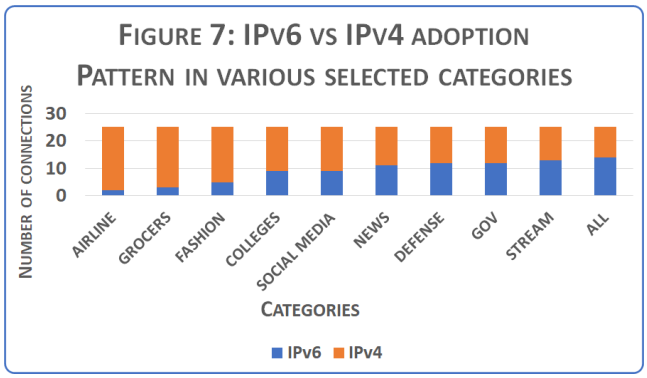
It is a public website listing the ranking of most visited websites in various categories worldwide [1]. We picked the top 25 most visited websites in ten different categories to analyze the percentage of current IPv6 connections.

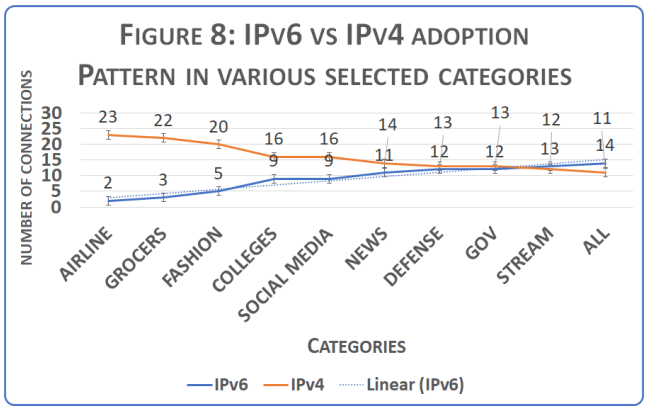
5. DISCUSSION

In this section, we provide data analysis and visualization of various selected categories we analyzed in the section top 25 websites running the IPv6.

5.1 SLOW ADOPTION

The usage of IPv6 in the airline, online grocers, and fashion industries is slow. The slow adoption may be due to legacy systems, lack of urgency, and limited resources. Many airlines and airports still use legacy systems that may need to be compatible with IPv6. Cost and time are essential in deciding if the infrastructure can be upgraded. IPv6 provides benefits like increased public address space with improved security. It may not be a compelling reason to switch to using NAT translation techniques employed currently. IPv6 requires significant new hardware and software; training and testing require additional resources. Companies that could be faster in the IPv6 adoption may need more resources and budget to accomplish such projects. Figure 7 shows a bar graph representation of the IPv6 to IPv4 connections in the top 25 categories.





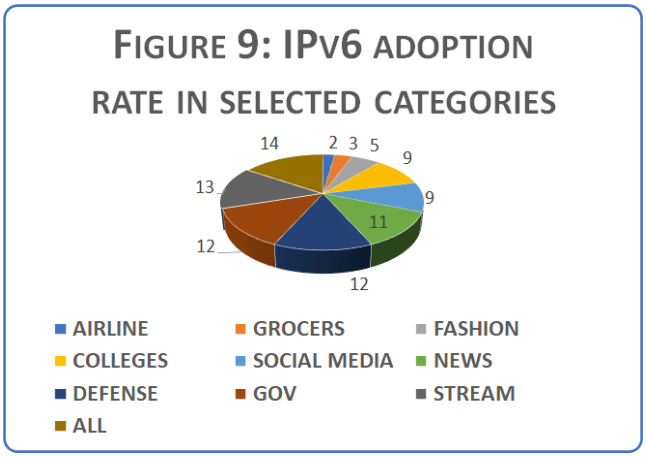
5.2 MEDIUM ADOPTION

Our experiments show that colleges & universities and social networking sites have a medium adoption rate of IPv6. Universities are rising to adopt IPv6 with recruitment in focus. If potential students are researching any college and are on an IPv6-only connection, they can not connect to the institution's website. It would hurt the business. So many universities are upgrading to IPv6 [6]. Likewise, social networking sites focus on reaching every user worldwide who may be on IPv6-only connections. We see an increasing migration trend. Figure 8 shows a line graph representation of the IPv6 to IPv4 connections in the top 25 categories.

5.3 HIGH ADOPTION

From the experiments we ran, the news media channels, national defense, streaming media, and government organizations tend to adopt IPv6 at a higher rate. These sites want to be part of early adopters recognizing the benefits offered, such as improved

security and scalability. The sites related to the government are ahead in the IPv6 adoption. In some countries, such as the US, the government has mandated the adoption of IPv6 and proposed a timeline for phasing out IPv4 [12]. Higher adoption rates are seen due to cloud services offering out-of-the-box support for IPv6 [13]. It makes it easier to use IPv6 when such websites are hosted on these platforms. Most of the top 25 all-category websites we analyzed cater to a technically savvy audience that may value the benefits of IPv6 [14]. We are witnessing a higher rate of important websites enabling IPv6 support. When we ran the top 1000 Alexa websites to check on the AAAA records, we found that 28% were running IPv6 connections. We also reviewed each site's AAAA records using the "www." version and without the "www." When we picked the top 500 websites to check on the AAAA records, we found that 32% were running IPv6 connections. Figure 9 shows a pie chart representation of the IPv6 to IPv4 connections in the top 25 categories. Our experimental analysis shows that some of the world's biggest content providers, like Google, Netflix, Facebook, and Microsoft, are on IPv6, and other companies maybe following this path.



6. CONCLUSION

After analyzing publicly available dashboards described in the dataset section and our experimental analysis on the various categories of the top 25 websites and one million Alexa websites, we find that IPv6 adoption is increasing slowly. All sites use IPv4 for sure, but it is growing steadily to see sites with the dual stack. More organizations will transition to IPv6 as their need for more extensive address space requirements increases with increased devices connecting to their systems. With cloud providers providing IPv6 support for free while charging for IPv4, it is an unnecessary cost to maintain IPv4. From various regional analyses and our experimental analysis on Alexa's top one million servers, we find that about 28% are now on IPv6. We also found in our various categories that enterprise networks tend to be slower to adopt IPv6, mainly due to the challenges of migrating large-scale, complex networks. With governmental push like in India, we might see countries going from 5% to more than 50% in just a few months. IPv6 is the only practical solution to IPv4 address exhaustion, and understanding the current usage pattern provides insights into its clear progress.

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