The linux networking architecture

the linux networking architecture The Linux operating system boasts a highly flexible and robust networking architecture that facilitates seamless communication between devices, services, and applications. Its design is modular, layered, and highly configurable, making it suitable for everything from small embedded systems to large-scale data centers. Understanding the Linux networking architecture involves exploring its core components, the various layers of network processing, and the mechanisms that enable data exchange across diverse network environments. This article provides an in-depth overview of the Linux networking architecture, emphasizing its layered structure, key subsystems, and the mechanisms that underpin network communication within Linux.

Overview of Linux Networking Architecture

Linux networking architecture is based on a layered model that mirrors the OSI model to a certain extent but is optimized for the operating system's design and practical implementation. The architecture encompasses hardware devices, kernel modules, network protocols, and user-space utilities that collectively enable network communication. The primary goal is to abstract hardware complexities, provide flexible protocol handling, and support diverse network configurations. The core components of Linux networking architecture include: - Network Interface Layer - Kernel Network Stack - Socket API - User-space Utilities and Applications Understanding each component's role and interactions provides insight into how Linux manages network data flow efficiently.

Layered Structure of Linux Networking

1. Hardware Layer (Physical and Data Link Layers)

At the base of the Linux networking stack are the physical network devices, such as Ethernet cards, Wi-Fi adapters, or virtual network interfaces. These devices operate at the physical and data link layers, handling the actual transmission and reception of raw bits over physical media. - Network Interface Cards (NICs): Hardware devices that connect the computer to the network. - Device Drivers: Kernel modules that abstract hardware specifics, enabling the kernel to interact with various network devices uniformly. - Data Link Layer Protocols: Such as Ethernet, Wi-Fi, or PPP, responsible for framing, addressing (MAC addresses), and error detection. The kernel interacts with these devices via device drivers, which are critical for hardware abstraction and support for multiple network interface types.

2. Kernel Network Stack

The kernel network stack is the core component that processes network data within the Linux kernel. It manages protocol handling, routing, packet filtering, and other network functions. - Packet Reception: When a packet arrives at a network interface, the driver passes it to the

kernel network stack. - Protocol Processing: The kernel inspects packet headers, determines the appropriate protocol handler (e.g., IP, ARP, TCP, UDP), and processes accordingly. - Routing: The kernel decides where to forward packets based on routing tables. - Network Buffer Management: Uses socket buffers (sk_buffs) to manage data efficiently during processing. - Protocol Modules: Linux supports a wide array of protocols, implemented as kernel modules, which can be loaded or unloaded dynamically. This layer's modularity allows Linux to support numerous protocols and networking features, including tunneling, VPNs, and network filtering.

3. Socket Layer and APIs

The socket API provides a standardized interface between user-space applications and the kernel network stack. - Sockets: Endpoints for network communication, created via system calls like `socket()`. - Transport Protocols: TCP, UDP, SCTP, etc., are implemented within the socket API, enabling applications to send and receive data over network connections. - Connection Management: Handles establishing, maintaining, and terminating network connections. - Data Transmission: Facilitates data transfer through send/recv calls, abstracts underlying protocol complexities. Sockets serve as the primary interface for applications to leverage the underlying network stack, making network programming portable and consistent across platforms.

4. User-space Utilities and Network Management

Beyond the kernel components, user-space utilities and configuration tools play a vital role in managing and monitoring network behavior. - Network Configuration Tools: `ifconfig`, `ip`, `ethtool`, `iwconfig`, etc., used to configure network interfaces. - Routing Utilities: `route`, `ip route` commands to manage routing tables. - Firewall and Filtering: `iptables`, `nftables`, and `firewalld` facilitate network security. - Network Services: DHCP servers, DNS servers, VPN services, and others run in user space. - Monitoring Tools: `netstat`, `ss`, `tcpdump`, `wireshark` for diagnosing and analyzing network traffic. These utilities provide administrators with the means to control, observe, and troubleshoot network operations effectively.

Key Components of Linux Networking Architecture

1. Network Interfaces

Network interfaces are the entry points for network data. Linux supports various types of interfaces: - Physical Interfaces: Ethernet, Wi-Fi, Fiber, etc. - Virtual Interfaces: Loopback (`lo`), VLAN, VPN interfaces, etc. - TUN/TAP Devices: Virtual network kernel devices used for tunneling and VPNs. Each interface is managed via the kernel and can have associated IP addresses, MAC addresses, and configuration settings.

2. Network Protocols and Protocol Stacks

Linux supports a comprehensive suite of protocols, including: - Link Layer: Ethernet, Wi-Fi, PPP - Internet Layer: IP (IPv4 and IPv6) - Transport Layer: TCP, UDP, SCTP - Application Layer: HTTP, FTP, SSH, DNS The protocol stack is implemented within the kernel network stack, with each

layer responsible for specific functions, allowing Linux to communicate over diverse network types.

3. Network Drivers and Hardware Abstraction

Device drivers are kernel modules that interface directly with hardware. They provide: - Hardware initialization - Data transfer routines - Interrupt handling - Error detection and correction Drivers abstract hardware differences, enabling Linux to work with a broad range of networking hardware seamlessly.

4. Routing and Forwarding

Routing determines the path that packets take across networks. Linux maintains routing tables, which specify destination networks and next-hop information. - Routing Table Management: Using commands like `ip route` or `route`. - Packet Forwarding: Linux can function as a router or gateway, forwarding packets between interfaces. - NAT and Masquerading: Implemented via iptables or nftables. Routing decisions are crucial for enabling communication between different network segments and managing traffic efficiently.

5. Network Security and Filtering

Security mechanisms are integral to Linux networking: - Firewall Rules: Using iptables/nftables to filter traffic based on rules. - SELinux/AppArmor: Security modules that enforce policies at the kernel level. - VPN and Encryption: Support for VPN protocols and encryption standards. These components ensure network integrity, confidentiality, and access control.

Networking Subsystems and Modules

Linux's modular design allows various subsystems and modules to extend its networking capabilities.

1. Netfilter Framework

Netfilter is a powerful framework within the Linux kernel responsible for packet filtering, network address translation, and packet mangling. Features include: - Firewall rules management - NAT support - Packet logging - Connection tracking Tools like `iptables` interface with netfilter to set rules.

2. Berkeley Packet Filter (BPF)

BPF provides a high-performance filtering mechanism for capturing and analyzing network packets. - eBPF (extended BPF): Extends BPF capabilities, allowing dynamic program loading into the kernel. - Used by tools like `tcpdump`, `Wireshark`, and performance monitoring utilities.

3. Network Namespaces and Virtualization

Linux supports network namespaces, isolating network resources for containers, virtual machines, and applications. - Multiple network namespaces can coexist, each with its own interfaces, routing tables, and firewall rules. - Facilitates containerization and network virtualization, enabling scalable and secure multi-tenant environments.

Conclusion

The Linux networking architecture is a complex yet highly adaptable system designed for efficiency, security, and extensibility. Its layered approach—from hardware interfaces to user-space utilities—ensures that Linux can support a broad spectrum of network types, protocols, and configurations. The modular kernel network stack, coupled with flexible tools and frameworks like netfilter and BPF, allows administrators and developers to tailor network functionalities to their specific needs. Whether operating as a simple workstation, a server, or a core component of a large data center, Linux's networking architecture provides a solid foundation for reliable and scalable network communication. Understanding its components and their interactions is essential for anyone seeking to harness the full potential of Linux's networking capabilities.

Linux Networking Architecture: An In-Depth Exploration

Introduction

Networking is a cornerstone of modern computing, enabling devices to communicate seamlessly across local and global environments. Linux, being a versatile and widely adopted operating system, has a robust and sophisticated networking architecture that supports a multitude of protocols, configurations, and functionalities. Understanding Linux's networking architecture is crucial for system administrators, network engineers, and developers aiming to optimize network performance, troubleshoot issues, or develop network-aware applications.

This comprehensive review delves into the core aspects of Linux networking architecture, exploring its layered design, key components, protocols, and mechanisms that work harmoniously to facilitate network communication.

Overview of Linux Networking Architecture

Linux's networking architecture is rooted in the OSI (Open Systems Interconnection) model and the TCP/IP model, but it emphasizes a modular, layered approach that allows flexibility and extensibility. The architecture is primarily divided into the following layers:

1. Application Layer
2. Transport Layer
3. Network Layer
4. Data Link Layer
5. Physical Layer

However, in Linux, much of the network stack is implemented within the kernel, with user-space

tools providing configuration and management capabilities.

Kernel Networking Stack

1. The Role of the Linux Kernel

The Linux kernel manages most of the network operations, including packet processing, protocol implementation, and device management. It provides a well-structured, modular stack that supports various network protocols and hardware.

1. Key Data Structures

1. sk_buff (Socket Buffer): Represents network packets within the kernel, encapsulating packet data and metadata.
2. net_device: Represents network interfaces (Ethernet, Wi-Fi, virtual interfaces).
3. Protocol Handlers: Functions registered to handle specific protocols (IP, TCP, UDP, etc.).

1. Protocol Stack Layers in Kernel

1. Device Drivers: Interface with hardware devices; handle low-level operations.
2. Network Layer Protocols: IP (Internet Protocol), ICMP, IGMP.
3. Transport Layer Protocols: TCP (Transmission Control Protocol), UDP (User Datagram Protocol).
4. Application Layer Protocols: HTTP, FTP, SSH, managed via sockets.

Network Interface Layer

1. Network Interfaces and Device Drivers

Linux supports a wide array of network interfaces through device drivers, including:

1. Ethernet (wired)
2. Wi-Fi (wireless)
3. Virtual interfaces (tun, tap, veth)
4. Loopback interface (`lo`)

Each interface is represented by a `net_device` structure, which maintains its state, configuration, and statistics.

1. Interface Configuration

Tools such as `ifconfig`, `ip`, and `netplan` are used to configure network interfaces. These configurations include:

1. IP address assignment
2. MAC address setup
3. MTU (Maximum Transmission Unit) settings
4. Interface enabling/disabling

Protocol Stack in Linux

1. Internet Protocol Suite (TCP/IP)

Linux's networking stack primarily implements the TCP/IP suite, providing core protocols:

1. IP (Internet Protocol): Handles addressing and routing.
2. ICMP (Internet Control Message Protocol): Facilitates network diagnostics.
3. TCP (Transmission Control Protocol): Provides reliable, connection-oriented communication.
4. UDP (User Datagram Protocol): Supports connectionless, low-overhead communication.

1. Additional Protocols and Support

1. ARP (Address Resolution Protocol): Resolves IP addresses to MAC addresses.
2. NDP (Neighbor Discovery Protocol): IPv6 counterpart to ARP.
3. Routing Protocols: OSPF, BGP, RIP (implemented via user-space daemons).

Routing and Forwarding

1. Routing Table Management

Linux maintains routing tables that determine packet forwarding paths. Key tools include:

1. `ip route`
2. `route`

Routing decisions are based on destination IP, subnet masks, and policies.

1. Routing Protocols

While Linux does not natively implement dynamic routing protocols, support is provided via daemons like:

1. Quagga / FRRouting: For BGP, OSPF, RIP.
2. Bird: Alternative routing daemon.

1. Packet Forwarding

Enabled via the `net.ipv4.ip_forward` kernel parameter, allowing Linux to operate as a router or gateway.

Network Address Translation (NAT) and Firewalling

1. NAT

Implemented through iptables or nftables, NAT allows translation of IP addresses and ports, facilitating internet sharing and address conservation.

1. Firewalling

1. iptables/nftables: Core tools for filtering, NAT, and packet mangling.
2. Firewalld: Dynamic firewall management.
3. SELinux/AppArmor: Security modules influencing network security policies.

Firewall rules can be applied at various points in the stack to permit, block, or modify traffic.

Network Namespaces and Virtualization

1. Network Namespaces

Linux provides network namespaces to isolate network environments, enabling containerization and virtualization. Each namespace has its own network interfaces, routing tables, and firewall rules.

1. Virtual Networking

1. Veth pairs: Virtual Ethernet interfaces connecting namespaces or containers.
2. Bridges: Virtual switches connecting multiple interfaces.
3. Overlay networks: VXLAN, GRE for creating virtual networks over physical infrastructure.
4. Software-defined Networking (SDN): Integration with controllers for advanced network management.

User-Space Networking Tools and Management

1. Configuration Utilities

1. `ip` (from iproute2): Modern tool for configuring interfaces, routes, rules.
2. `ifconfig`: Legacy tool, still widely used.
3. `nmcli`, `nmtui`: NetworkManager command-line and text UI.

1. Socket Programming

Linux provides a rich API for socket-based communication:

1. Unix sockets: Inter-process communication.
2. INET sockets: TCP/UDP over IP.
3. Raw sockets: Custom protocol implementation or network analysis.

1. Network Monitoring and Diagnostics

1. `ping`, `traceroute`, `netstat`, `ss`, `tcpdump`, `wireshark`.

Advanced Networking Features

1. Quality of Service (QoS)

Linux supports traffic shaping and prioritization via tc (traffic control), enabling bandwidth management and latency control.

1. VPN and Tunneling

Tools like OpenVPN, WireGuard, and IPsec enable secure remote connectivity.

1. Network Boot and PXE

Linux supports network booting via PXE, facilitating diskless systems and automated deployments.

Security Mechanisms in Linux Networking

1. Firewall rules: Define access policies.
2. Secure protocols: SSH, TLS.

3. Kernel security modules: SELinux, AppArmor.
4. Network namespace isolation: Limits attack surface.

Conclusion

The Linux networking architecture is a testament to the operating system’s flexibility, robustness, and modularity. From hardware interface management to complex routing, firewalling, and virtualization, Linux offers an extensive suite of tools and mechanisms to build, manage, and secure networks of all scales. Its layered design ensures that each component interacts seamlessly, enabling developers and administrators to customize and optimize network configurations for a variety of use cases.

By deeply understanding this architecture, one gains the ability to troubleshoot complex network issues, implement advanced networking solutions, and contribute to the development of Linux's ever-evolving network capabilities. As networking technologies continue to advance, Linux remains at the forefront, adapting through open-source collaboration and innovation.

Not everyone sits down with a clear intention to learn. Sometimes reading starts simply because something catches attention. A title, a recommendation, or a moment of curiosity. The option to download *The Linux Networking Architecture* makes those moments easier to follow, turning small sparks of interest into meaningful engagement.

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Interaction adds another layer. Highlighting lines that stand out, adding brief notes, or placing bookmarks creates a sense of ownership. The book slowly reflects the reader’s thought process, becoming more personal with each interaction.

Search tools quietly enhance confidence. Readers know they can always find what they need without frustration. This makes the book useful not only for reading, but also for quick reference and clarification. It becomes something to return to, not something to finish and forget.

Affordability encourages exploration. When access is free or low-cost through legal platforms, readers take more chances. They open books outside their usual interests and follow ideas without fear of wasted effort. This openness often leads to unexpected insights.

Public libraries in digital form play a crucial role. Project Gutenberg, Open Library, and Internet Archive preserve valuable works and make them available to a global audience. Academic platforms extend this access by offering research and analysis that add depth and context.

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In professional life, downloadable books function quietly in the background. They are consulted when questions arise, revisited when clarity is needed, and relied upon for reference. Learning integrates into work instead of interrupting it.

Students experience a similar advantage. Study becomes flexible rather than rigid. Difficult sections can be revisited without pressure, and understanding develops gradually. Offline access supports focus when connectivity is limited.

Different reading personalities find comfort here. Some readers prefer structure, others prefer exploration. The format supports both without judgment. *The Linux Networking Architecture* adapts to individual habits rather than enforcing a single approach.

Accessibility features broaden participation. Adjustable text sizes, reading assistance, and compatibility with support tools allow more people to engage comfortably. These options quietly remove barriers without drawing attention to themselves.

Organization becomes intuitive over time. Digital libraries grow alongside interests. Notes remain saved, highlights preserved, and bookmarks easy to find. Learning feels continuous instead of fragmented.

There is also a subtle emotional shift. When readers know a book is always available, anxiety decreases. There is no rush to understand everything at once. Ideas are allowed to settle slowly, becoming clearer with each return.

Global access adds richness. Readers from different backgrounds engage with the same material, often interpreting ideas through unique lenses. This shared access broadens perspective and encourages reflection.

Exploration becomes easier when effort is low. Readers connect ideas across topics, move between subjects, and allow curiosity to guide them. This kind of learning feels organic rather than planned.

Long-term engagement grows quietly. Notes taken months ago still matter. Bookmarks still guide attention. The book becomes part of an ongoing learning process rather than a temporary focus.

Over time, books stop feeling like tasks. They become companions. They wait without demanding attention, ready to be opened again when questions return.

This steady presence shapes attitude. Learning feels less intimidating. Curiosity feels welcome. Understanding feels earned through patience rather than speed.

Accessing *The Linux Networking Architecture* in this way reflects how people actually live. Attention moves, time fragments, interests evolve. The book adapts to these realities instead of resisting them.

There is no clear endpoint here. Reading pauses and resumes. Understanding deepens gradually. Ideas resurface in new contexts.

What remains is familiarity. The comfort of knowing that insight is close, waiting quietly, ready to be explored again whenever curiosity decides to return.

Questions & Answers About the linux networking architecture

No	Question	Answer
1	What are the main components of Linux networking architecture?	Linux networking architecture primarily consists of network interfaces (like Ethernet, Wi-Fi), the network stack (including layers such as IP, TCP/UDP), network drivers, and network services like DHCP, DNS, and routing daemons that facilitate communication between devices.

2	How does Linux handle network packet processing?	Linux processes network packets through a layered architecture involving kernel modules that handle packet reception, filtering (iptables/nftables), routing, and delivery to user-space applications. The netfilter framework manages packet filtering and NAT, while the socket API provides interfaces for user applications.
3	What role do network namespaces play in Linux networking?	Network namespaces in Linux allow the creation of isolated network environments, each with its own network interfaces, routing tables, and firewall rules. This is essential for containerization and virtualization, providing separation and security for different network stacks within the same host.
4	How is routing managed in Linux networking architecture?	Routing in Linux is managed via routing tables, which determine how packets are forwarded based on destination IP addresses. Commands like 'ip route' or 'route' configure static routes, while dynamic routing protocols can be implemented using daemons like quagga or FRRouting.
5	What is the significance of network bridges and virtual switches in Linux?	Network bridges and virtual switches in Linux enable the connection of multiple network interfaces at Layer 2, facilitating network segmentation, virtualization, and container networking. Tools like Open vSwitch provide advanced virtual switching capabilities for cloud and data center environments.

Linux networking, network stack, TCP/IP, network interfaces, routing, network protocols, socket programming, network configuration, Linux kernel networking, network security

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Reading The Linux Networking Architecture in digital format can be a highly effective and enjoyable experience when done with the right approach. Unlike traditional printed books, digital reading offers flexibility, customization, and powerful tools that can improve comprehension and retention. However, without proper habits, digital reading can also lead to fatigue or reduced focus. Applying practical reading strategies helps you get the most value from The Linux Networking Architecture.

One of the most important tips is to break your reading into manageable sessions. Long, uninterrupted reading on a screen can strain the eyes and reduce concentration. Instead of reading for several hours at once, divide your time into shorter sessions with regular breaks. This approach helps maintain focus, improves understanding, and prevents mental exhaustion. Using techniques such as the Pomodoro method—reading for 25–30 minutes followed by a short break—can be particularly effective.

Using bookmarks is another simple yet powerful habit. Most digital reading platforms allow you to bookmark chapters, sections, or specific pages. Bookmarks make it easy to return to important parts of The Linux Networking Architecture without scrolling or searching manually.

This is especially useful for long documents, study materials, or reference-based reading where you may need to revisit certain sections frequently.

Highlighting key points and adding annotations can significantly improve comprehension. Digital highlights allow you to visually mark important ideas, definitions, or summaries. Adding notes in your own words helps reinforce understanding and creates a personalized study guide. Over time, these highlights and annotations turn The Linux Networking Architecture into an interactive learning resource rather than passive reading material.

Adjusting screen settings plays a crucial role in reading comfort. Most reading apps allow you to customize font size, font style, line spacing, and background color. Increasing font size and line spacing can reduce eye strain, while using dark mode or sepia backgrounds may improve readability in low-light environments. Adjusting screen brightness to match ambient lighting further enhances comfort and protects eye health during long reading sessions.

Creating a focused reading environment

A distraction-free environment improves reading efficiency and enjoyment. When reading The Linux Networking Architecture, try to minimize notifications from messaging apps or social media. Many devices offer “focus mode” or “do not disturb” settings that help maintain concentration. Choosing a quiet, comfortable location with proper lighting also contributes to a better reading experience.

For study or professional reading, setting clear goals before starting can be beneficial. Decide whether you are reading for general understanding, detailed analysis, or quick reference. Clear objectives help guide how deeply you engage with the content and which sections deserve closer attention.

Access Formats

The Linux Networking Architecture is often available in multiple formats, each offering unique advantages. Understanding these formats helps you choose the one that best matches your preferences, devices, and reading habits.

PDF format:

PDF is one of the most common formats for The Linux Networking Architecture. It preserves the original layout, fonts, and images, ensuring consistency across devices. PDFs are ideal for documents with structured layouts, charts, or academic formatting. They work well on computers and tablets but may require zooming on smaller screens. Annotation and highlighting tools are widely supported in PDF readers, making this format suitable for study and professional use.

ePub format:

ePub is a flexible and reflowable format designed for eReaders and mobile devices. Text automatically adjusts to different screen sizes, allowing comfortable reading on smartphones and dedicated eReaders. If you prioritize readability and customization, ePub is often the best

choice for reading The Linux Networking Architecture on the go. However, complex layouts may not always appear exactly as intended.

Audiobook format:
Audiobooks offer an alternative way to experience The Linux Networking Architecture content. Instead of reading text, users listen to narrated versions. Audiobooks are ideal for multitasking, commuting, or users who prefer auditory learning. While they do not allow highlighting or visual reference, they provide accessibility and convenience for busy lifestyles.

Selecting the right format depends on your device, reading goals, and personal preferences. Many readers combine multiple formats—for example, reading the PDF for detailed study and listening to the audiobook for review or reinforcement.

Benefits of Digital Copies
Digital copies of The Linux Networking Architecture offer several advantages over traditional printed books, making them increasingly popular among modern readers. One of the most significant benefits is portability. Hundreds or even thousands of digital books can be stored on a single device, eliminating the need for physical storage space and making it easy to carry an entire library anywhere.

Searchable text is another major advantage. Instead of flipping through pages, digital readers can instantly search for keywords, phrases, or topics within The Linux Networking Architecture. This feature is invaluable for research, study, and professional reference, saving time and improving efficiency.

Offline access enhances flexibility. Once downloaded, digital copies of The Linux Networking Architecture can be accessed without an internet connection. This is especially useful for travel, remote study, or areas with limited connectivity. Offline access ensures uninterrupted reading regardless of location.

Annotation tools add further value. Highlights, notes, and bookmarks transform digital reading into an interactive experience. These tools help readers organize information, revisit important sections, and personalize their learning process. Notes can often be exported or synced across devices, providing continuity and convenience.

Cost and sustainability advantages
Digital copies are often more affordable than printed books. Many platforms offer discounts, subscription models, or free access to public domain works. Over time, digital reading can significantly reduce costs for students, professionals, and avid readers.

From an environmental perspective, digital books reduce paper consumption, printing, and transportation. Choosing digital versions of The Linux Networking Architecture contributes to more sustainable reading habits and a smaller environmental footprint.

Accessibility and inclusivity

Digital reading platforms often include accessibility features that benefit a wide range of users. Adjustable fonts, text-to-speech options, screen reader compatibility, and contrast settings make The Linux Networking Architecture more accessible to readers with visual impairments or learning differences. These features help ensure that knowledge is available to a broader audience.

Balancing digital and traditional reading

While digital copies offer many benefits, balancing them with healthy reading habits is important. Taking regular breaks, maintaining good posture, and limiting screen exposure before bedtime help prevent fatigue and eye strain. Some readers choose to alternate between digital and printed formats depending on the context and purpose of reading.

Building a long-term reading habit

Consistency is key to getting the most value from The Linux Networking Architecture. Setting a regular reading schedule, even for a short daily session, helps build a sustainable habit. Tracking progress using reading apps or journals can increase motivation and provide a sense of achievement.

Final thoughts on reading The Linux Networking Architecture

Reading The Linux Networking Architecture digitally offers flexibility, efficiency, and powerful tools that enhance understanding and engagement. By applying effective reading strategies, choosing the right format, and taking advantage of digital features, readers can create a comfortable and productive reading experience. Whether for learning, professional growth, or personal enjoyment, digital copies of The Linux Networking Architecture provide a modern and accessible way to consume structured knowledge anytime and anywhere.