Iterative Resolution with IPv6 Packets Failing

Momoka Yamamoto, Jin Nakazato, Manabu Tsukada, Hiroshi Esaki

The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

Emails: momoka@hongo.wide.ad.jp, {jin-nakazato,mtsukada}@g.ecc.u-tokyo.ac.jp, hiroshi@wide.ad.jp

Abstract—The exhaustion of IPv4 addresses has driven the rapid adoption of IPv6 networks, which has created challenges in the domain name resolution process, particularly for IPv6-only iterative resolvers. This paper presents an experimental analysis to quantify the extent of this problem, revealing a significantly lower success rate of name resolution using IPv6-only resolvers (64.1%) compared to IPv4-only resolvers (98.8%). By analysing the success rates and percentages of A and AAAA records for the top 1,000,000 domains in the Tranco list, we identify the limitations of IPv6-only iterative resolvers and highlight the urgent need for comprehensive solutions to improve DNS resolution in IPv6-only networks. Our findings emphasise the importance of full IPv6 adoption for improved compatibility in IPv6-only environments, and serve as a basis for addressing the challenges faced by IPv6-only networks.

Index Terms—IPv6, DNS, Measurement, IPv6-only networks

I. Introduction

The adoption of IPv6 has been steadily increasing due to the exhaustion of IPv4 addresses, necessitating a larger address space. As networks transition to IPv6-only operation, ensuring seamless connectivity and maintaining global interoperability of the Internet is essential. To achieve optimal performance and maintain control over their DNS infrastructure, it is recommended that Internet Service Providers (ISPs) implement their own iterative resolver instead of relying on public resolvers like Google DNS [1]. According to Section 4 of RFC3901 DNS IPv6 Transport Guidelines [2], every DNS zone should be served by at least one IPv4-reachable authoritative name server to preserve namespace continuity. However, the guidelines do not explicitly state that IPv6-reachable authoritative name servers should also serve DNS zones. As the adoption of IPv6-only networks grows and the need for IPv6-only resolvers increases, it becomes increasingly important for authoritative name servers to support both IPv6 and IPv4 protocols. One of the challenges faced during this transition is the inability of IPv6-only iterative resolvers to resolve domain names served by IPv4-only authoritative servers. This study quantifies the problem by investigating the number of domains an IPv6-only resolver can resolve. Our findings will help highlight the urgent need for solutions that enable IPv6-only networks to resolve domain names served by IPv4-only authoritative servers, promoting a more efficient transition to IPv6-only operation.

II. Problem Definition

An "IPv6-only iterative resolver" is a DNS resolver that operates exclusively using the IPv6 protocol, without IPv4 connectivity. In an IPv6-only environment, this resolver can only communicate with IPv6-supporting authoritative name servers, leading to challenges in resolving domain names served by IPv4-only servers.

The main issue faced by IPv6-only iterative resolvers is their inability to communicate directly with IPv4-only networks, resulting in failed resolutions for domain names served by IPv4-only authoritative servers. Streibelt et al. [3] found that a significant fraction of zones cannot be resolved in a strict IPv6-only scenario. The presence of an AAAA resource record for a zone's nameserver does not guarantee its resolvability from an IPv6-only resolver, as the entire DNS delegation chain must resolve via IPv6. The study also revealed the continuing centralization of the Internet significantly impacts IPv6 readiness.

The root cause of the problem lies in the insufficient adoption of IPv6 across domains and authoritative name servers. Partial IPv6 adoption can result in a domain having an IPv6 address, but the iterative resolver cannot resolve it due to insufficient IPv6 support in the DNS delegation chain.

As more networks transition to IPv6-only operations, addressing this challenge becomes crucial for ensuring seamless internet experiences and maintaining global internet interoperability.

III. Analysis and Discussions

This section presents the experiment methodology and a discussion of the obtained results, providing insights into the challenges faced by IPv6-only iterative resolvers when attempting to resolve domain names.

A. Experiment Methodology

The objective of the experiment was to compare the capability of an IPv6-only resolver to resolve 1 million domain names taken from the Tranco list [4] using IPv6 packets, compared to an IPv4-only resolver. The experiment was conducted using active measurements, with Unbound configured to perform both IPv6-only and IPv4-only resolutions. The experiment was conducted on a server with only an IPv6 address. In developing the methodology for this study, previous work [3] served as a reference point.

The key variables considered in our experiment were the success rates of A and AAAA record resolutions when using an IPv4-only iterative resolver and an IPv6-only iterative resolver. The experiment was conducted from March 20th to 25th, 2023. To ensure the reliability and validity of the measurements, name resolution was performed multiple times, and the most frequent output was considered as the data.
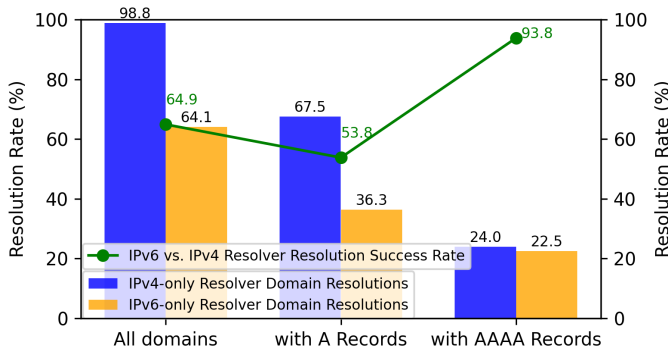
Fig. 1. IPv6/IPv4 Resolver-resolved Domains with Record Type Breakdown

Fig. 2. Comparison of resolution rates for different popularity rankings

To minimize potential biases and ethical considerations, the results were cached to avoid sending redundant queries to authoritative servers.

B. Discussion

Figure 1 demonstrates the performance disparities between IPv4 and IPv6 resolvers, where IPv6-only resolvers resolve merely 64.1% of domains, in contrast to the 98.8% resolved by IPv4 resolvers. The green line shows that the IPv6 resolver resolved 64.9% of the domains that the IPv4 resolver did. This discrepancy suggests fragmented IPv6 adoption affecting performance. For A-record-only domains, the IPv6 resolver achieved 53.8% of the IPv4 resolver's performance. For domains with AAAA records, it reached 93.8% of the IPv4 resolver's performance, indicating a positive impact of AAAA records on IPv6 resolver success rates. However, some domains with AAAA records remain unresolvable by IPv6-only resolvers due to DNS delegation chain limitations. For example, wikipedia.org and nginx.org have authoritative servers without AAAA records, hindering IPv6-only resolution. In the Tranco list [4], 6.2% of domains with AAAA records (1.48% of all domains) share this issue, making them unresolvable by IPv6-only resolvers. The situation becomes intriguing when the same operator is responsible for both the authoritative server and a domain with an AAAA record. The presence of an AAAA record suggests that the domain operator has access to IPv6 connectivity. However, it is puzzling why the authoritative server lacks an IPv6 address when the actual content supports IPv6. There are a few possible reasons for this inconsistency, such as the operator overlooking the need for an IPv6 address on the authoritative server and only implementing IPv6 for the content server. Alternatively, the operator might assume that adding IPv6 connectivity to the authoritative server could negatively impact name resolution speed. Regardless of these potential explanations, equipping authoritative servers with IPv6 addresses is essential as failing to do so creates difficulties for IPv6-only resolvers when attempting to resolve domains with AAAA records.

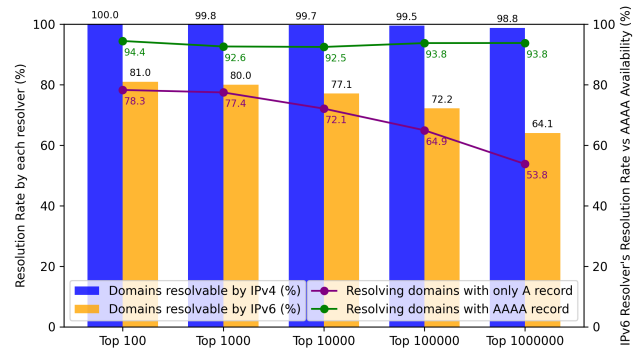Figure 2 compares the resolvability of domains by IPv4-only and IPv6-only resolvers across different popularity rank-ings, as determined by the Tranco list. It can be observed that popular domains are more likely to be resolved successfully by both IPv4 and IPv6 resolvers. The resolving rates of domains with AAAA records remain relatively consistent for different popularity rankings. In contrast, the resolving rates of domains with only A records exhibit a more significant decline as the popularity decreases. This may be attributed to fewer domains having AAAA records, and those that do are likely to have an AAAA record on the authoritative resolver. On the other hand, domains with only an A record may also not have IPv6 address connectivity for their authoritative server, which results in lower resolvability by IPv6-only resolvers for less popular domains.

IV. CONCLUSIONS

This study highlights the challenges faced by IPv6-only iterative resolvers due to limited IPv6 adoption. Our experiment revealed a lower success rate in name resolution for IPv6-only resolvers (64.1%) compared to IPv4-only resolvers (98.8%), with the IPv6-only resolver resolving 64.9% of the domains that an IPv4 resolver could. A key contribution of this paper is the division of the success rate of domains being resolved by an IPv6-only iterative resolver depending on whether the domain has an AAAA record or not. When focusing on domains with AAAA records, the IPv6-only resolver's performance improved notably, resolving 93.8% of these domains but still lower than the resolution rate of an IPv4-only resolver. The results emphasize the need for solutions enabling seamless DNS resolution in IPv6-only networks, promoting efficient transition and global interoperability.

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