Name: Alhambra, Berna Marie C.
Section: CS301

Individual Research Activity: Exploring IPv6 Addressing

Objective: To understand the structure, benefits, and practical implications of IPv6 addressing in modern networking, and compare it with IPv4.

Part 1: Introduction to IPv6

1. Definition:
IPv6 has been in the works since 1998 this is because of the need to address the shortfall of IP addresses that are available under IPv4. The warnings about running out of internet addresses have stopped and the migration from IPv4 to IPv6 slowly but surely has begun. The IPv6 provides the latest version of Internet Protocol, in which it identifies the devices across the internet so that they can be located. With the growth of the internet, IPv4 eventually ran out of address spaces and needed to have more addresses that introduced Ipv6 which contains 128-bit addressing and supports approximately 340 trillion trillion compared to the Ipv4 which uses 32-bit addressing scheme to support 4.3 billion devices.

2. **Comparison to IPv4:**
To Identify and compare the key differences between IPv4 and IPv6.

- **Address length**
  IPv4 has a 32-bit address length, while IPv6 has 128-bit.

- **Address space (number of addresses)**
  Since the IPv4 offers 32-bit address length this amounts to 4.3 billion total number of unique addresses available while the IPv6 can provide a 340 trillion trillion unique addresses available.

- **Representation (dotted decimal vs hexadecimal)**
  In IPv4 IP addresses are written in a format of four decimal numbers and are separated with dots, such as 192.168.1.1.

  While on IPv6 it is written in 8 hexadecimal numbers separated by colon (:), such as 2001:0db8:85a3::8a2e:0370:7334

- **Header format**
  IPv4 has a mandatory header in which the first 20 bytes in the header are mandatory. The Options field following the 20 bytes has a variable length.

  IPv6 has a header format of 40 bytes long and has details where the data should go and how to get there.

- **Network communication improvements (e.g., multicast, anycast, unicast)**
  The major improvement in network communication that IPv6 has to offer is that in multicast since it already provides a native support which allows for efficient distribution of data to multiple recipients.

  In anycast, IPv6 also provides native and explicit support which allows any unicast address to be used as an anycast address. Whereas in IPv4 it does not have a specific address range dedicated for anycast.

  Compared to IPv4, IPv6 unicast addresses provide a more efficient and scalable way to identify network interfaces, this ensures a direct one-to-one communication without relying on broadcasts that effectively reduces network congestion.

3. **Problem Solved by IPv6:**

- **Explain the limitations of IPv4 that led to the development and adoption of IPv6.**
  As the internet popularity grew along with the number of connected devices. The current Internet Protocol (IPv4) 32-bit addresses will be exhausted. One of the main reasons why the development of IPv6 happened is to address the shortage of addresses in IPv4. Along with that, IPv6 also aims to improve the routing efficiency, enhance security and introduce new features.

- Discuss the problem of IPv4 exhaustion and how IPv6 addresses this issue.
  IPv4 address exhaustion became a major issue since there are only 4.3 billion unique available addresses. With the rise of devices being connected it has become evident that IPv4 won't be sufficient. With that said, the solution to that is to introduce IPv6 with a 128-bit address length that provides 340 trillion trillion unique addresses available. This produces an increase in address space of 79 octillion percent compared to IPv4.

4. **IPv6 Address Representation:**

Learn and explain how an IPv6 address is represented.

- **Address length (128 bits)**
  The preferred IPv6 address representation is: x:x:x:x:x:x:x:x, where each x is the hexadecimal values of the eight 16-bit pieces of the address.

These can range from 0000:0000:0000:0000:0000:0000:0000:0000 to ffff:ffff:ffff:ffff:ffff:ffff:ffff:ffff.

- **Hexadecimal notation**
  A typical IPv6 address looks like
  2001:0db8:85a3:0000:0000:8a2e:0370:7334

- **Compression rules (zero compression, leading zero suppression)**
  Zero compression:
  Continuous zeroes can be eliminated when compressing an IPv6 address.You simply use a double colon or "::" symbol. Rather than the single colon that typically breaks up the eight fields of the address, this double colon indicates that a segment of continuous zeroes has been removed.

  Leading zero compression:
  In this rule, you are still compressing zeroes but in this case it will be the leading zeroes in each field that will be removed. If any of the eight fields in the address starts with a zero, or multiple zeroes, you can remove those zeroes without altering the address. So, you would not use the "::" symbol, and would instead just stick with the standard single colon divider between fields.

- **Provide examples of full IPv6 addresses and their compressed formats.**
  IPv6 address using zero compression:
  Before: 1111 : 0000 : 0000 : 0000 : 1234 : abcd : abcd : abcd
  After: 1111 :: 1234 : abcd : abcd : abcd

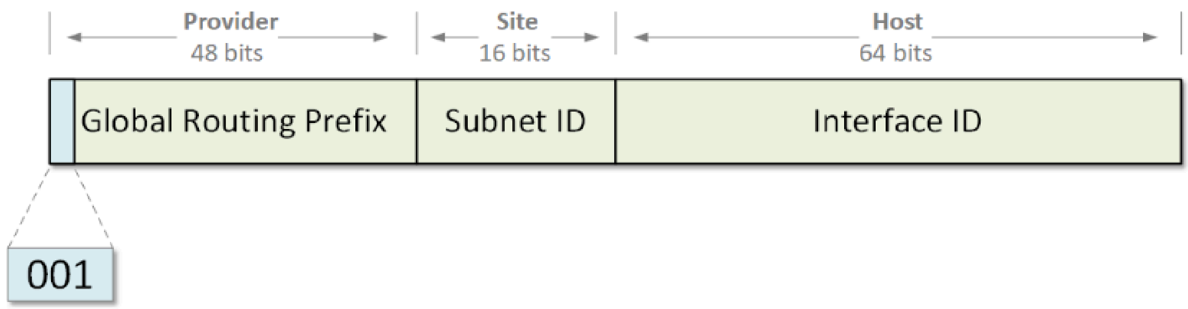
  IPv6 address using leading zero compression:
  Before: 1111 : 0123 : 0012 : 0001 : abcd : 0abc : 9891 : abcd
  After: 1111 : 123: 12 : 1 : abcd : abc : 9891 : abcd

Part 2: IPv6 Addressing Structure

1. Address Format:
o Break down the structure of an IPv6 address, describing its main components:

- Global Routing Prefix
- Subnet ID
- Interface ID

IPv6 address compose of 128-bits and structured as follows:
Global Routing Prefix (First 48 bits)
Subnet ID (Next 16 bits)
Interface ID (Last 64 bits)



In the global routing prefix this identifies the network and is assigned by the Internet Service Provider(ISP) or network authority. The Subnet ID in which this specifies the subnet within the larger network that helps organizations divide their network into smaller subnetworks. Lastly, the Interface ID identifies the specific device within the subnet.

2. Types of IPv6 Addresses:
Research and describe the different types of IPv6 addresses:
Provide a use case for each type.

- **Global Unicast Address (GUA)**
  At present, all global unicast addresses start with binary value 001 (2000::/3).
  The structure is as follows:
  48-bit global routing prefix
  16-bit subnet ID which is also referred to as Site-Level Aggregator (SLA).

  Let's look at the following scenario:
  Internet Assigned Numbers Authority (IANA) allocates addresses from the prefix 2000::/3 to the regional providers. Let us say that it is allocated to American Registry for Internet Numbers (ARIN)in which ARIN then allocates sub-parts of this address space 2001:18::/23 to ISPs and large customers. This makes the Global Unicast Address aggregatable that allows for public access from anywhere.

- **Link-Local Address (LLA)**
  Link-local is a special type of unicast address because it is auto-configured on any interface using a combination of link-local prefix FE80::/10 (first 10 bits equal to 1111 1110 10) and the MAC address of the interface

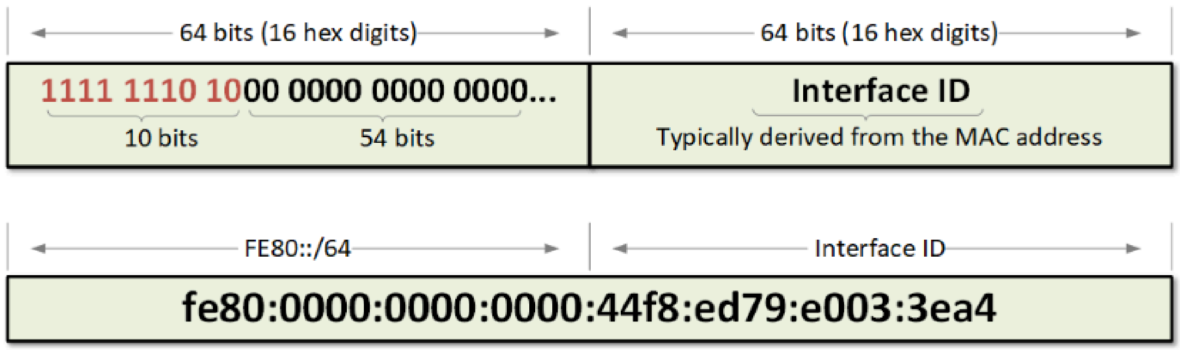


Figure 5. IPv6 Link-local address structure

  The main idea is that devices on the same local network can talk to each other without needing an internet address.

- **Unique Local Address (ULA)**
  A special IPv6 address used for private networks, this is quite similar to private IPs in IPv4. It is globally unique to prevent conflicts but is not routable on the internet which ensures secure internal communication without ISP dependence. This is most useful in home networks that do not need internet access or private communications within organizations.

- **Multicast Address**
  In IPv6, multicast addresses are special because they always start with hex digits “FF”. This helps devices recognize them as multicast addresses. So, any address that begins with "FF" is used for sending data to multiple devices at once. One example of this is the streaming of audio/video to multiple users.

- **Anycast Address**
  An anycast address is a special type of IP address that can be assigned to multiple devices in different locations. When a device sends data to an anycast address, the network automatically delivers it to the nearest available device based on the best route. Anycast address can be used in load balancing and to direct users to the nearest server.

3. IPv6 Address Allocation:

- **Explore how IPv6 addresses are allocated globally by organizations such as IANA (Internet Assigned Numbers Authority).**
  IPv6 addresses are allocated globally by the Internet Assigned Numbers Authority (IANA) which distributes them to Regional Internet Registries (RIRs). Each RIR receives at least a /12 IPv6 block in order to meet the demands for at least 18 months.

  RIRs can request additional allocations if their available space falls below 50% of a /12 or if their projected needs for the next 9 months exceed their current supply. IANA ensures transparency by announcing all allocations through official channels.

- **Discuss address space allocation policies and how they impact ISPs, organizations, and end-users.**

  IPv6 address space allocation follows structured policies that have a significant impact on ISPs, organizations, and end-users differently. ISPs receive large blocks of IPv6 addresses from regional registries, this enables them to assign unique addresses to their customers and support widespread adoption.

  For organizations, it is role dependent and organizations may receive allocations to manage their internal networks or provide services to others that ensures efficient address utilization.

  Typically, end-users receive smaller address blocks from their ISPs, sufficient for personal or home network needs for them to be able to facilitate seamless connectivity for devices like IoT gadgets and home computers.

Part 3: IPv6 Deployment

1. Real-World Use:
Research the current state of IPv6 deployment across the globe.

- **Identify which regions or countries have adopted IPv6 more extensively, and which lag behind.**
  In the current year, based on IPv6 traffic to Google the global adoption stands at 43%. WIth countries such as the United States only slightly above 50%, while France, Germany, and India have much higher adoption rates at 80%, 75% and 74% respectively. However, for other countries like the Philippines the adoption rate is just 17.31% which is incredibly low along with one of the lowest which is in the region of Africa specifically Comoros in which only scored 0.01%.

2. Transition Strategies:
Investigate the various transition mechanisms from IPv4 to IPv6:

- **Dual Stack**
- **Tunneling**
- **Translation (NAT64, DNS64)**

Explain the benefits and challenges associated with each mechanism.

The primary methods on how to implement transition from IPv4 to IPv6 includes the following: Dual stack, Tunneling, Translation

Dual stack
Dual-Stack Mode which configure network equipment to be able to be able to operate in dual stack mode which enables both IPv4 and IPv6 communications. This allows for flexibility due to the available support of IPv4 and IPv6 but this is not considered a long-term solution and increase complexity in network management

Tunneling
Involves encapsulation of IPv6 packets within IPv4 packets. This enables the IPv6 hosts to communicate using existing IPv4 infrastructure which got the name tunneling. This is useful for temporary connectivity solutions and avoids the intermediate need to upgrade to IPv6. However, this can also introduce latency and overhead. The tunnel endpoints require proper configuration and may reduce performance due to tunneling.

Translation
Translation approach which is represented by Network Address Translation-Protocol Translation (NAT-PT), converts packet headers between IPv4 and IPv6 formats. This conversion enables communication between networks that exclusively utilize either IPv4 or IPv6, which enhances interoperability between diverse IP protocol versions. This facilitates phased adoption of IPv6 but can cause delays and efficiency losses due to translation.

3. Obstacles to Adoption:

- **Identify key technical, economic, and policy challenges that are slowing down IPv6 adoption**

  Adopting another technology is complex and requires a lot of processes. With that being said, transitioning to IPv6 has some notable challenges. Technical challenges often include lack of backward compatibility with IPv4 and requires configuration or complex transition mechanisms. Experts such as network administrators also face difficulties with DNS configuration.

  Economic challenges includes the need for large amount of investment in hardwares and training, which many ISPs, businesses hesitate to undertake while IPv4 still functions.

  Policy challenges includes lack of incentives from many ISPs to push to IPv6 since IP4 solutions still remain profitable. Adding to that, government and regulatory bodies are slow to enforce IPv6 transition policies which results to the delay of widespread adoption.

Part 4: Conclusion

1. Reflection:
   - Reflect on the importance of IPv6 for the future of the internet.
     IPv6 importance for the future internet is crucial due to the amount of available addresses it provides along with security and other features available. Not all countries are widely adopting IPv6 due to particular reasons and for the Philippines it is only 17%. The future, based on how I see it and upon looking at the trend I believe that the vast majority will adopt IPv6, maybe seeing a 70-90% increase in adoption.

   - Discuss the personal insights gained from exploring the differences and advantages of IPv6 addressing.
     As a computer science student with limited exposure to networking, researching IPv6 has been enlightening. Understanding how its simplified header structure enhances routing efficiency has provided me with a clearer picture of network performance optimization. Along with that the transition from IPv4 which only holds 4.3 billion available addresses to IPv6 which holds 340 trillion trillion available addresses still amazes me how brilliant humans can come up with that.

2. Future of IPv6:
   - Predict how widespread IPv6 adoption will impact global networking in the next decade, considering the continued growth of IoT and mobile networks
     I believe that in the future, the adoption of IPv6 will significantly transform global networking over the next decade. Considering the rise of IOT and mobile networks. IPv6 address space will be able to accommodate an almost limitless number of unique numbers. Its provided features such as simplified headers and security enhancement will lead to more efficient and secure network operations. However, I also see IPv6 will have the same path as IPv4 since if the trend keeps going then the consideration of IPv6 exhaustion is also possible.

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