Design of seamless namespace management scheme for overlay networks

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ABSTRACT

The Internet's evolution has led to various network models catering to unique service requirements. Content-centric networking (CCN) and named data networking (NDN) have been developed to facilitate scalable content distribution. Seamless mobility protocols address limitations in network accessibility and communication efficiency on the Internet. These models can be considered virtual overlay networks. While conventional overlay networks are designed for specific services, their identification mechanisms may not be compatible. This paper proposes a seamless namespace management scheme for overlay networks, specifically focusing on the CYber PHysical Overlay Network over Internet Communication (CYPHONIC) protocol. The scheme introduces a virtual Fully Qualified Domain Name (FQDN)-based namespace for overlay networks to enable interoperability with the current Internet system. The proposed function hooks query FQDN information and access a cloud service to establish virtual communication. The demonstration of the implementation showcases the practical DNS query search performance, validating the proposed concept.

1. INTRODUCTION

The spread of new service models on the Internet has caused several types of unique network models for their specific usage. Peer-to-peer protocols have been designed for direct communication over the Internet to exchange information among hosts [1], [2]. As the purpose of the information exchange, content-centric networking (CCN) and named data networking (NDN) has emerged as a component of the following Internet architecture to support scalable content distribution [3]–[7]. Seamless mobility protocols also conceal the limitations such as network accessibility and ineffective communication on the Internet [8], [9]. Since these network models make their network environment on the Internet, they can be regarded as virtual overlay networks [10].

The traditional Internet works with Internet Protocol (IP) based communication. Therefore, the overlay networks typically operate over the current IP-based networks. Additionally, traditional Internet Protocol (IP) based communication is still a primary stream. Therefore, almost all hosts require simultaneous communication to overlay networks and the current Internet when overlay networks are available on the hosts.

Conventional overlay networks are typically designed to cater to specific services, incorporating mechanisms specific to their purpose. This often includes employing unique identification mechanisms within the overlay network that may not be compatible with other overlay network mechanisms.

In general, most applications utilize IP-based communication for establishing connections. However, IP addresses are not user-friendly for typical Internet users; therefore, naming hosts becomes essential for service identification. The current Internet utilizes the Domain Name System (DNS) to manage hostnames in the Fully Qualified Domain Name (FQDN) format. Consequently, most general applications use FQDN to initiate communication with designated hosts. When overlay networks are used for general applications, the naming format of each network host becomes crucial for ensuring interoperability with the current Internet system.

This paper proposes a seamless namespace management scheme for overlay networks, building upon our previously developed CYber PHysical Overlay Network over Internet Communication (CYPHONIC) protocol [11]. Our practical implementation focuses on supporting hosts that handle both the overlay network and current Internet services. The utilization of FQDN-based naming is vital to meet the requirements of general applications. To achieve this, we introduce a naming management function into hosts that intercept query information for FQDN. This function provides a virtual FQDN-based namespace for overlay networks independent of the current FQDN namespace. By accessing our cloud service, the scheme identifies a virtual FQDN and triggers the overlay network function, enabling virtual communication. As the cloud service supports any type of FQDN, separate from the real FQDN namespace, our proposed scheme ensures

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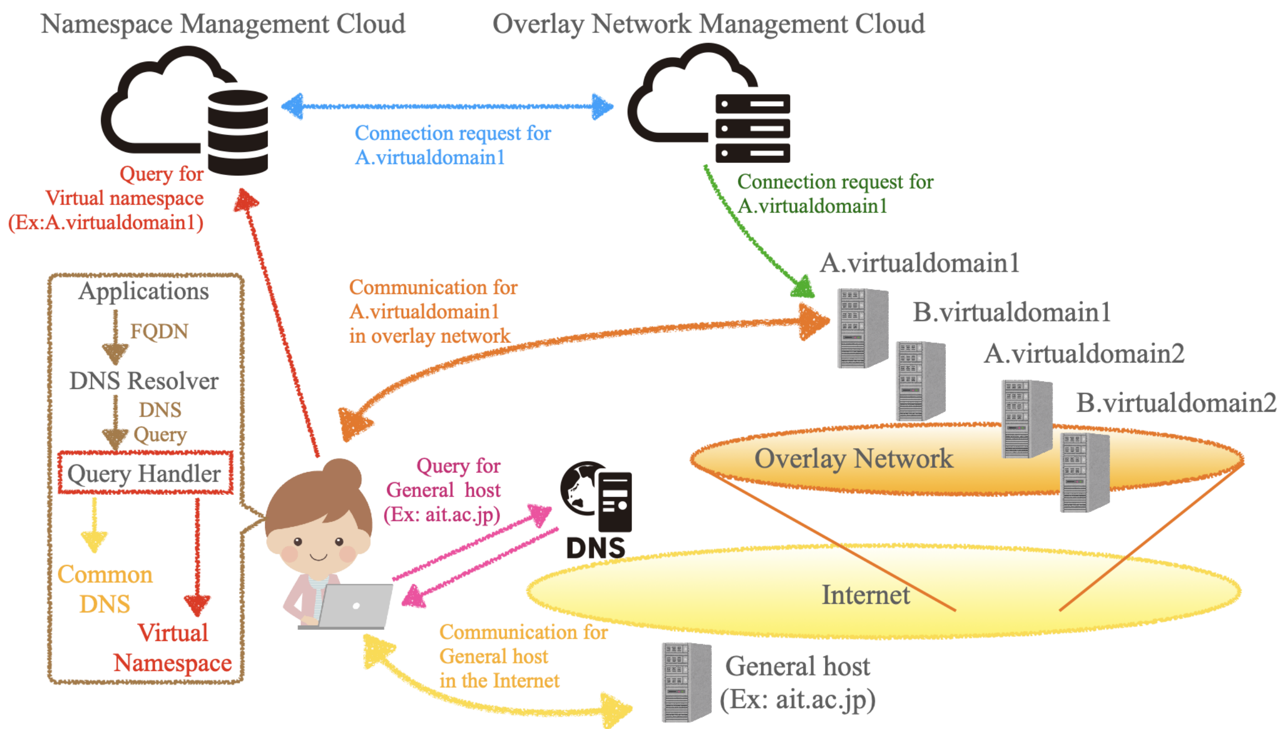

Fig. 1. Overview of seamless namespace management scheme

compatibility with general applications. Additionally, the scheme efficiently forwards DNS queries for general hosts to the current DNS service, facilitating seamless access to both the existing Internet and overlay networks based on FQDN-based information. To validate our approach, we have developed a host implementation of the proposed scheme for our overlay network and conducted a demonstration to showcase the proof of concepts and practical DNS query search performance.

2. INTEROPERABLE NAMESPACE MANAGEMENT

This paper aims to achieve a seamless namespace integration between the common namespace based on traditional DNS and the virtual namespace based on the overlay network. To accomplish this, a unique mechanism is designed to handle DNS processing on a host since applications typically initiate communication using FQDNs. However, modifying the kernel code for DNS resolution can lead to maintenance difficulties. To avoid this, the proposed scheme introduces a user-space query handler to intercept DNS processing.

2.1. Overview

Figure 1 overviews the proposed seamless namespace management scheme. While the implementation example assumes Linux as the underlying OS, it can be applied to other operating systems like Windows and macOS.

In the Linux environment, the DNS resolver manages all FQDN information from applications and creates DNS queries to inquire about FQDN information from designated DNS servers. The proposed scheme intercepts this process by implementing a query handler on the user space, which allows handling both the common and virtual namespaces. Since the DNS resolver operates in the kernel space, modifying it would require changes to the kernel code, resulting in complex maintenance. Instead, the proposed scheme introduces the query handler, acting as a local DNS, to intercept the FQDN resolution process in the user space.

The query handler is designed to handle all DNS queries from the DNS resolver by adjusting the configuration of the DNS resolver. It identifies whether a target FQDN is managed under the overlay network by accessing the cloud of the overlay network. As the cloud can handle any FQDN type independently of the traditional DNS namespace on the Internet, the proposed scheme can manage any hostname and domain, thus extending the namespace using a virtual FQDN based on a virtual hostname and a virtual domain.

However, it is also crucial to ensure interoperability with the traditional Internet. For this purpose, a straightforward scheme is implemented using timeout operations for multiple DNS servers. The special DNS handler for the overlay network is the primary DNS server for the

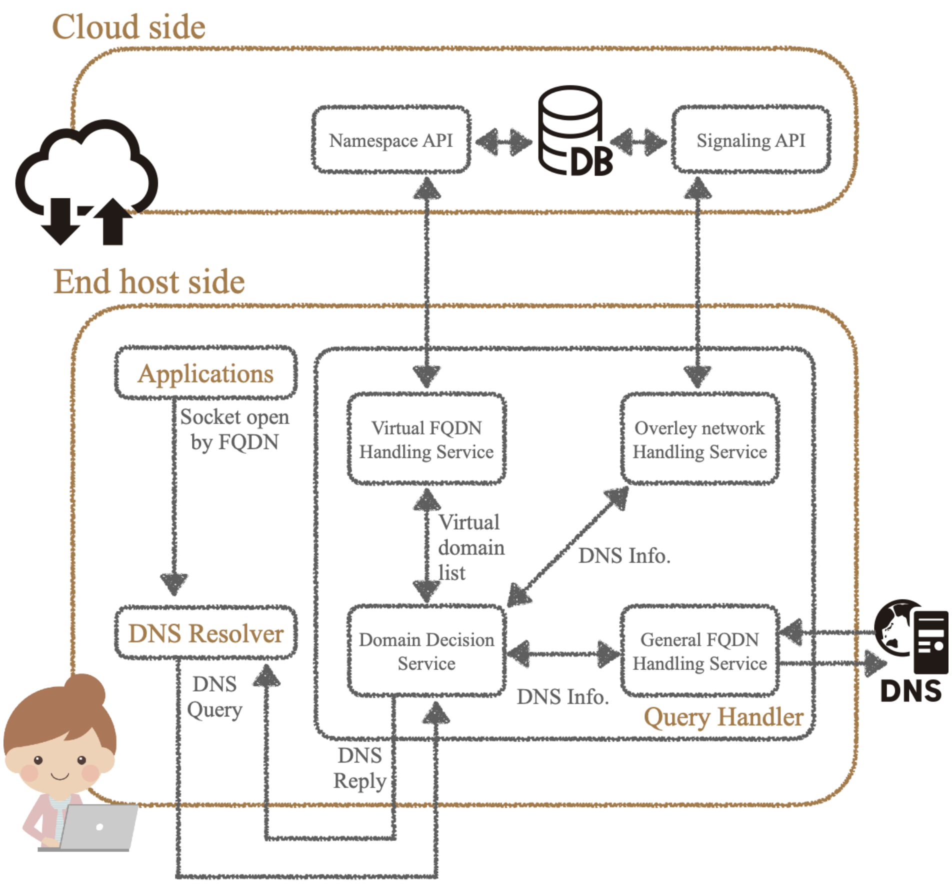

Fig. 2. System model

DNS resolver, while the general DNS server for the Internet is the secondary DNS server. When applications request FQDNs, all queries are sent to the primary DNS server. The primary DNS server responds to the query if the requested FQDN is managed under the virtual namespace. In contrast, the primary DNS server ignores the query if the FQDN belongs to the general DNS namespace. Subsequently, the DNS resolver detects a timeout and initiates a new inquiry to the secondary DNS server, which handles general DNS queries. This process allows for multiple accesses to the traditional Internet and the overlay network. However, applications may experience delays due to waiting for the timeout when accessing hosts on the general Internet, potentially degrading user experience for most applications, except for those utilizing the overlay network.

The proposed scheme involves a special query handler for DNS queries within a host. Since most applications use FQDNs to identify the hosts for communication, all DNS queries from the DNS resolver on the host are routed to the query handler. This query handler performs several functions, including management of virtual domain lists, interpreting DNS queries, forwarding DNS queries, triggering overlay network connections, and reconstructing DNS replies. By comparing the requested FQDN with elements in the virtual domain lists, the query handler determines whether the corresponding FQDN is valid on the Internet or the overlay network. If the FQDN is available on the overlay network, it triggers the overlay network function to establish a connection through the Namespace Management Cloud and the Overlay Network Management Cloud. In cases where the FQDN belongs to a host on the Internet, the query handler forwards the DNS query to the designated DNS server. In this manner, the proposed scheme seamlessly extends the virtual namespace for overlay networks while ensuring interoperability with the traditional Internet.

2.2. System Model

Figure 2 presents the system model for the proposed seamless namespace management scheme, which has been prototyped for the Linux system. Since all applications on Linux utilize the DNS resolver to open network sockets using FQDN, the system must handle DNS messages from the DNS resolver.

The DNS resolver typically accesses a configured DNS

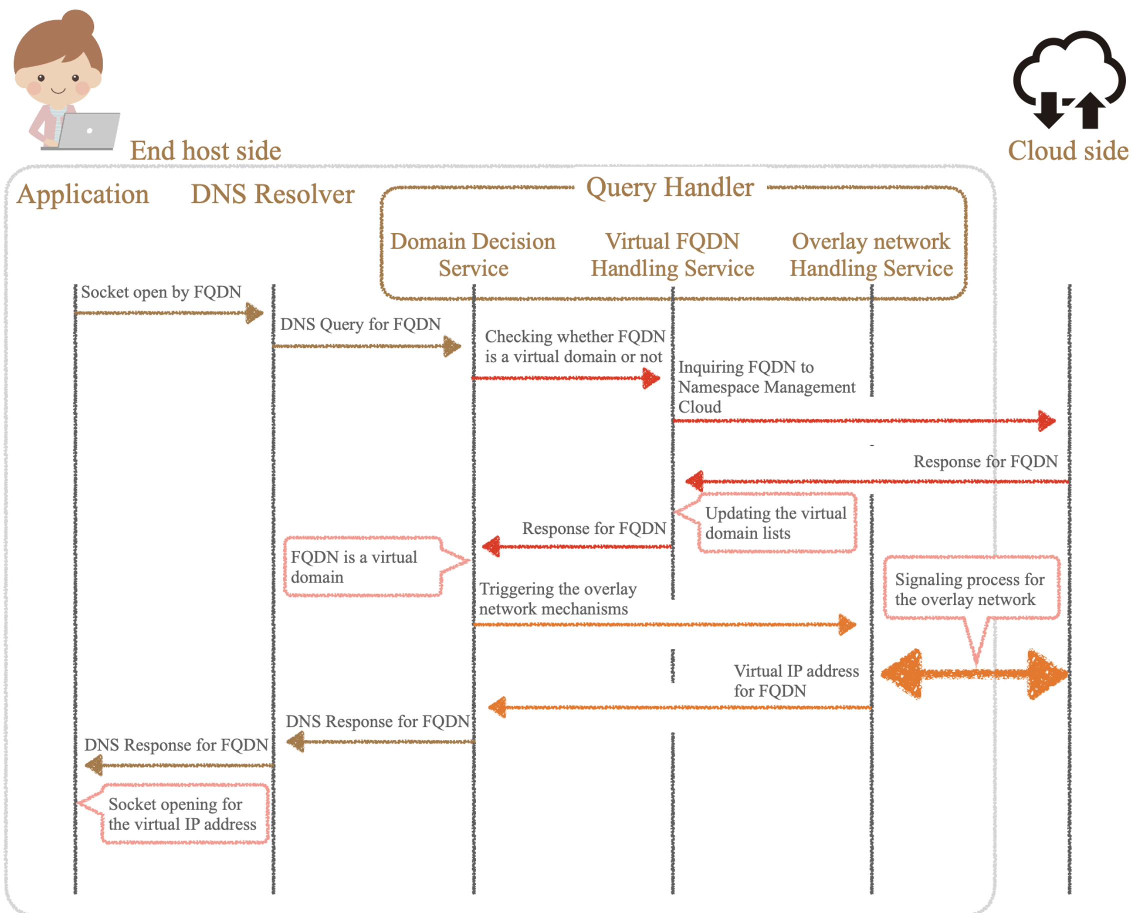

Fig. 3. Signaling for virtual FQDN

server to obtain DNS information based on FQDN. In the proposed scheme, a DNS server function called "Query Handler" is prepared on the local system to capture DNS messages from the DNS resolver. Query Handler receives all DNS messages from the host OS and handles them based on the FQDN information. Initially, all domains for FQDN are managed by public DNS information. However, the proposed system differentiates virtual domains and public domains in Query Handler by accessing our cloud service. Consequently, the proposed scheme allows defining any FQDN on any virtual domains for overlay networks while ensuring interoperability with FQDN-based access. Applications can seamlessly access hosts on the Internet and overlay networks using FQDN, enabling overlay networks to support conventional applications without any modifications. The following are the details of each element in the query handler:

- Domain Decision Service
  The domain decision service is the initial process for requested FQDNs from the DNS resolver. It differentiates between public FQDNs and virtual FQDNs by checking whether the virtual domain lists include the requested FQDN. The virtual FQDNs are managed under the Namespace Management Cloud. Therefore, the query handler updates the virtual domain lists by requesting the virtual FQDN handling service to inquire about the latest lists on the cloud. When the domain decision service determines that the requested FQDN is virtual, it requests the overlay network handling service to establish a connection to the requested FQDN host. The overlay network handling service provides the IP address of the requested FQDN host when the connection is established over the overlay network and includes it in the DNS response. For non-virtual FQDNs, the domain decision service forwards the DNS query to the general FQDN handling service to inquire about the requested FQDN from the public DNS server, facilitating seamless namespace management between public and virtual domain spaces.
- Virtual FQDN Handling Service
  The virtual FQDN handling service manages the virtual domain lists. To reduce response delay, it caches the latest inquiry results of virtual domains

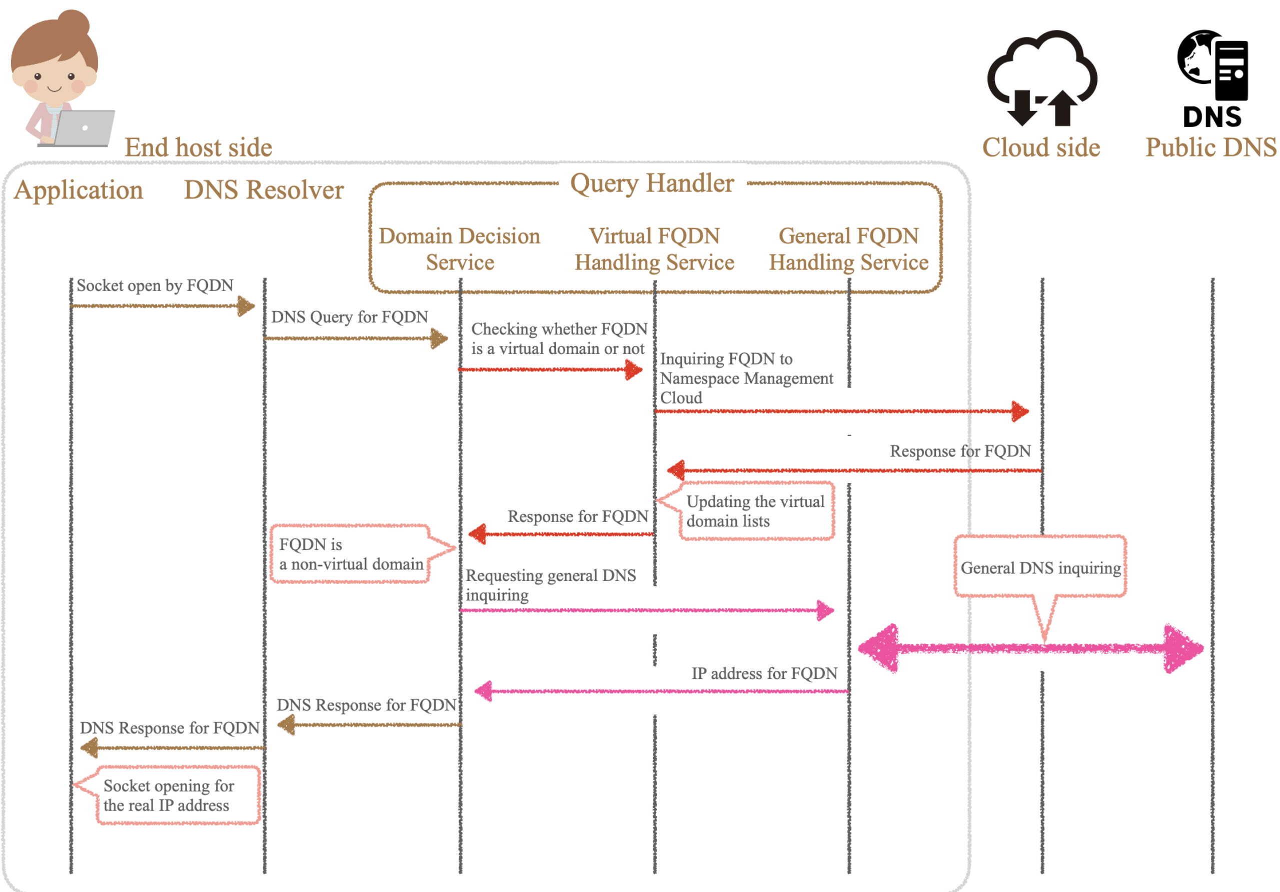

Fig. 4. Signaling for non-virtual FQDN

into the virtual domain lists. When the requested FQDN is not included in the virtual domain lists, the virtual FQDN handling service inquires about the domain of the requested FQDN to the cloud and updates the virtual domain lists. It also responds to the domain decision service regarding whether the requested FQDN is included in the virtual domain or not.

- Overlay Network Handling Service
  The overlay network handling service manages the overlay network functions, with CYPHONIC assumed as the virtual IP-based overlay network in this paper. CYPHONIC facilitates secure end-to-end communication for the overlay network by collaborating with the CYPHONIC cloud service. After establishing end-to-end communication, the client service for CYPHONIC obtains a virtual IP address of the destination node. The overlay network handling service includes the virtual IP address of the destination node corresponding to the requested FQDN in the DNS response.
- General FQDN Handling Service
  The general FQDN handling service is responsible for inquiring about public domains. As it sends regular DNS queries to public DNS servers, the proposed scheme maintains compatibility with the general DNS service even when the Query handler intercepts DNS queries from the DNS resolver.

2.3. Signaling for virtual FQDNs

Figure 3 illustrates the comprehensive signaling process for virtual FQDNs managed within our extended namespace. The sequence for obtaining the corresponding IP address for a virtual FQDN is outlined as follows:

- The application initiates communication with the virtual FQDN node by establishing a network socket associated with the virtual FQDN.
- The DNS resolver intercepts the application's request to open a network socket. It also queries the requested FQDN to the designated DNS server, our Query Handler, in the proposed scheme.
- Since Query Handler works as a traditional DNS server, it obtained the requested FQDN in the DNS query message. It also determines the virtual namespace responsible for managing the requested FQDN.
- In cases where the cache table for the respective

virtual namespace does not contain the requested FQDN, the Query Handler directs a query regarding the FQDN to the cloud service.
- When the cloud service manages the requested FQDN, Query Handler updates the cache table to insert the requested FQDN and triggers the overlay network mechanisms.
- Our paper employs CYPHONIC as the designated overlay network solution. The procedures outlined by CYPHONIC facilitate the establishment of a secure tunnel for communication, enabling the realization of an overlay network. Moreover, CYPHONIC provides a virtual IP address corresponding to the initially requested FQDN.
- The Query Handler constructs a DNS response message containing the virtual IP address, which is then transmitted as a reply to the DNS resolver.
- Subsequently, the DNS resolver furnishes the application with the virtual IP address in response to the original request for the desired FQDN.
- The application opens the socket with the provided virtual IP address and starts the communication. Since the packets with the virtual IP address destination are routed to the overlay network, the application communicates over the overlay network.

2.4. Signaling for non-virtual FQDNs

Fig. 4 depicts the comprehensive signaling process for non-virtual FQDNs within the traditional public namespace. The sequence for acquiring the corresponding IP address for a non-virtual FQDN is delineated as follows:

- The application initiates communication using the same approach as in the case of virtual FQDNs.
- The DNS resolver directs a query for the requested FQDN to our designated DNS server, referred to as the Query Handler, as outlined in the proposed scheme.
- The Query Handler determines the virtual namespace responsible for managing the requested FQDN. In situations where the requested FQDN is associated with the public namespace, the Query Handler directs the query for the requested FQDN to the traditional DNS server.
- Upon receiving a response from the DNS server, the Query Handler relays this response to the DNS resolver.
- Consequently, the DNS resolver supplies the IP address in response to the initial request for the desired FQDN.
- The application establishes a socket using the provided IP address, initiating communication in a standard manner.

TABLE I
Specifications of the measuring devices

CYPHONIC cloud: AS, NMS, TRS on Virtual hosts	
OS	22.04 (Jammy Jellyfish)
CPU	Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz 2 cores, 2 threads
Memory	2GB RAM
CYPHONIC node on Virtual host	
Host OS	Mac OS Ventura
Host CPU	Intel(R) Core(TM) i5 CPU @ 1.6GHz
Host Memory	8GB RAM

TABLE II
Measuring processing time

Standard procedure	6.0ms
Proposed(Non-Virtual FQDNs)	10.5ms
Proposed(Virtual FQDNs)	3.7ms

3. EVALUATION

We have developed a prototype implementation for foundational evaluation purposes. Given that the current implementation of CYPHONIC utilizes the Golang programming language for its mechanisms, our prototype also adopts Golang. To facilitate DNS functions, we have employed the CoreDNS library, streamlining the handling of DNS messages.

For the evaluation phase, we conducted measurements across three scenarios: the standard procedure, the proposed approach for non-virtual FQDNs, and the suggested method for virtual FQDNs. Table I details the machine specifications relevant to the evaluation. Notably, all services operate within dockerized virtual environments.

Table II presents the outcomes of our measurements about processing times for local DNS operations. The findings indicate that standard DNS processing entails a substantial time frame. Furthermore, the procedure proposed for non-virtual FQDNs similarly involves standard DNS processing, thereby prolonging processing times. Conversely, the proposed procedure for virtual FQDNs circumvents traditional DNS protocols and instead adopts an original virtual DNS approach tailored for overlay networks. Consequently, this adaptation reduces local processing times, eliminating the customary overhead associated with standard DNS processing.

4. CONCLUSIONS

This paper has proposed a seamless namespace management scheme for overlay networks. The proposed design introduces our naming management function into a host to hook query information for FQDN. The proposed function provides a virtual FQDN-based-name space for overlay networks independent of the current FQDN namespace. Therefore, it can manage a virtual FQDN available over the overlay networks. The prototype implementation can support Linux OS systems to realize the proposed naming management function by installing a special query handler.

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