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Original article

Hierarchical IPv6 Network Design Using SLAAC and DHCPv6 for Enterprise Environments

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Abstract
The increasing number of networked devices and the limitations of IPv4, such as limited assignable addresses, complex subnetting structure, and inefficient employment of NAT, among others. It is because of these shortcomings of IPv4 that have led to a greater adoption of Internet Protocol version 6 (IPv6) as a scalable and future-ready networking solution. This project outlines the design and execution of a hierarchical IPv6 addressing scheme for a multi-location enterprise network. The design employs a structured subnetting approach, assigning a /48 IPv6 prefix to each site, a /56 prefix to each building, and a /64 prefix to individual subnets. This method ensures efficient use of addresses, scalability, and easier network management. IPv6 Stateless Address Autoconfiguration (SLAAC) is utilized, enabling end devices to dynamically generate their own IPv6 addresses. Additionally, DHCPv6 is incorporated to provide extra network parameters like DNS server information and domain names. This combined approach merges the ease of SLAAC with the administrative oversight provided by DHCPv6. The network architecture is implemented and tested using Cisco Packet Tracer and GNS3 software, featuring multiple routers, switches, and end devices spread across various sites and buildings. IPv6 routing is managed through OSPFv3 to ensure effective and dynamic communication between sites. The findings indicate that the proposed hierarchical IPv6 design improves network scalability, supports efficient address allocation, and facilitates seamless connectivity across different locations. This work underscores the practicality and effectiveness of structured IPv6 subnetting alongside SLAAC and DHCPv6 for contemporary enterprise network setups.
Keywords. IPv4, NAT, Internet Protocol Version 6 (IPv6), Stateless Address Autoconfiguration (SLAAC), DHCPv6.

Introduction

With the rapid development of the Internet, the Internet Assigned Numbers Authority (IANA) exhausted all the IPv4 addresses in Feb 2011 [1]. Yet, the new Internet technologies, such as IOT, bring with them a continuous demand for the allocation of IP addresses. The swift rise in connected devices has created notable challenges for Internet Protocol version 4 (IPv4), especially regarding address depletion, scalability, and network management. Consequently, Internet Protocol version 6 (IPv6) has been developed as the successor to IPv4, providing a significantly larger address space, better routing efficiency, enhanced security features, and built-in automatic address configuration support [2-4]. These benefits make IPv6 crucial for large and geographically dispersed organizations. In organizations with multiple locations, network design must tackle issues such as scalability, effective address allocation, simplified routing, and ease of management. A hierarchical IPv6 addressing model is vital for addressing these needs by structuring the address space logically and systematically [3]. This hierarchical approach allows network administrators to aggregate routes effectively, minimize routing table sizes, and maintain clear distinctions between various organizational levels, including sites, buildings, and individual subnets [3].

The transition from Internet Protocol version 4 (IPv4) to Internet Protocol version 6 (IPv6) has been widely studied in the literature due to the rapid depletion of IPv4 addresses and the increasing need for scalable network systems [2,3]. IPv6 introduces a 128-bit address space, providing an almost unlimited number of addresses and enabling more efficient hierarchical network structures compared to IPv4 [2]. Researchers emphasize that IPv6 was specifically designed to support large-scale multi-location networks through structured address allocation and improved routing aggregation. Hierarchical addressing in IPv6 has been identified as a fundamental approach for scalable networks in enterprises and service providers. As noted by Davies (3), hierarchical subnetting simplifies network management by organizing addresses based on geographical or organizational boundaries, such as sites and buildings. The Internet Engineering Task Force (IETF) recommends allocating a /48 prefix to each site to allow sufficient internal subnetting and future growth, while ensuring efficient route summarization [5]. This recommendation has been widely adopted in IPv6 design for enterprises. Further studies highlight the significance of subnetting within sites using smaller prefix lengths.

The allocation of a /56 prefix per building allows network administrators to create up to 256 /64 subnets, which is considered adequate for most organizational needs [2]. The /64 prefix length is highly recommended for individual subnets in IPv6 networks, as it is required for Stateless Address Autoconfiguration (SLAAC) and ensures compatibility with modern IPv6 functionalities [6]. Many authors argue that deviating from the /64 standard may lead to operational challenges and reduced interoperability [3]. The mechanisms for

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address configuration in IPv6 have also received significant attention in the literature. SLAAC enables hosts to automatically configure their own IPv6 addresses using Router Advertisements, eliminating the need for manual configuration or centralized address assignment servers [8]. This mechanism reduces administrative overhead and improves network flexibility, especially in dynamic environments. However, SLAAC alone does not provide additional configuration parameters such as DNS server information, which limits its usefulness in enterprise networks.

To address this limitation, researchers propose the integration of DHCPv6 alongside SLAAC. DHCPv6 allows network administrators to centrally manage configuration parameters while still benefiting from automated address generation [7]. This hybrid approach, often referred to as stateless DHCPv6, has been widely recommended for enterprise deployments as it balances ease of configuration with administrative control [2]. Studies show that combining SLAAC and DHCPv6 enhances network scalability, reduces configuration errors, and improves overall network reliability. Overall, the current literature indicates that a hierarchical IPv6 addressing scheme using /48 per site, /56 per building, and /64 per subnet represents a best-practice approach for large and distributed organizations [2,5,6]. The integration of SLAAC and DHCPv6 further enhances automation, scalability, and manageability [7,8]. This project builds upon these established principles by designing and implementing a practical hierarchical IPv6 network model that adheres to IETF standards and meets modern enterprise networking needs.

This project centers on creating and implementing a hierarchical IPv6 addressing scheme specifically designed for a multi-location organization. The proposed design employs a structured subnetting approach, allocating a /48 IPv6 prefix to each site, a /56 prefix to each building within the site, and a /64 prefix for individual subnets or VLANs [2,5,6]. This strategy adheres to IPv6 best practices and recommendations, ensuring ample address capacity while allowing for future network growth. In addition to addressing planning, the project highlights the importance of automated address configuration methods to streamline host setup and lessen administrative burdens. IPv6 Stateless Address Autoconfiguration (SLAAC) is utilized to enable end devices to automatically create their own IPv6 addresses based on network advertisements, removing the need for manual setup [8]. Additionally, Dynamic Host Configuration Protocol for IPv6 (DHCPv6) is incorporated to provide extra network information, such as DNS server addresses and domain names [7]. The combination of SLAAC and DHCPv6 offers a well-rounded solution that merges automation with centralized management.

The proposed hierarchical IPv6 network design is implemented and assessed using Cisco Packet Tracer and GNS3 software, simulating various sites, buildings, routers, switches, and end devices. IPv6 routing is facilitated through OSPFv3 to ensure efficient and dynamic communication between network segments [9]. This implementation illustrates how a well-organized IPv6 addressing plan, paired with modern autoconfiguration techniques, can improve network scalability, reliability, and manageability in enterprise settings.

Methods

Study Design

This study utilizes a structured and standards-based methodology to design and implement a hierarchical IPv6 addressing scheme for an organization with multiple locations. The methodology focuses on address planning, hierarchical subnetting, automated address configuration, and routing design, following best practices recommended by the Internet Engineering Task Force (IETF) and existing IPv6 research.

Network Design Approach

A hierarchical network design model is adopted to ensure scalability, efficient routing, and simplified management across geographically distributed locations. As shown in the network topology Fig. 1, the organization is divided into multiple sites, including the Headquarters (HQ), Site A, and Site B. Each site contains multiple buildings (Building A, Building B, and Building C), and each building is further segmented into multiple VLAN-based subnets supporting end-user devices, printers, servers, and administrative systems. Core routing functionality is centralized at the HQ, which interconnects the remote sites through site routers. Access and distribution layers are implemented using multilayer switches and access switches to support VLAN segmentation and IPv6 connectivity. This hierarchical structure establishes clear boundaries for address allocation and supports route aggregation, which reduces the size of the routing table and improves network performance. The global IPv6 prefix assigned to the organization is derived from the documentation prefix space defined in RFC 3849. From this global prefix, subnetting is done in a top-down manner to align with the organizational structure.

IPv6 Addressing and Subnetting Methodology

The IPv6 addressing scheme follows a standardized prefix allocation strategy:

/48 per Site

Each geographical site (HQ, Site A, and Site B) is allocated a /48 IPv6 prefix. This allocation provides sufficient address space for internal subnetting and supporting long-term growth and flexibility as recommended for enterprise networks (RFC 6177).

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/56 per Building
Within each site, individual buildings (Building A, Building B, and Building C) are assigned /56 prefixes. This allows up to 256 /64 subnets per building, which is adequate for segmenting departments, floors, or functional network zones.

/64 per Subnet (VLAN)
Each VLAN is allocated a /64 IPv6 prefix (VLANs 10 through 80), which is a fundamental requirement for IPv6 Stateless Address Autoconfiguration (SLAAC). Using /64 prefixes ensures compatibility with IPv6 standards and allows end devices to generate interface identifiers automatically (RFC 4291).
This hierarchical subnetting approach ensures efficient address utilization, simplifies troubleshooting, and supports route summarization at site and building boundaries.

Address Assignment Mechanisms
To automate IPv6 address configuration and reduce administrative overhead, a hybrid approach using both SLAAC and DHCPv6 is implemented.

Stateless Address Autoconfiguration (SLAAC)
SLAAC is enabled on all access network interfaces connected to end devices. Routers periodically send Router Advertisement (RA) messages, allowing hosts to automatically generate their IPv6 addresses and default gateways. This mechanism eliminates the need for manual address configuration and supports plug-and-play network connectivity (RFC 4862).

DHCPv6 (Stateless Mode)
DHCPv6 is integrated in stateless mode to provide additional configuration parameters such as DNS server addresses and domain names. Router Advertisement flags are configured to instruct hosts to use DHCPv6 for supplementary information while continuing to rely on SLAAC for address generation (RFC 8415). This combination provides a balance between automation and centralized administrative control.

Routing Design
Dynamic IPv6 routing is implemented using Open Shortest Path First version 3 (OSPFv3). OSPFv3 is selected due to its native IPv6 support, fast convergence, and ability to operate efficiently within hierarchical network architectures. Site-level routers participate in OSPFv3 to exchange IPv6 routes between HQ, Site A, and Site B, while route aggregation is applied to reduce routing overhead and improve scalability (RFC 5340).

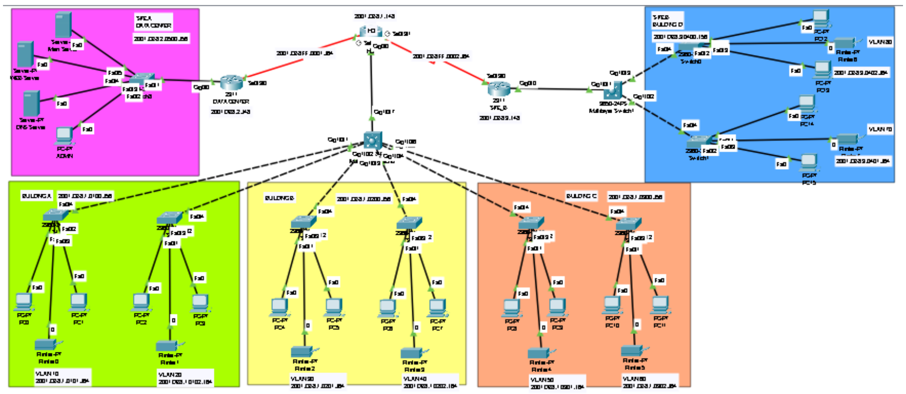

Figure 1. Network Diagram

Network Implementation
The hierarchical IPv6 network design was implemented using CISCO Packet Tracer software for test simulation and GNS3 software for the final phase of the simulation. The implementation includes a Headquarters (HQ), two remote sites (Site A and Site B), a centralized Data Center (within Site A), and multiple buildings within each site. Each building is segmented into several VLANs to support end-user devices, printers, and servers. Routers were configured at the core and site levels to provide inter-site connectivity, while multilayer and access switches were deployed to enable VLAN segmentation and IPv6 forwarding. All network devices were configured to support IPv6 unicast routing, ensuring end-to-end IPv6 connectivity across the entire topology.

IPv6 Addressing Implementation
The IPv6 addressing scheme was implemented according to the hierarchical subnetting methodology defined in the design phase: A unique /48 prefix was assigned to each site (HQ, Site A, and Site B). Each building

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within a site was allocated a /56 prefix. Individual VLANs (VLAN 10 to VLAN 80) were assigned /64 prefixes to support IPv6 host addressing and SLAAC functionality.

Table 1. Assigned IPv6 Addresses for each site

Site	IPv6 address	Prefix length
HQ	2001:DB8:1	/48
Site A	2001:DB8:2	/48
Site B	2001:DB8:3	/48

Table 2. Assigned IPv6 Addresses for each building

Building	IPv6 address	Prefix length
Data Center	2001:DB8:2:0500	/56
Building A	2001:DB8:1:0100	/56
Building B	2001:DB8:1:0200	/56
Building C	2001:DB8:1:0300	/56
Building D	2001:DB8:2:0400	/56

Table 3. Assigned IPv6 Addresses for each VLAN

Subnet	IPv6 Address	Prefix
VLAN 10	2001:DB8:1:0101	64
VLAN 20	2001:DB8:1:0102	64
VLAN 30	2001:DB8:1:0201	64
VLAN 40	2001:DB8:1:0202	64
VLAN 50	2001:DB8:1:0301	64
VLAN 60	2001:DB8:1:0302	64
VLAN 70	2001:DB8:3:0470	64
VLAN 80	2001:DB8:3:0480	64

Router Configuration

Enabling IPv6 Routing Functionality

By default, in Cisco routers, IPv6 packet forwarding is disabled to prevent unintended routing behavior. Therefore, the initial and most critical step in the router configuration process was to enable IPv6 unicast routing. This command allows the router to operate as a Layer 3 IPv6 device capable of processing and forwarding IPv6 packets between different network segments. The IPv6 routing was enabled on each router using the IPv6 unicast-routing command, and was examined using the Cisco IOS command show running-config. This command confirms that IPv6 unicast routing is enabled on the device.

IPv6 routing verification (HQ)

```
HQ#sh running-config
Building configuration...
!
ipv6 unicast-routing
```

IPv6 routing verification (Site A, Data Center)

```
DC#sh running-config
Building configuration...
!
ipv6 unicast-routing
```

IPv6 routing verification (Site B)

```
SITE_B#sh running-config
Building configuration...
!
ipv6 unicast-routing
```

IPv6 Interface Address Configuration

Each router interface was assigned an IPv6 address from a /64 subnet derived from the predefined hierarchical structure. The /64 prefix length was consistently used in accordance with IPv6 standards and to support Stateless Address Autoconfiguration (SLAAC) for end devices.

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LAN Interfaces
Router interfaces connected to local area networks were configured to act as default gateways for hosts within their respective subnets. These interfaces were assigned the first available IPv6 address within the subnet to simplify network management and troubleshooting.

Point-to-Point Interfaces
Router interfaces used for point-to-point connections between routers were also assigned IPv6 addresses from dedicated /64 subnets. These subnets were allocated specifically for inter-router communication to ensure logical separation from user networks. To display and verify the operational status and address assignment of each interface. Cisco IOS provides the show ipv6 interface brief command to provide a concise overview of all router interfaces, including their operational status and assigned IPv6 addresses.

Table 4. IPv6 interface verification (HQ)

Interface	IPv6 Address	Prefix	Status	Protocol	Description
GigabitEthernet0/0.10	2001:DB8:1:101::1	64	Up	Up	VLAN 10
GigabitEthernet0/0.20	2001:DB8:1:102::1	64	Up	Up	VLAN 20
GigabitEthernet0/0.30	2001:DB8:1:201::1	64	Up	Up	VLAN 30
GigabitEthernet0/0.40	2001:DB8:1:202::1	64	Up	Up	VLAN 40
GigabitEthernet0/0.50	2001:DB8:1:301::1	64	Up	Up	VLAN 50
GigabitEthernet0/0.60	2001:DB8:1:302::1	64	Up	Up	VLAN 60

Table 5. IPv6 interface verification (Site A, Data Center)

Interface	IPv6 Address	Prefix	Status	Protocol	Description
GigabitEthernet0/0	2001:DB8:2:500::1	56	Up	Up	Connected to DC
Serial0/3/0	2001:DB8:FF:1::2	64	Up	Up	Connected to HQ

Table 6. IPv6 interface verification (Site B)

Interface	IPv6 Address	Prefix	Status	Protocol	Description
GigabitEthernet0/0.70	2001:DB8:3:401::1	64	Up	Up	VLAN 70
GigabitEthernet0/0.80	2001:DB8:3:402::1	64			VLAN 80
Serial0/3/0	2001:DB8:FF:2::2	64	Up	Up	Connected to HQ

IPv6 Routing Protocol Configuration
To enable scalable and dynamic IPv6 routing across the multi-site network, a dedicated IPv6 routing protocol was implemented. In this work, Open Shortest Path First version 3 (OSPFv3) was selected as the interior gateway protocol due to its efficient convergence properties, support for hierarchical network design, and native compatibility with IPv6. OSPFv3 enables routers to automatically exchange IPv6 routing information, adapt to topology changes, and maintain consistent routing tables across the network without manual intervention. Successful adjacency formation was verified using the show ipv6 ospf neighbor command, which verifies that OSPFv3 neighbor relationships are formed correctly and helps in troubleshooting IPv6 routing issues.

Table 7. OSPFv3 neighbor verification (HQ)

Neighbor ID	State	Interface	Description
3.3.3.3	FULL	Serial0/3/0	Site A, Data Center
1.1.1.1	FULL	Serial0/3/1	Site B

Table 8. OSPFv3 neighbor verification (Site A, Data Center)

Neighbor ID	State	Interface	Description
2.2.2.2	FULL	Serial0/3/0	HQ

Table 9. OSPFv3 neighbor verification (Site B)

Neighbor ID	State	Interface	Description
2.2.2.2	FULL	Serial0/3/0	HQ

SLAAC and Stateless DHCPv6 Configuration
To achieve efficient and automated IPv6 address assignment while maintaining centralized control over essential network parameters, a hybrid configuration combining Stateless Address Autoconfiguration (SLAAC) and Stateless DHCPv6 was implemented. This approach aligns with IPv6 best practices and is widely adopted in enterprise network environments.

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Stateless Address Autoconfiguration (SLAAC)
SLAAC allows IPv6-enabled hosts to automatically configure their own global unicast addresses based on the network prefix advertised by the router.
To enable SLAAC, each router interface connected to an end-user subnet was configured with an IPv6 `/64` prefix.

Enabling Stateless DHCPv6 Support
While SLAAC efficiently handles IPv6 address generation, DHCPv6 provides additional configuration information, such as DNS server address and Domain names.
to verify that end devices are correctly obtaining IPv6 addresses and network configuration parameters. Verification was performed at both the host level and the router level to ensure proper operation of SLAAC and DHCPv6 services.

Verifying SLAAC on End Hosts
SLAAC operation was verified by examining the IPv6 configuration of end devices configured for automatic IPv6 addressing by the ipconfig command

Verifying Router Advertisements (RA)
Router Advertisement functionality was verified on the router interfaces connected to client networks by the show running-config command.

IPv6 SLAAC Configuration
```
!
interface GigabitEthernet0/0.10
encapsulation dot1Q 10
no ip address
ipv6 address 2001:DB8:1:101::1/64
ipv6 nd other-config-flag
ipv6 enable
ipv6 ospf 1 area 0
ipv6 dhcp server vlan10_pool
!
interface GigabitEthernet0/0.20
encapsulation dot1Q 20
no ip address
ipv6 address 2001:DB8:1:102::1/64
ipv6 nd other-config-flag
ipv6 enable
ipv6 ospf 1 area 0
ipv6 dhcp server vlan20_pool
!
interface GigabitEthernet0/0.30
encapsulation dot1Q 30
no ip address
ipv6 address 2001:DB8:1:201::1/64
ipv6 nd other-config-flag
ipv6 enable
ipv6 ospf 1 area 0
ipv6 dhcp server vlan30_pool
!
interface GigabitEthernet0/0.40
encapsulation dot1Q 40
no ip address
ipv6 address 2001:DB8:1:202::1/64
ipv6 nd other-config-flag
ipv6 enable
ipv6 ospf 1 area 0
ipv6 dhcp server vlan40_pool
!
interface GigabitEthernet0/0.50
encapsulation dot1Q 50
no ip address
ipv6 address 2001:DB8:1:301::1/64
```


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```
ipv6 nd other-config-flag
ipv6 enable
ipv6 ospf 1 area 0
ipv6 dhcp server vlan50_pool
!
interface GigabitEthernet0/0.60
encapsulation dot1Q 60
no ip address
ipv6 address 2001:DB8:1:302::1/64
ipv6 nd other-config-flag
ipv6 enable
ipv6 ospf 1 area 0
ipv6 dhcp server vlan60_pool
!
```

Verifying DHCPv6 Operation on the Router

To verify Stateless DHCPv6 operation, the DHCPv6 bindings and statistics on the router were examined by show ipv6 dhcp pool.

DHCPv6 Configuration (HQ)

```
DHCPv6 pool: vlan10_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan10
Active clients: 0
DHCPv6 pool: vlan20_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan20
Active clients: 0
DHCPv6 pool: vlan30_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan30
Active clients: 0
DHCPv6 pool: vlan40_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan40
Active clients: 0
DHCPv6 pool: vlan50_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan50
Active clients: 0
DHCPv6 pool: vlan60_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan60
Active clients: 0
```

DHCPv6 Configuration (Site B)

```
DHCPv6 pool: vlan70_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan70
Active clients: 0
DHCPv6 pool: vlan80_pool
DNS server: 2001:DB8:2:500::10
Domain name: vlan80
Active clients: 0
```

Network Testing

To ensure the correctness, reliability, and efficiency of the proposed hierarchical IPv6 network design, the testing phase aimed to verify IPv6 address assignment, routing functionality, inter-VLAN communication, and the proper operation of SLAAC and Stateless DHCPv6 across all network segments and locations.

The verification of IPv6 address assignment is the initial and most critical step in the testing phase. SLAAC functionality was tested by configuring hosts to use automatic IPv6 addressing and observing address generation without manual intervention. Successful address configuration confirmed the correct operation

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of Router Advertisements. Stateless DHCPv6 was tested by verifying that hosts received additional network parameters from the DHCPv6 server. DNS server and domain name assignment.

Results and Discussion

The hierarchical IPv6 network design was successfully implemented and tested using Cisco Packet Tracer and GNS3 simulation environments. The results demonstrate that the proposed addressing scheme and configuration mechanisms provide efficient IPv6 connectivity, reliable routing, and automated address assignment across all network locations. IPv6 connectivity tests confirmed that devices in different VLANs, buildings, and remote sites were able to communicate using global unicast IPv6 addresses. End devices automatically generated their IPv6 addresses using Stateless Address Autoconfiguration (SLAAC), while additional configuration parameters, such as DNS server information, were correctly obtained through stateless DHCPv6. The address allocation strategy based on /48 per site, /56 per building, and /64 per subnet proved to be scalable and flexible. New subnets could be added without restructuring the existing addressing plan. The hierarchical design simplified troubleshooting and improved network organization by clearly separating addressing levels.

The results of the implementation indicate that adopting a hierarchical IPv6 addressing model significantly enhances network scalability and manageability in enterprise environments. By assigning /48 prefixes to sites and /56 prefixes to buildings, the design enables effective route aggregation and minimizes the number of routing entries required in OSPFv3. This is an important advantage for large organizations where routing table growth can negatively affect network performance. The use of /64 prefixes for individual VLANs proved essential for compatibility with IPv6 mechanisms such as SLAAC. The automatic address configuration process reduced administrative workload and eliminated the need for manual IP assignment. At the same time, integrating stateless DHCPv6 provided centralized control over additional network parameters, solving one of the main limitations of SLAAC-only configurations. The combination of SLAAC and DHCPv6 showed that hybrid configuration approaches are well-suited for enterprise networks where both automation and administration are required. This approach also reduced potential configuration errors and improved consistency across different sites and buildings. Overall, the discussion highlights that hierarchical IPv6 design is not only theoretically efficient but also practically applicable. The results support existing literature that recommends structured subnetting, /64 subnet prefixes, and hybrid autoconfiguration techniques for modern enterprise networks.

Conclusion

The study designed and implemented a hierarchical IPv6 addressing scheme for a multi-location enterprise network. Using a structured allocation strategy (/48 for sites, /56 for buildings, /64 for subnets), the model ensured scalability, logical organization, and room for future expansion. Implementation was carried out in Cisco Packet Tracer and GNS3, with OSPFv3 enabling inter-site routing. IPv6 address assignment was automated through Stateless Address Autoconfiguration (SLAAC) combined with stateless DHCPv6, balancing flexibility with centralized control. Simulation results confirmed full IPv6 connectivity, demonstrating that hierarchical subnetting simplifies management, reduces routing complexity, and supports enterprise scalability. The approach highlights the practicality of combining structured IPv6 design with SLAAC and DHCPv6 for organizations transitioning from IPv4. Suggested future work includes adding security features (ACLs, IPSec), testing on real hardware, and integrating QoS for delay-sensitive applications.

Conflict of interest. Nil

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