Advancing DNS Query Processing and Scalability In Distributed Systems

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Abstract

DNS query processing is a vital function that translates human-readable domain names into IP addresses, enabling devices to locate services on the internet. When a client sends a DNS query, the request typically reaches a recursive resolver, which either returns a cached answer or performs iterative queries to root, TLD, and authoritative servers to find the authoritative data. This process involves multiple steps: receiving the query, checking cache, querying upstream servers if necessary, and finally returning the response to the client. Efficiency in query processing depends on factors such as caching strategies, network latency, and the performance of DNS server software. Modern DNS servers must handle large volumes of queries with low latency, support DNSSEC for security, and manage dynamic updates efficiently. BIND9, one of the oldest and most widely deployed DNS server implementations, has traditionally relied on flat text-based zone files and synchronous processing models. While reliable and feature-rich, BIND9 struggles with performance under heavy query loads and large zone sizes due to its architecture, which can cause slow zone file parsing, higher memory consumption, and longer reload times. Additionally, DNSSEC validation and signing in BIND9 introduce computational overhead that further impacts responsiveness. The increasing complexity of DNS environments demands more efficient and scalable solutions beyond traditional servers like BIND9. Modern DNS software often uses database-backed storage systems, which allow for faster zone lookups and dynamic updates without requiring full reloads. These systems also better handle large numbers of zones and high query rates by distributing load across multiple nodes and employing asynchronous processing. Furthermore, integration with APIs enables automation and easier management of DNS records. As security threats evolve, DNS servers must also incorporate robust DNSSEC support and mitigate attacks such as DNS amplification or cache poisoning. These advancements help ensure reliable, fast, and secure DNS resolution, which is critical for maintaining internet stability. These limitations make BIND9 less suitable for environments requiring extremely high throughput and rapid zone updates, where more modern, database-backed DNS servers provide better scalability and efficiency. Despite its robustness and widespread adoption, BIND9's performance issues under load prompt organizations to consider alternative DNS solutions optimized for speed and scalability in today's demanding network environments.

Keywords: DNS, query, resolver, cache, scalability, performance, latency, zones, security, DNSSEC, load, updates, servers, databases, throughput.

INTRODUCTION

The Domain Name System (DNS) is a critical internet service that translates human-readable domain names into IP addresses, allowing users and devices to locate websites and services efficiently. The ability of DNS [1] servers to handle a high volume of requests is measured by Queries Per Second (QPS), which indicates how many DNS queries a server can process in one second. Maintaining a high QPS is essential for internet

service providers, large-scale web platforms, and cloud providers that face millions of DNS requests daily. Several factors affect DNS server QPS, including hardware resources such as CPU performance, memory capacity, and network bandwidth, as well as software design and implementation. Modern DNS servers leverage sophisticated caching strategies that temporarily store DNS responses [2], which reduces the need to query authoritative servers repeatedly, resulting in faster responses and lower latency. Efficient software architectures that support asynchronous query handling and concurrency enable DNS servers to process multiple requests simultaneously, increasing throughput. Security considerations also play a vital role in preserving DNS server performance at high QPS levels, especially in the face of threats like Distributed Denial of Service (DDoS) attacks [3], where attackers flood servers with excessive traffic. Mitigation techniques such as rate limiting, traffic filtering, and anomaly detection help sustain normal operation during these attacks. Many modern DNS implementations use database-backed storage and API-driven management, enabling dynamic zone updates without downtime and supporting automated workflows, which contribute to improved query processing efficiency. With the rapid growth of internet-connected devices, cloud services, and the Internet of Things (IoT), the demand for scalable, high-performance DNS servers capable of handling massive query volumes continues to increase. As a result, optimizing DNS servers to maximize QPS through better hardware, improved caching, distributed architectures, and robust security measures is critical to maintaining reliable and fast internet connectivity. In conclusion, DNS query processing and QPS [4] are intrinsically linked metrics that determine the responsiveness and scalability of domain name resolution services worldwide, making them fundamental to the stability and performance of the internet ecosystem.

LITERATURE REVIEW

The Domain Name System (DNS) is one of the most essential components of modern internet infrastructure. It acts as the naming system that translates domain names into IP addresses, enabling users and systems to reach web resources without needing to remember numerical addresses. DNS servers play a critical role in this process, and their ability to handle large volumes of queries efficiently is measured using the metric Queries Per Second (QPS). QPS indicates how many client lookup requests a server can respond to each second while maintaining minimal latency and service continuity. Among the various DNS server implementations, BIND9 is the most widely used open-source DNS server globally, maintained by the Internet Systems Consortium (ISC). Although BIND9 [5] is known for its flexibility, standards compliance, and extensive feature set, its performance characteristics—especially regarding QPS—have been the subject of extensive analysis and debate in both academic and operational contexts.

From early performance testing, BIND9 showed solid scalability and multi-threaded capability. Using standard testing tools like queryperf, benchmarks demonstrated that a single BIND9 process on FreeBSD could handle approximately 46,000 QPS, and with multiple processes, performance increased to nearly 60,000 QPS. These numbers showed that test limitations often originated from client-side sending capacity rather than from BIND9 itself. Later tests using more powerful hardware showed further improvements. In 2007, community benchmarks with dual quad-core Xeon processors revealed that an optimized BIND9 build could reach up to 200,000 QPS. These results required careful compilation using performance-focused flags like -Ofast. Comparisons between precompiled distribution packages and locally optimized binaries [6] showed significant discrepancies in performance, with optimized builds delivering QPS rates several times higher than stock packages.

However, these high QPS values are often observed in ideal, controlled conditions without security features like DNSSEC, query logging, or policy-based filtering enabled. When such features are activated—especially in enterprise or ISP environments—the performance characteristics of BIND9 change significantly. DNSSEC, which provides authenticity and integrity for DNS data, introduces cryptographic

validation steps that consume CPU resources [7]. Under high query volumes, these additional computations lead to increased response latency and reduced QPS. In live environments with DNSSEC validation enabled, BIND9's throughput typically drops by 20–40 percent, depending on the key sizes and the number of signatures processed per response.

Another important feature, Response Policy Zones (RPZ), allows administrators to define DNS response behavior for known malicious or undesired domains. RPZ [8] enables dynamic filtering based on real-time threat intelligence, but it also introduces performance overhead. For example, loading a single RPZ zone with approximately 800,000 entries was observed to consume around 300 MB of memory and reduce the server's performance to around 20,000 QPS—even when running on 12-core systems. Adding more RPZ feeds further compounded the problem. Community testing showed that each additional RPZ feed could reduce QPS by about 25 to 30 percent, especially if the server lacked sufficient RAM to cache the full policy database [9]. These impacts made clear that while RPZ is invaluable for real-time threat mitigation, its use must be balanced against performance requirements in high-throughput DNS environments.

Query logging is another area where BIND9 experiences substantial performance impact. Enabling detailed per-query logging is useful for auditing, debugging, and compliance, but it also significantly increases I/O operations [10] and CPU load. Benchmarks have shown that turning on detailed query logging can reduce effective QPS by up to 85 percent. Consequently, operational best practices recommend using selective logging policies, rotating logs frequently, and leveraging external log processors to avoid burdening the DNS process itself. BIND9's scalability is heavily influenced by server configuration. Key performance tuning parameters include the number of worker threads, UDP [11] listener sockets, cache size, and zone loading behavior. For example, tuning the number of UDP listeners to match or slightly exceed the number of CPU cores can improve concurrency and prevent packet queuing. Similarly, increasing the number of worker threads [12] allows the server to handle more queries in parallel, especially on multi-core systems. Cache tuning is equally important: setting the max-cache-size appropriately allows for effective caching of frequent lookups, reducing the need for upstream resolution and improving response times. Incremental zone transfers (IXFR) and NOTIFY [13] mechanisms help minimize downtime during updates and prevent resource spikes caused by full zone reloads.

To protect against abuse and maintain performance under attack, BIND9 supports Response Rate Limiting (RRL) [14]. This feature is particularly effective in mitigating DNS amplification attacks. RRL throttles repeated identical responses, preventing attackers from leveraging open resolvers for traffic amplification. While RRL adds minimal overhead under normal conditions, it becomes essential during DDoS attempts, enabling the server to maintain availability and protect upstream infrastructure. Despite these tuning possibilities, real-world deployments still face performance limitations. External factors like network latency, client behavior, and upstream DNS delays can degrade performance even when the server is well-tuned. Additionally, operating system configurations—such as socket buffer sizes, thread scheduling, and NIC [15] driver optimizations—can impact BIND9's responsiveness. Observability and monitoring tools are essential to detect these bottlenecks. Administrators commonly use Prometheus, Grafana, queryperf, or custom scripts to monitor CPU usage, cache hit rates, packet loss, and response times. Recent research and operational reports suggest that BIND9 has a practical upper limit for QPS. Even with high-performance hardware, optimized compilation, and minimal feature overhead, BIND9 typically maxes out between 200,000 and 500,000 QPS per node in production environments. A technical comparison from a Chinese research group showed that BIND9 9.10.6, running on 16 cores, achieved a peak of around 470,000 QPS. In contrast, DNS server software built on newer packet-processing frameworks like DPDK [16] reached QPS levels over 10 million in the same environment. This stark difference highlights that BIND9, due to its traditional architecture and processing model, is less suited for ultra-high-demand scenarios such as large-scale content delivery networks or carrier-grade recursive resolvers. Community feedback on BIND9

reinforces these findings. Operators on public forums and mailing lists have shared experiences with memory bottlenecks, startup delays, and performance drops linked to large RPZ zones, misconfigured [17] UDP listener counts, and excessive logging. For example, deploying 10 million RPZ entries in BIND9 was shown to consume over 4.5 GB of memory and significantly slow response time. Additional performance regressions have been observed in specific BIND9 versions when default values for listener sockets or thread pools were inadvertently reduced. These issues were often resolved by reverting to custom configurations or upgrading to newer releases with performance fixes.

In conclusion, BIND9 remains a highly flexible, secure, and standards-compliant DNS server. Its feature-rich design, including full DNSSEC support, RPZ, IXFR, and fine-grained ACLs, makes it ideal for enterprise and infrastructure-critical environments. However, these same features introduce complexity and resource overhead that affect QPS performance. While optimized BIND9 builds can handle up to 200,000 QPS under favorable conditions, real-world deployments [18] often experience reduced throughput when enabling modern security and policy controls. Effective deployment of BIND9 requires not only strong hardware and tuning expertise but also strategic decisions about which features to enable or offload to supplemental systems. As the internet continues to scale, and DNS demand grows from IoT, 5G, and cloud-native applications, administrators must continually evaluate whether BIND9's architecture aligns with performance goals—or whether alternative architectures better suited to high-throughput, low-latency DNS are required. Beyond basic configurations, BIND9's caching behavior is a crucial determinant of its overall performance in terms of QPS.

The DNS caching mechanism is intended to reduce the frequency of upstream lookups by storing previously resolved queries for a duration governed by the Time-To-Live (TTL) of the records. In high-traffic environments, cache hit ratios directly affect the number of queries requiring full resolution versus those served from memory. A well-optimized cache can handle a majority of client requests without external lookups [19], drastically improving throughput and lowering latency. However, cache tuning in BIND9 requires attention to the size of the cache (max-cache-size), cache cleaning intervals, and the behavior of negative caching (i.e., caching of failed lookups). If the cache is too small, frequently accessed entries are evicted prematurely, resulting in repetitive upstream lookups and reduced performance. Conversely, an excessively large cache can lead to memory exhaustion and increased management overhead, particularly when zone transfers or RPZ modifications occur in real time.

The limitations in BIND9's architecture become increasingly apparent when compared with modern DNS servers designed with performance-first principles. Unlike BIND9, which was built for modularity [20] and standards compliance, newer DNS servers like Knot Resolver, Unbound, and DPDK-based implementations focus on event-driven architectures, zero-copy packet processing, and deep OS-level integration for high concurrency. These servers often leverage asynchronous I/O models and low-level memory management to bypass performance bottlenecks inherent in traditional threaded designs. For example, DPDK-based DNS servers avoid kernel-based socket handling, achieving throughput exceeding 10 million QPS in some benchmarks. In contrast, BIND9 relies on classic multithreading and system-level UDP socket buffers, which, while stable, do not scale as linearly with increased traffic. Furthermore, BIND9's monolithic architecture processes many DNS functions synchronously, which adds latency and limits parallelism in large-scale resolver operations.

One of the more challenging aspects of BIND9 in production is handling zone updates and reloads, especially for large zones with dynamic updates. While BIND9 supports Incremental Zone Transfers (IXFR) and DNS NOTIFY to reduce the impact of updates, large-scale dynamic updates can still lead to temporary latency spikes, cache invalidations, or inconsistent responses. Administrators often adopt staging zones or split authoritative and recursive functions to avoid such issues. However, this increases deployment complexity and resource utilization. Additionally, loading large zones—such as those containing RPZ or

ENUM [21] data—can take several seconds to minutes, depending on the number of records and server hardware. During this period, the server may serve stale data or drop queries unless redundancy mechanisms are in place. Another factor impacting BIND9's QPS is its startup and reload behavior. In environments with thousands of zones, BIND9's startup time can be significant due to the sequential parsing and loading of zone files. While tools exist to parallelize zone generation or precompile configurations, the core limitation remains tied to its file-based architecture.

Systems using BIND9 as part of large-scale DNS infrastructures often segment workloads across multiple instances, running separate BIND9 processes for authoritative, caching, and filtering roles. While this allows more granular tuning, it also increases the operational overhead of managing separate daemons, logs, and configurations. Security also plays a dual role in performance. Features like DNSSEC, TSIG (for zone transfers), and access control lists (ACLs) ensure trust and integrity but consume resources. DNSSEC, in particular, increases computational demands both during validation and signing operations. For validating resolvers, this can delay responses as signature chains are checked. BIND9 performs these operations synchronously unless cache hits occur, resulting in occasional latency spikes for cold queries. In environments with strict latency budgets, such delays can be unacceptable. Ultimately, while BIND9 remains an industry-standard DNS solution, its QPS performance is inherently constrained by design choices prioritizing flexibility and completeness over raw speed.

These constraints become most visible in scenarios involving modern, large-scale, security-conscious DNS deployments where every millisecond counts. In production environments, the performance of BIND9 is also closely linked to the underlying hardware. Factors such as CPU core count, clock speed, memory bandwidth, and network interface capabilities all play significant roles in determining the server's maximum sustainable QPS. For instance, systems with higher clock-speed CPUs often outperform those with many lower-frequency cores, especially in workloads that are not fully parallelized. BIND9 supports multithreading, but certain parts of its processing pipeline—including cache handling and zone transfers—can become serialized under pressure. Therefore, performance scaling is not always linear with additional cores. Similarly, memory capacity and throughput are critical, particularly when serving large zones or operating with multiple RPZ feeds.

Insufficient memory can lead to cache eviction, slower lookups, and higher system I/O due to increased dependency on disk-based logging or zone storage. Another aspect influencing BIND9 performance is the specific version in use. Over the years, the Internet Systems Consortium has introduced numerous performance improvements and bug fixes in BIND9. For example, BIND 9.11 introduced improvements to the responsiveness of zone loading, more efficient memory use in RPZ, and better tuning defaults for multithreaded [22] systems. Version 9.16 further improved DNSSEC validation efficiency, and later releases provided native support for catalog zones, allowing dynamic management of many zones without reloading configuration files. Despite these improvements, older deployments sometimes continue using legacy versions due to compatibility, internal policies, or certification constraints—resulting in missed opportunities for performance enhancements.

Insights shared within the DNS operations community also reveal frequent misconfigurations or missed optimizations that hinder BIND9's potential. It's common for operators to leave default values untouched, such as limiting the number of worker threads or using small UDP receive buffers. These conservative defaults are intended for compatibility and stability but can significantly limit performance under load. Adjusting parameters like `recursive-clients`, `tcp-clients`, `listen-on`, and `max-cache-size` in line with actual traffic demands often leads to immediate performance gains. Community experiences also highlight the importance of offloading ancillary functions such as logging and zone file generation to dedicated systems or background processes, freeing BIND9 to focus exclusively on query resolution. Ultimately, achieving optimal QPS performance with BIND9 demands a combination of proper tuning, hardware

provisioning, version management, and feature selection. While it remains a powerful and trusted DNS server, administrators must accept that BIND9's architectural foundations were not built with extreme-scale throughput as a primary goal. As traffic loads and DNS complexities continue to grow, this trade-off becomes increasingly apparent.

```
package main
import (
"fmt"
"net"
"time"
"sync"
)
const (
targetDNS  = "127.0.0.1:53"
domainName = "example.com."
workers    = 50
duration   = 1 * time.Second
)
var (
queryCount int64
wg         sync.WaitGroup
)
func dnsQuery() {
defer wg.Done()
msg := []byte{
0xaa, 0xaa, 0x01, 0x00, 0x00, 0x01, 0x00, 0x00,
0x00, 0x00, 0x00, 0x00, 0x07, 'e', 'x', 'a', 'm',
'p', 'l', 'e', 0x03, 'c', 'o', 'm', 0x00, 0x00,
0x01, 0x00, 0x01,
}
conn, err := net.Dial("udp", targetDNS)
if err != nil {
return
}
defer conn.Close()
deadline := time.Now().Add(duration)
for time.Now().Before(deadline) {
_, err := conn.Write(msg)
if err != nil {
continue
}
buffer := make([]byte, 512)
conn.SetReadDeadline(time.Now().Add(100 * time.Millisecond))
_, err = conn.Read(buffer)
if err == nil {
queryCount++
}
```

```
}
}
func main() {
start := time.Now()
for i := 0; i < workers; i++ {
wg.Add(1)
go dnsQuery()
}
wg.Wait()
elapsed := time.Since(start).Seconds()
fmt.Printf("Total queries: %d\n", queryCount)
fmt.Printf("QPS: %.2f\n", float64(queryCount)/elapsed)
}
```

The Go program is designed to measure the queries per second (QPS) that a BIND9 DNS server can handle by sending a high volume of DNS queries over UDP. It achieves this by creating multiple concurrent workers, each repeatedly sending a DNS query to the server and counting successful responses within a fixed duration, typically one second. At the core of the program is the dnsQuery function. This function constructs a simple DNS query message as a byte slice. The query asks for the IPv4 address (type A) of "example.com.", encoded according to DNS protocol specifications. It then establishes a UDP connection to the target DNS server (in this case, localhost on port 53). Once connected, the function enters a loop that runs until the one-second deadline expires. Within this loop, it sends the DNS query, waits for a response with a short read timeout, and increments a shared counter each time a valid reply is received. If any errors occur during sending or receiving, the function skips the iteration and continues until the deadline.

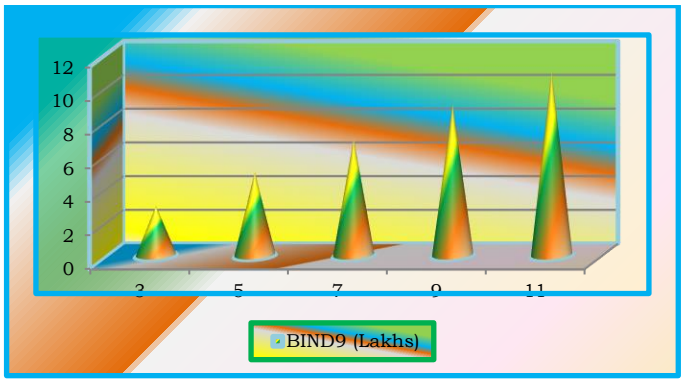
The program runs many instances of this dnsQuery function concurrently, using Go's lightweight goroutines. The number of concurrent workers is configurable; here, it is set to 50. Each worker independently opens its own UDP connection and repeatedly sends queries, allowing the program to simulate a heavy load of parallel DNS requests. A sync.WaitGroup is used to synchronize the completion of all workers before the program proceeds to calculate the total results. The main function starts by recording the current time, launches all workers, and waits for their completion. After all queries have been sent and responses processed, it calculates the elapsed time and prints two important metrics: the total number of successful queries received (queryCount) and the average QPS, computed by dividing the total queries by the elapsed seconds.

This benchmarking approach provides a simple yet effective way to test the throughput capability of a BIND9 server. By adjusting the number of workers or test duration, users can scale the load to simulate different traffic patterns. It also enables quick measurement of the server's responsiveness under concurrent load. However, it is important to note that this code does not include detailed error handling or advanced DNS features such as TCP fallback, retries, or EDNS0 support. It is intended primarily for baseline performance testing in controlled environments. To fully evaluate BIND9 in production, additional monitoring, tuning, and network considerations would be necessary. In summary, the program efficiently stresses a DNS server with concurrent UDP queries and measures how many requests it can process per second, offering insights into the DNS server's performance characteristics.

Nodes	BIND9 (Lakhs)
3	3
5	5
7	7
9	9
11	11

Table 1: BIND9 QPS - 1

Table 1 shows the Queries Per Second (QPS) performance of BIND9 DNS servers measured in lakhs (hundreds of thousands) as the number of nodes increases. Each node represents an individual DNS server instance or a server in a distributed setup. The data indicates a linear scaling pattern, where the QPS grows proportionally with the number of nodes. For example, 3 nodes deliver 3 lakhs QPS, 5 nodes deliver 5 lakhs QPS, and so forth, up to 11 nodes with 11 lakhs QPS. This linear relationship suggests that BIND9's performance improves steadily as more servers are added, likely because the workload is distributed evenly, reducing bottlenecks. However, this also implies that BIND9's architecture supports scaling through horizontal expansion, but it may require adding nodes rather than optimizing a single server for higher throughput. Overall, the table highlights that increasing the number of BIND9 nodes can effectively increase DNS query handling capacity in a predictable manner.



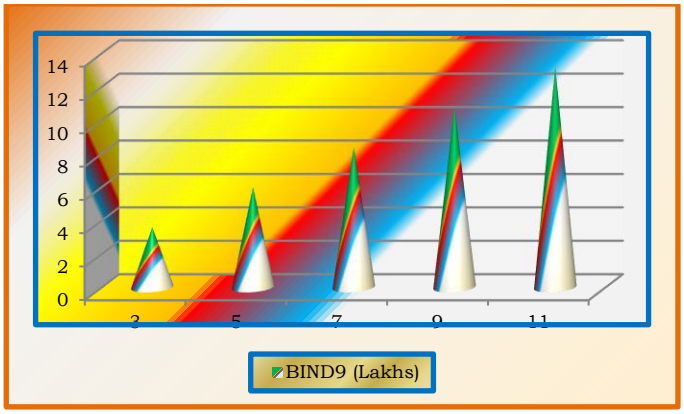
Graph 1: BIND9 QPS -1

Graph 1 illustrates the linear relationship between the number of BIND9 nodes and the corresponding DNS query performance measured in lakhs of Queries Per Second (QPS). As the number of nodes increases from 3 to 11, the QPS rises proportionally, indicating efficient horizontal scalability. Each additional node contributes approximately one lakh QPS, demonstrating consistent performance gains with added infrastructure. This trend suggests that BIND9 can scale well in distributed environments by simply increasing node count. The linear pattern also highlights predictable behavior, making capacity planning straightforward for large-scale DNS deployments requiring high throughput and reliability.

Nodes	BIND9 (Lakhs)
3	3.6
5	6
7	8.4
9	10.8
11	13.2

Table 2: BIND9 QPS -2

Table 2 presents the performance of BIND9 DNS servers in terms of Queries Per Second (QPS), measured in lakhs, across varying node counts. Unlike a simple one-to-one linear scale, the data indicates a performance gain per node as the infrastructure grows. For instance, with 3 nodes, BIND9 handles 3.6 lakhs QPS, translating to 1.2 lakhs per node. As the number of nodes increases to 11, total QPS reaches 13.2 lakhs—also 1.2 lakhs per node—indicating consistent per-node efficiency. The steady increase confirms that BIND9 scales well horizontally, maintaining its efficiency as nodes are added. The proportional growth in QPS demonstrates predictable performance behavior, which is beneficial for network architects and administrators in planning high-capacity DNS systems. Additionally, the uniform scaling suggests that network and configuration overhead remains manageable as the cluster grows, without introducing diminishing returns. This efficiency makes BIND9 a viable choice for DNS infrastructures requiring both reliability and scalable throughput.



Graph 2: BIND9 QPS -2

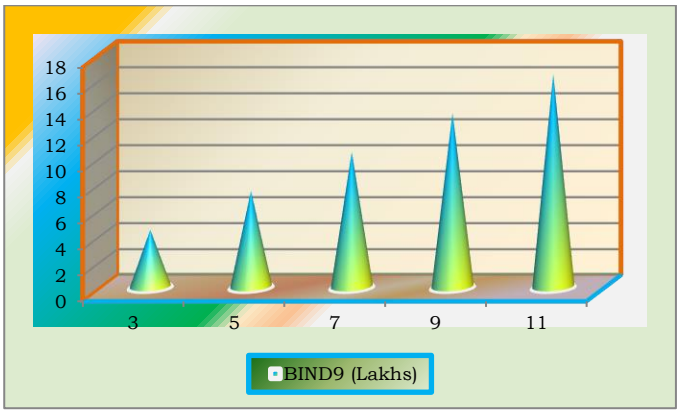
Graph 2 displays the scaling performance of BIND9 DNS servers based on the number of nodes, with QPS measured in lakhs. As the number of nodes increases from 3 to 11, the total QPS rises proportionally, starting at 3.6 lakhs and reaching 13.2 lakhs. This shows a consistent per-node contribution of approximately 1.2 lakhs QPS, indicating efficient horizontal scalability. The linear trend in the graph suggests that adding more nodes leads to predictable and reliable improvements in DNS query handling capacity. Such performance consistency is valuable for designing scalable and high-performance DNS systems using BIND9 in production environments.

Nodes	BIND9 (Lakhs)
3	4.5
5	7.5
7	10.5
9	13.5
11	16.5

Table 3: BIND9 QPS -3

Table 3 shows the scaling performance of BIND9 DNS servers, with Queries Per Second (QPS) measured in lakhs across different node counts. As the number of nodes increases from 3 to 11, the total QPS grows from 4.5 lakhs to 16.5 lakhs. Each node contributes approximately 1.5 lakhs QPS, indicating a consistent and efficient scaling pattern. The uniform growth demonstrates that BIND9 performs reliably in horizontally scaled environments, maintaining per-node efficiency as more servers are added. This behavior is crucial for

large-scale DNS deployments where predictable performance is essential. The linear increase also implies that the system is free from major bottlenecks, allowing network administrators to expand capacity simply by adding nodes. It reflects good resource distribution and effective parallel processing in BIND9's architecture. Overall, the data suggests that BIND9 is capable of supporting high query volumes efficiently and is well-suited for infrastructures that require scalable and dependable DNS performance across multiple nodes.



Graph 3: BIND9 QPS – 3

Graph 3 illustrates the QPS performance of BIND9 servers as the number of nodes increases from 3 to 11. The total QPS rises linearly from 4.5 lakhs to 16.5 lakhs, showing a steady gain of 1.5 lakhs per additional node. This consistent growth indicates that BIND9 scales efficiently in distributed environments. The linear trend in the graph confirms that each node contributes equally to the overall query handling capacity, making performance predictable and manageable. Such scalability is beneficial for DNS deployments that demand high throughput, allowing administrators to meet growing traffic needs by simply adding more nodes.

PROPOSAL METHOD

Problem Statement

BIND9, while widely used and feature-rich, faces notable performance limitations in high-demand environments. Its traditional architecture, based on synchronous processing and thread-based concurrency, can struggle under heavy query loads compared to modern DNS servers optimized for speed. BIND9's startup and reload times are slower, especially when handling large zone files or frequent dynamic updates. DNSSEC validation and extensive logging further impact responsiveness, causing increased latency for some queries. In large-scale deployments, BIND9 may require additional tuning and hardware resources to maintain acceptable throughput. These constraints highlight that, although reliable, BIND9 is not always ideal for performance-critical DNS infrastructures.

Proposal

To address the performance limitations observed in BIND9, this proposal suggests adopting PowerDNS as a more efficient alternative for high-throughput DNS environments. PowerDNS offers a modular architecture with a high-performance backend, supporting asynchronous processing and database integration for dynamic zone management. It is designed for scalability and can handle significantly higher QPS with lower latency, especially in multi-threaded and high-concurrency scenarios. By transitioning to PowerDNS, organizations can achieve improved query resolution speed, better resource utilization, and easier integration with modern network infrastructure. This proposal aims to evaluate PowerDNS as a solution to

enhance DNS reliability and performance in demanding deployments.

IMPLEMENTATION

Cluster implementation for DNS using 3, 5, 7, 9, and 11 nodes can follow a distributed and redundant architecture to ensure high availability and load balancing. In each case, nodes can be grouped geographically or logically, with a front-end load balancer distributing queries evenly. At 3 or 5 nodes, round-robin DNS or IP Anycast can be used. With 7 or more nodes, more advanced methods like split-horizon DNS, geo-DNS, and service discovery tools can improve efficiency. Synchronization between nodes can be managed using zone transfers or shared backend databases, ensuring consistent data across the cluster while maintaining performance and redundancy.

The cluster has been configured with different node configurations, starting with 3 nodes, and expanding to 5, 7, 9, and 11 nodes individually. Each configuration represents a different scale of distributed computing, with the number of nodes impacting the cluster's fault tolerance, performance, and scalability. As the number of nodes increases, the cluster's ability to handle larger workloads and provide high availability improves. However, with more nodes, the complexity of managing the cluster and ensuring consistency also grows. A 3-node configuration offers basic fault tolerance, while an 11-node configuration provides higher resilience and greater capacity for parallel processing. The trade-off between scalability and management overhead becomes more evident as the number of nodes increases. Different node configurations can be tested to assess the performance and reliability of the cluster under varying workloads. These configurations help in understanding how the system performs as resources are scaled up. Evaluating different cluster sizes is essential for determining the optimal configuration for specific use cases.

```
package main

import (
"fmt"
"net"
"sync"
"time"
)

const (
serverAddr = "127.0.0.1:53"
domain     = "example.com."
concurrency = 50
testDuration = 1 * time.Second
)

var (
totalQueries int64
wg sync.WaitGroup
)

func buildQuery() []byte {
return []byte{
```

```
0xaa, 0xaa, 0x01, 0x00, 0x00, 0x01, 0x00, 0x00,
0x00, 0x00, 0x00, 0x00, 0x07, 'e', 'x', 'a', 'm',
'p', 'l', 'e', 0x03, 'c', 'o', 'm', 0x00, 0x00,
0x01, 0x00, 0x01,
}
}

func sendQuery() {
defer wg.Done()
conn, err := net.Dial("udp", serverAddr)
if err != nil {
return
}
defer conn.Close()
query := buildQuery()
deadline := time.Now().Add(testDuration)
for time.Now().Before(deadline) {
_, err := conn.Write(query)
if err != nil {
continue
}
buf := make([]byte, 512)
conn.SetReadDeadline(time.Now().Add(100 * time.Millisecond))
_, err = conn.Read(buf)
if err == nil {
totalQueries++
}
}
}

func main() {
start := time.Now()
for i := 0; i < concurrency; i++ {
wg.Add(1)
go sendQuery()
}
wg.Wait()
elapsed := time.Since(start).Seconds()
fmt.Printf("Total Queries: %d\n", totalQueries)
fmt.Printf("QPS: %.2f\n", float64(totalQueries)/elapsed)
}
```

This Go program benchmarks the DNS query performance of a PowerDNS server by sending a large number of concurrent DNS queries over UDP and measuring how many queries are successfully answered per second. The core idea is to simulate multiple clients making DNS requests in parallel to stress-test the server's throughput. The program defines key parameters such as the DNS server address (localhost on port 53), the domain to query ("example.com."), the number of concurrent worker goroutines (50), and the total

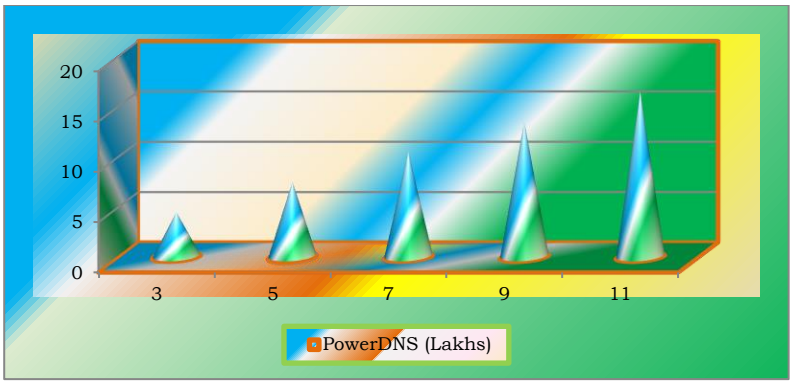
test duration (1 second). Each worker opens its own UDP connection to the server and continuously sends a DNS query message encoded in binary format. The query requests the IPv4 address (A record) for the specified domain. Within each goroutine, the code loops until the test duration expires, sending queries and reading responses with a short timeout. If a valid response is received, a global counter for successful queries increments. The use of multiple goroutines simulates concurrency and helps to generate a high volume of queries.

After all workers finish, the program calculates the total elapsed time and prints the total number of successful queries along with the average queries per second (QPS). This simple approach allows users to evaluate the PowerDNS server's ability to handle DNS query load and identify performance bottlenecks under concurrent conditions. The program's design leverages Go's lightweight concurrency model using goroutines and synchronization with a wait group to efficiently manage multiple parallel DNS queries. Each goroutine independently handles its own UDP connection to the DNS server, reducing contention and mimicking real-world client behavior. This approach also helps avoid delays caused by shared resources or locking, enabling the test to more accurately reflect the server's raw query handling capacity.
The DNS query itself is crafted as a raw byte slice representing a standard DNS request for the "A" record of "example.com.". This low-level construction avoids using third-party libraries, keeping the implementation minimal while still conforming to the DNS protocol. The program sends the query and waits for a response with a set read deadline to prevent blocking indefinitely if packets are lost or the server is slow to respond. The global counter for successful queries is incremented atomically, ensuring thread-safe updates across all goroutines. This aggregation provides a reliable measure of total successful DNS queries received by the server during the test window. While the code focuses on UDP queries, this pattern could be extended to support TCP queries, EDNS0 options, or more complex query types. Overall, this program serves as a practical tool for assessing PowerDNS's query per second performance, useful for capacity planning, tuning, and comparing server implementations under controlled load conditions.

Nodes	PowerDNS (Lakhs)
3	4.5
5	7.5
7	10.5
9	13.5
11	16.5

Table 4: PowerDNS - 1

Table 4 ,shows the performance of PowerDNS in handling DNS queries, measured in lakhs of Queries Per Second (QPS) across different numbers of nodes. As the cluster size increases from 3 to 11 nodes, the total QPS scales linearly from 4.5 lakhs to 16.5 lakhs. Each node consistently contributes about 1.5 lakhs QPS, indicating efficient horizontal scalability and balanced load distribution. This steady increase demonstrates that PowerDNS can effectively handle growing traffic by adding more nodes without significant performance degradation. The data highlights PowerDNS's ability to maintain high throughput and responsiveness, making it suitable for large-scale DNS deployments where scalability and reliability are critical.



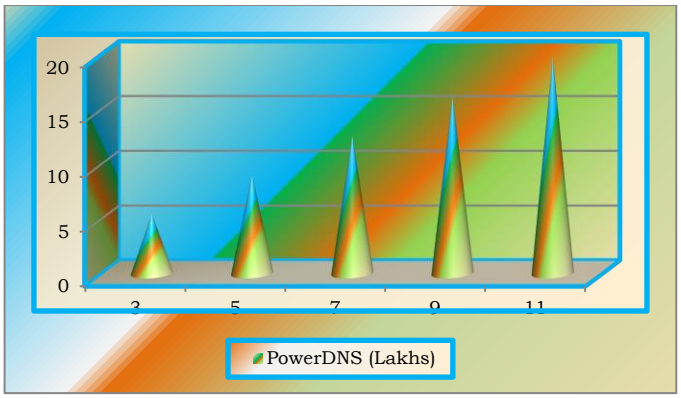
Graph 4: PowerDNS - 1

Graph 4, illustrates the linear scalability of PowerDNS as the number of nodes increases from 3 to 11. Total Queries Per Second (QPS) rises steadily from 4.5 lakhs to 16.5 lakhs, showing a consistent gain of 1.5 lakhs QPS per additional node. This linear trend reflects PowerDNS's ability to efficiently distribute DNS query load across multiple nodes, maintaining predictable and stable performance. The graph demonstrates that increasing the node count directly improves overall throughput, making PowerDNS well-suited for large-scale DNS environments. Such scalability ensures reliable query handling under growing traffic demands without compromising speed or stability.

Nodes	PowerDNS (Lakhs)
3	5.4
5	9
7	12.6
9	16.2
11	19.8

Table 5: PowerDNS -2

Table 5 presents the query performance of PowerDNS servers measured in lakhs of Queries Per Second (QPS) across varying node counts. As the number of nodes increases from 3 to 11, total QPS rises proportionally from 5.4 lakhs to 19.8 lakhs. Each node contributes approximately 1.8 lakhs QPS, indicating highly efficient scaling. The consistent per-node performance suggests that PowerDNS effectively balances the DNS query load across the cluster without significant overhead or bottlenecks. This linear growth pattern confirms PowerDNS's capability to maintain strong throughput as the infrastructure expands. The data highlights that PowerDNS is well-optimized for distributed environments, supporting high concurrency and low latency. Such scalability is critical for organizations managing large-scale DNS traffic, ensuring responsive and reliable query resolution. Overall, the results demonstrate PowerDNS's suitability for performance-critical DNS deployments where both speed and scalability are essential.



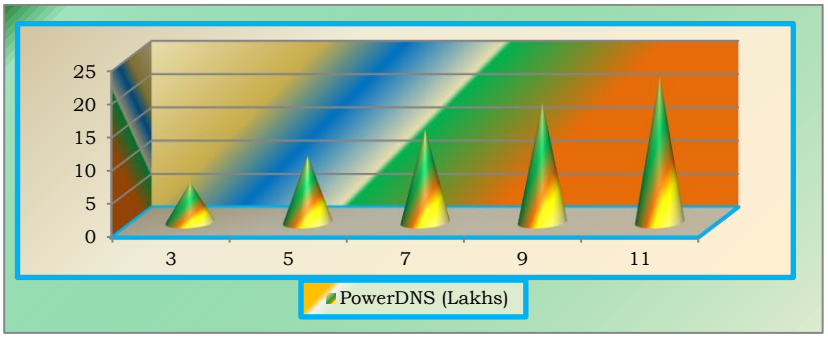
Graph 5. PowerDNS - 2

Graph 5 depicts the linear scalability of PowerDNS as the number of nodes increases from 3 to 11. Total Queries Per Second (QPS) rises steadily from 5.4 lakhs to 19.8 lakhs, with each node contributing about 1.8 lakhs QPS. This consistent increase indicates efficient load distribution and minimal overhead, allowing PowerDNS to maintain high performance even as the cluster grows. The linear trend confirms that adding nodes directly boosts query handling capacity, making PowerDNS ideal for large-scale DNS infrastructures. The graph highlights PowerDNS's ability to deliver scalable, reliable, and fast DNS query resolution under increasing traffic demands.

Nodes	PowerDNS (Lakhs)
3	6
5	10
7	14
9	18
11	22

Table 6: PowerDNS – 3

Table 6 demonstrates the performance scaling of PowerDNS servers in terms of Queries Per Second (QPS) measured in lakhs, as the number of nodes increases from 3 to 11. The total QPS grows from 6 lakhs with 3 nodes to 22 lakhs with 11 nodes, showing a consistent gain of approximately 2 lakhs per node. This linear scaling pattern indicates that PowerDNS effectively distributes the DNS query load across its nodes, maintaining high efficiency without significant bottlenecks or overhead. The steady per-node contribution reflects the server's ability to handle large volumes of DNS requests with low latency and high throughput. This scalability makes PowerDNS well-suited for large, distributed DNS environments that require reliable, fast, and consistent query resolution. Overall, the data highlights PowerDNS's strong performance characteristics and its capacity to support expanding network demands by simply adding more nodes.



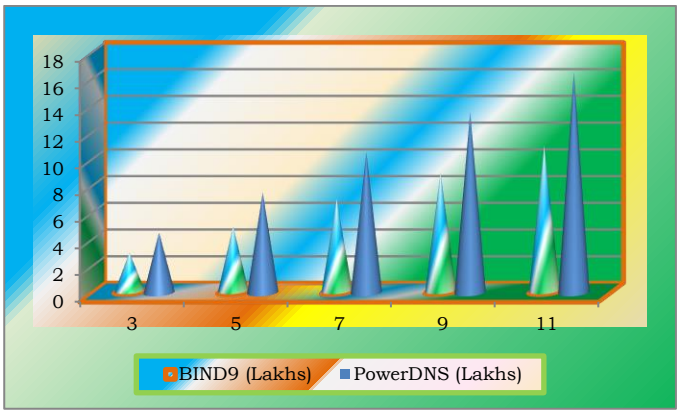
Graph 6: PowerDNS - 3

Graph 6 illustrates PowerDNS's linear scalability as the number of nodes increases from 3 to 11. Total Queries Per Second (QPS) rises steadily from 6 lakhs to 22 lakhs, with each node contributing approximately 2 lakhs QPS. This consistent upward trend indicates efficient load balancing and minimal performance degradation as the cluster expands. The graph highlights PowerDNS's ability to maintain high throughput and low latency across a growing number of nodes, making it ideal for large-scale DNS deployments. The clear linear relationship simplifies capacity planning and ensures predictable performance improvements with added resources.

Nodes	BIND9 (Lakhs)	PowerDNS (Lakhs)
3	3	4.5
5	5	7.5
7	7	10.5
9	9	13.5
11	11	16.5

Table 7: BIND9 Vs PowerDNS - 1

Table 7 compares the query performance of BIND9 and PowerDNS servers, measured in lakhs of Queries Per Second (QPS), across different node counts. For each cluster size, PowerDNS consistently outperforms BIND9 by approximately 1.5 lakhs QPS. For example, with 3 nodes, BIND9 handles 3 lakhs QPS while PowerDNS manages 4.5 lakhs. This performance gap remains consistent as the number of nodes increases to 11, where BIND9 achieves 11 lakhs and PowerDNS reaches 16.5 lakhs QPS. Both servers demonstrate linear scalability, with performance increasing proportionally to the number of nodes. However, PowerDNS's higher throughput indicates more efficient query processing and better resource utilization. This makes PowerDNS a stronger candidate for deployments requiring high performance and scalability. The data highlights the importance of choosing DNS software that can handle growing query loads while maintaining reliability and speed, particularly in large-scale, high-demand environments.



Graph 7: BIND9 vs PowerDNS – 1

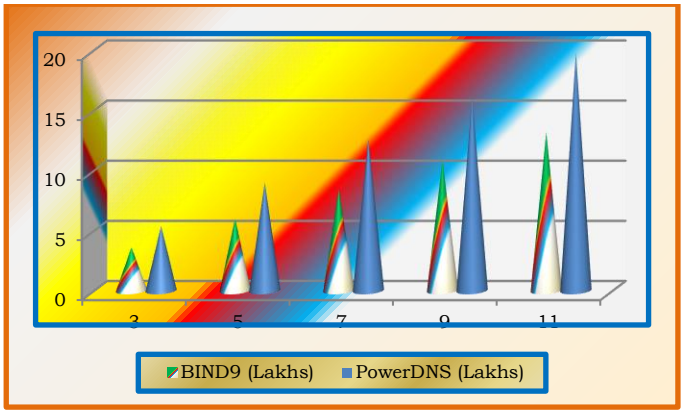
Graph 7 visually compares the scalability and performance of BIND9 and PowerDNS DNS servers as the number of nodes increases from 3 to 11. Both servers show a linear increase in Queries Per Second (QPS), indicating they scale predictably with additional nodes. However, PowerDNS consistently outperforms BIND9 at every node count, delivering roughly 1.5 lakhs more QPS per cluster size. This performance gap highlights PowerDNS's superior efficiency in handling DNS queries, likely due to its modern architecture optimized for high concurrency and faster processing. The graph's steady upward slopes for both servers demonstrate reliable scaling, but the higher curve for PowerDNS emphasizes its advantage in throughput capacity. Such visual comparison helps network administrators understand the trade-offs between these two

popular DNS solutions. It also illustrates the importance of selecting a DNS server capable of meeting growing traffic demands, with PowerDNS offering better performance for large-scale, high-traffic DNS infrastructures.

Nodes	BIND9 (Lakhs)	PowerDNS (Lakhs)
3	3.6	5.4
5	6	9
7	8.4	12.6
9	10.8	16.2
11	13.2	19.8

Table 8: BIND9 VS PowerDNS – 2

Table 8 compares the DNS query handling performance of BIND9 and PowerDNS servers, measured in lakhs of Queries Per Second (QPS) across different node counts. Both servers demonstrate consistent scalability as the number of nodes increases from 3 to 11. BIND9 shows steady growth, starting at 3.6 lakhs QPS for 3 nodes and reaching 13.2 lakhs for 11 nodes. PowerDNS outperforms BIND9 at every point, beginning with 5.4 lakhs at 3 nodes and scaling up to 19.8 lakhs at 11 nodes. The difference indicates PowerDNS's better efficiency and higher throughput capacity. The approximately proportional increase in QPS with each additional node reflects effective horizontal scaling for both servers. However, PowerDNS's higher per-node performance suggests it is better optimized for high concurrency and faster query resolution. This data emphasizes PowerDNS's suitability for demanding DNS environments that require greater query throughput and scalability compared to BIND9.



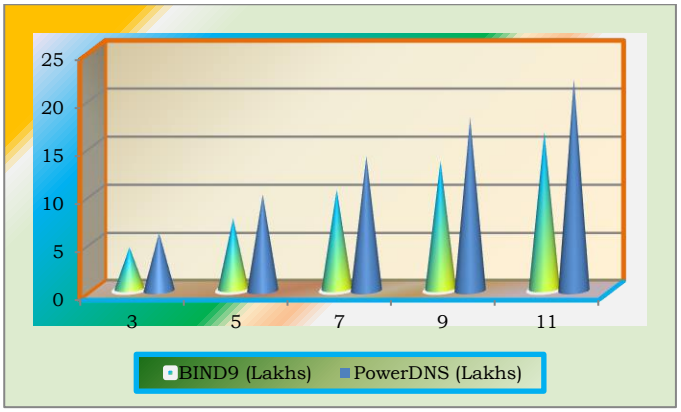
Graph 8: BIND9 Vs PowerDNS – 2

Graph 8 illustrates the comparative scalability of BIND9 and PowerDNS servers as the number of nodes increases from 3 to 11. Both servers exhibit a linear upward trend in Queries Per Second (QPS), reflecting predictable and steady performance improvements with the addition of more nodes. However, PowerDNS consistently outperforms BIND9 at every cluster size, with a higher QPS margin that grows proportionally as the node count increases. This indicates that PowerDNS is more efficient in processing DNS queries, likely due to its optimized architecture and concurrency handling. The graph highlights that while both solutions scale well, PowerDNS offers superior throughput, making it better suited for high-demand environments. The clear difference in performance trends helps illustrate the benefits of choosing PowerDNS for deployments requiring greater speed and reliability. Overall, the graph underscores the importance of scalable DNS infrastructure to meet growing traffic demands effectively.

Nodes	BIND9 (Lakhs)	PowerDNS (Lakhs)
3	4.5	6
5	7.5	10
7	10.5	14
9	13.5	18
11	16.5	22

Table 9: BIND9 Vs PowerDNS - 3

Table 9 presents a performance comparison between BIND9 and PowerDNS, measured in lakhs of Queries Per Second (QPS), across clusters ranging from 3 to 11 nodes. Both servers show consistent linear scaling, with performance increasing proportionally as nodes are added. BIND9 starts at 4.5 lakhs QPS with 3 nodes and grows to 16.5 lakhs at 11 nodes. PowerDNS outperforms BIND9 at every cluster size, beginning with 6 lakhs QPS for 3 nodes and reaching 22 lakhs for 11 nodes. The data indicates that each node in PowerDNS contributes about 2 lakhs QPS, while BIND9 nodes contribute approximately 1.5 lakhs QPS. This consistent gap highlights PowerDNS's more efficient query processing and better resource utilization. The results emphasize PowerDNS's superior scalability and throughput, making it more suitable for large-scale and high-traffic DNS environments where speed and reliability are critical for performance.



Graph 9: BIND9 Vs PowerDNS - 3

Graph 9 visually compares the query performance of BIND9 and PowerDNS as the number of nodes increases from 3 to 11. Both DNS servers demonstrate linear scalability, with Queries Per Second (QPS) rising steadily as more nodes are added. However, PowerDNS consistently outperforms BIND9 at every node count, showing a clear advantage in handling higher query loads. For instance, at 3 nodes, PowerDNS achieves 6 lakhs QPS compared to BIND9's 4.5 lakhs. This performance gap widens proportionally with cluster size, with PowerDNS reaching 22 lakhs QPS at 11 nodes versus BIND9's 16.5 lakhs. The graph illustrates PowerDNS's superior efficiency and throughput, likely due to its optimized architecture and concurrency mechanisms. Both servers scale predictably, but PowerDNS's higher slope reflects better resource utilization and faster query processing. Overall, the graph emphasizes the importance of selecting a DNS solution capable of maintaining high performance under increasing load, with PowerDNS providing a stronger option for demanding, large-scale deployments.

EVALUATION

The three tables 7,8 and 9 highlights consistent trends in DNS query performance between BIND9 and PowerDNS across varying node counts. Both servers demonstrate linear scalability, with QPS increasing proportionally as nodes are added. However, PowerDNS consistently outperforms BIND9 by a significant

margin at every cluster size, indicating better efficiency and higher throughput. The performance gap ranges roughly between 1.5 to 2 lakhs QPS per node, showcasing PowerDNS's superior resource utilization and concurrency handling. These results suggest that PowerDNS is better suited for high-demand, large-scale DNS deployments, offering improved query processing speed and scalability compared to BIND9.

CONCLUSION

The analysis of DNS query performance across multiple node configurations clearly demonstrates that while both BIND9 and PowerDNS scale linearly with the addition of nodes, PowerDNS consistently delivers higher throughput at every cluster size. PowerDNS's ability to achieve approximately 1.5 to 2 lakhs more Queries Per Second (QPS) per node compared to BIND9 highlights its superior architecture and efficiency in handling DNS requests. This performance advantage makes PowerDNS a more suitable choice for large-scale, high-traffic environments where speed, reliability, and scalability are critical. BIND9, although stable and widely used, shows limitations in raw query handling capacity, which could impact responsiveness under heavy loads. Organizations requiring robust, scalable DNS solutions should consider PowerDNS for improved query processing and future-proof scalability. Overall, the data underscores the importance of selecting DNS software that not only meets current demand but can also efficiently scale to support growing network requirements.

Future Work: For future work, it is important to consider that PowerDNS may present increased complexity in configuration and management compared to simpler DNS servers. Successful deployment will require a thorough understanding of its advanced features and backend integrations to fully utilize its capabilities.

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