White Paper

JUNOS:
The Next-Generation in Enterprise Router OS

JUNOS Software for Secure and Assured Networks

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Abstract

While business requirements are placing more and more demands on networks each year, the fundamental software architectures of the underlying routing platforms have changed little in the last decade. Legacy router operating systems were never designed with today's dynamic IP traffic flows in mind, forcing users into difficult tradeoffs and compromises among business and operations needs.

The fundamental design limitation is the monolithic software architecture of older Internet operating systems. In attempting to keep up, the code base of the legacy OS has grown unwieldy, constraining the intelligence and agility available to support dynamic IP traffic flows. The resulting challenges of the older systems include security issues, such as console port lockup during distributed denial of service (DDOS) attacks; software stability concerns; performance degradation, particularly with services activated; and the operations drain to manage the complex systems.

In response to these challenges, Juniper Networks developed its modular operating system – JUNOS. With its modern software architecture JUNOS enables organizations to build smart networks to meet the diverse requirements of dynamic IP flows.

The performance and integrity of JUNOS have been proven in the largest IP networks in the world. Now, JUNOS is available to enterprises, government agencies, and research and education organizations through the introduction of Juniper Networks J- and M-series routers.

The modular software architecture of JUNOS provides full control over the router with protected processing resources for each function and next-generation Command Line Interface (CLI) to ease configuration and management. With only one code train, JUNOS ensures continuity of features that work as expected, without problem, from the first customer shipment.

Deploying Juniper Networks routers adds new levels of security, uptime, performance and operations flexibility to the network, with many systems and tools to assist platform introduction. With Juniper Networks routers, organizations can keep pace with their changing needs, satisfying the full set of requirements for secure and assured, next-generation IP networks.

Reconsidering the Status Quo

Historically the needs of applications for IP networks were relatively straightforward with the primary concern simply being connectivity. Now, the introduction of new voice and video applications and the expanding user base within and outside corporations have created many new requirements. Today's IP networks must balance between the traditional operations needs of performance, reliability and security and the expanding business needs for increased network intelligence, broader access policies and greater device flexibility.

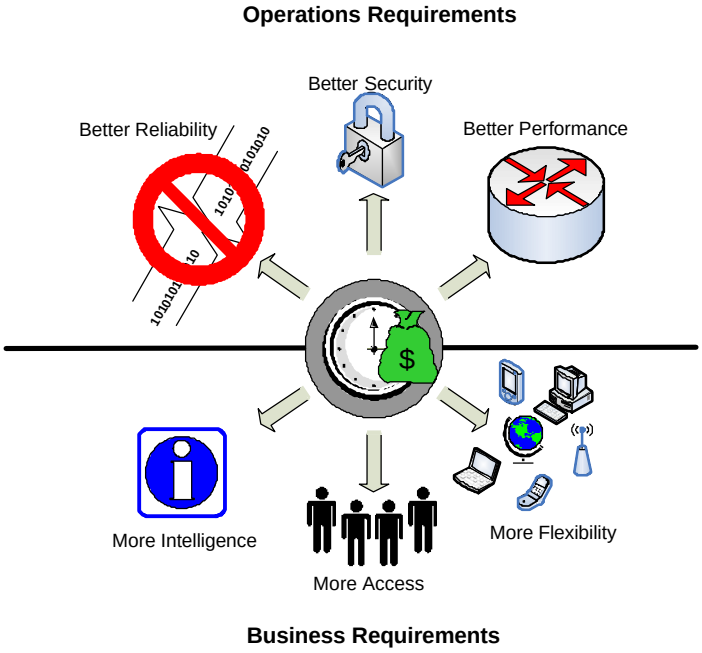

Figure 1. Today's Networks Require Many Trade-offs.

While business requirements have been placing more and more demands on networks each year, the fundamental software architectures of the routing systems underlying the infrastructure have changed little in the last decade. The operating systems of legacy routers were designed prior to the development of most of today's dynamic IP applications and within the hardware and software technology constraints of the time.

The fundamental design limitation in meeting emerging needs is the monolithic software architecture of older Internet operating systems. In attempting to keep up with all the new demands, the code base of legacy OS has grown unwieldy, constraining the intelligence and agility available to support dynamic IP traffic flows. This limitation has become even more debilitating as more and more services are now being integrated into the same already overextended code base.

The typical design has a single, monolithic code base with all routing functions intertwined and sharing the same CPU cycles. The overextended, commingled architecture creates inherent processing conflicts that impact the security, stability and performance of the router. For example, the shared, commingled architecture allows the packet forwarding function of the router to consume all processing resources, leaving control and service functions starved for cycles.

For this reason, it's not uncommon to hear about the console port of a legacy router locking up during a distributed denial of service (DDOS) attack. As another example of the processing limitations of commingled architectures, most organizations significantly over-engineer their network instead of using available QOS mechanisms. In legacy router operating systems, activating these QOS tools can severely degrade throughput performance because processing resources cannot be managed effectively.

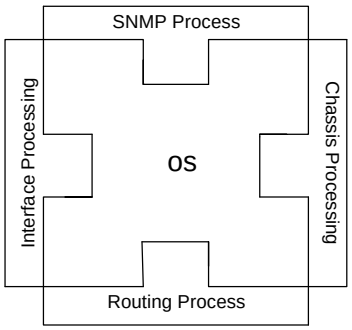

Figure 2. Commingled Legacy Operating System Architecture.

The commingled architecture also fails to isolate problems, so small issues can rapidly grow into an extensive outage. Consider a small glitch from a task with a memory leak or an error that causes overwrite of another task's code or data structures. These types of errors can lead to more tasks failing and eventually a crash of the entire operating system. The only way to recover from this failure type is to reboot the whole platform.

Further, the routers are intrinsically complex – difficult to configure and maintain – requiring significant time and high levels of expertise. Traditional CLI takes multiple steps to perform basic functions and offers minimal protection against simple errors that can create security holes or performance degradation. With many details to consider in how one feature or function may impact another, network changes require careful design, engineering and implementation that can delay application rollout for months.

Another challenge of the commingled architecture is new feature development and the resulting large number of images to support all possible platform permutations. The overall software architecture becomes so enormous that it loses flexibility, scalability and system stability. Modifications become extremely difficult to make because the act of adding a single new feature can impact the entire code base. In addition, the size and complexity of the code determine how rapidly a vendor can issue new software releases to correct acute internetworking problems or add important new features.

While legacy systems have attempted to keep pace with all the changing requirements during the last decade, the traditional method of "one image per feature or fix" only creates more challenges. With a patchwork of legacy router code that can be platform-, interface- and release-specific, over 5000 images are available for enterprise-class devices. Some organizations run as many as one hundred different image versions. Finding the right image for each device to fit a specific requirement is itself a daunting effort.

With the transparency of software complexity in legacy router OS, organizations typically avoid software maintenance as much as possible because something as simple as a single feature-add can impact the entire code base. When patches and upgrades are absolutely needed, it can take months to evaluate and test the many different device images for system stability and interoperability. Because of the pain of software updates, organizations also commonly order many more features and much more memory than

needed to avoid the hassle of future changes.

Introducing JUNOS – A Next-Generation Operating System

Modern IP applications require a smart network that can meet a diverse set of requirements for security, uptime, performance and flexible operations without compromise. Addressing these challenges requires a new design approach founded in software modularity and modern programming techniques.

The JUNOS operating system from Juniper Networks is purpose-built for the secure and assured networks demanded by today's dynamic IP traffic flows. By running the modular JUNOS software on protected system resources, Juniper Networks routers overcome the many design drawbacks of legacy router operating systems.

Juniper Networks routing products are renowned within the service provider community for their advanced systems and operations designs. Today over 90% of the Internet's traffic passes through Juniper Networks routers. Now as enterprise networks must increasingly meet many of the same service levels as carrier infrastructure, Juniper Networks extends its advanced JUNOS operating system to smaller platforms in the J- and M-series routers.

Juniper Networks system architecture represents a set of fundamental changes in the design and development of routing platforms. Juniper Networks routers employ a strict division of labor to provide intelligence and performance at scale in a way that no other platform can. The modular system architecture enables organizations to meet the diverse demands of next-generation IP infrastructures.

The development approach is founded on four key design principals.

- **Protected Processing** – always-available resources to ensure router stability and control
- **Modular Software Architecture** – clean separation of independent software functions
- **Next-generation CLI** - advanced configuration and diagnostic tools
- **One Image Train** – common code base developed through a rigorous release process

The following considers each of these key design principals in more detail with the many resulting benefits of these principals discussed in the next section.

Protected Processing Resources – Juniper Networks platforms guarantee resources for each function through a strict division of labor that assures that one function cannot starve another. The modular design separates control functions from packet forwarding and from services processes.

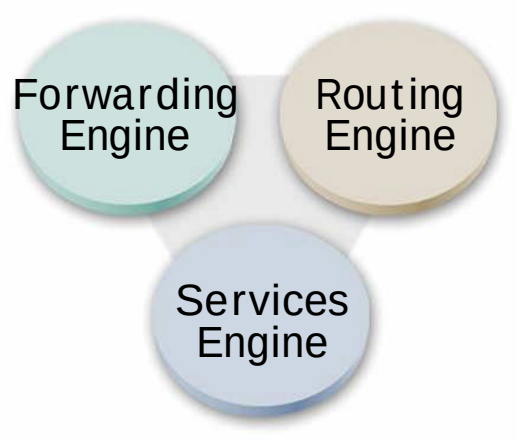

Figure 3. Modular System Architecture Juniper Routers

The world-class architecture consists of three independent system components – the Routing Engine, the Forwarding Engine, and Services Engine. Each has its own dedicated ASIC or assigned CPU resources along with protected memory so that processing conflicts are never an issue.

- Routing Engine - manages all routing and control functions of the system, including the maintenance of peer relationships, routing protocol processing and the creation and update of the routing and the forwarding tables
- Packet Forwarding Engine – receives packets, performs routing lookups and sends the packets to the output interfaces
- Services Engine - provides advanced packet processing services such as Network Address Translation, encryption, Stateful firewall filters, accounting and real-time performance monitoring

The robust protected memory architecture of Juniper Networks routers allocates a unique address space to each operating process. Since each task has its own dedicated ASIC or protected processing resources, JUNOS provides intelligence and performance at scale in a way that no other OS can approach.

By maintaining visibility into CPU and memory utilization of individual processes, JUNOS allows for unprecedented control and predictability of the IP infrastructure. Armed with real-time information and tighter control of the IP network, network managers can proactively head off issues such as performance degradation and downtime.

Modular Software Architecture – Complementing the division of labor in processing resources is the modular software architecture of the JUNOS operating system. JUNOS software was built for stability using modern operating system design principles and ensures that changes or complications in one module do not impact the entire operating system.

Modular software architecture is fundamental to securely and reliably supporting a large number of dynamic IP traffic flows with different performance needs. The JUNOS operating system is a completely modular software platform enabling a functional division of labor for seamless development and operation of many advanced features and capabilities.

By partitioning the software system, tasks are broken into manageable subsets that interact infrequently. Loading of one does not affect the other, eliminating a common failure mode

of legacy routers. Between these independent modules, there are clean, well-defined interfaces that provide interprocess communication, resulting in a highly reliable software architecture.

The routing protocols, interface management, chassis management, SNMP management and other key functions each execute as independent processes with their own memory protection. Key processes such as the Routing Protocol Daemon and SNMP can be independently restarted or changed without adversely affecting the operation of the router.

The development of the modular JUNOS during the past eight years has propelled operating system architectures into the next generation within the networking industry. Modularity is now followed as best practice software design in all next-generation systems. While the 1.0 release of the newest systems of Juniper Networks' competitors use modular software, the enterprise-class devices remain tethered to the shortcomings of legacy software code and its commingled architecture.

Next-generation CLI – JUNOS extends its modern design beyond system architecture with advanced administrative features. The structured CLI of JUNOS will be immediately intuitive to users of UNIX-based host systems. Its intelligent, hierarchical organization is well suited to operations tasks, with a number of innovative features built-in to ease overall network deployment, configuration and restoration.

- **Command Help and Command Completion –** The JUNOS CLI provides context-sensitive help with the full listing of all available commands at each level of the command hierarchy. Additionally, the CLI will complete a partially entered command or option.
- **Commit Check** - In the CLI editor the user creates a set of changes that are applied as a set of grouped commands rather than individually as is the case with competitors. Within the editor, the user can verify the syntax of a command set and then apply all changes in one step, rather than entering changes line-by-line.
- **Commit Confirm** – In remotely configuring devices, there's always a risk of accidentally isolating the device or terminating the management session. The Commit Confirm command helps prevent loss of connectivity in these situations, as the system reverts back to its previous configuration if it does not receive a notice of change confirmation.
- **Rollback** - If an activated configuration degrades operations, JUNOS CLI offers a rollback command to quickly restore one of the fifty prior configurations. Using rollbacks to recover previous configurations is faster and easier than undoing individual commands.
- **Configuration Compare -** The J-Web graphical management interface for J-series displays the commit history along with the current configuration file. Network managers can also initiate a comparison between two different configuration versions to highlight file differences.
- **Rescue Button –** The J-series routers have a recessed button linked to an optionally defined rescue file. The rescue button is unlike a router reset which typically reboots to the same problematic configuration. With the button, any on-site personnel can initiate quick and secure rollback to the rescue configuration.

One Image Train – Juniper Networks follows a rigorous, well-defined development release process with a single code base across its J-, M- and T-series routing platforms. The common code base, along with the inherent flexibility of independent modules within JUNOS, enables efficient feature development and rigorous regression testing to quickly introduce

new capabilities required by customers.

Under Juniper Networks strict development standards, features are added, supported, tested and reliably carried forward, with major releases four times a year and minor updates available monthly. As a modular software platform, many developers can create new features for JUNOS simultaneously without impacting each others' work. Appropriate features developed for one platform are available in others, for both enterprises and service providers, enabling rapid feature introduction and consistency throughout the portfolio.

The uniform code base of JUNOS also allows software developers to perform rigorous regression testing between releases as a fundamental part of the product development process. The approach provides a consistent and predictable path to system maintenance and upgrade and ensures continuity of features with high quality code that works as expected, without problem, from the very first customer shipment.

JUNOS Aligns Network Capability and Business Requirements

Juniper Networks routers enriched by the modular operating system – JUNOS – enable organizations to design secure and assured networks that meet the diverse requirements of dynamic IP flows. Deploying Juniper Networks routers adds new levels of security, uptime, performance and operations flexibility with many systems and tools to assist introduction to the network and to operations teams.

SUPOR Benefits of the JUNOS Operating System

The many benefits of the advanced architecture design of Juniper Networks routers can be remembered with the mnemonic S-U-P-O-R. Juniper Networks delivers new levels of Security, Uptime, Performance, and Operations in Routers as summarized in the table.

SUPOR Advantages	Key Differentiator
Security	Protected system resources ensure complete router control. Even while under attack, the console port is always available to add new filters and policies in a few simple steps.
Uptime	Modular JUNOS isolates problems before they can proliferate to deliver high software stability with next-generation CLI providing protection against configuration errors.
Performance	Modular JUNOS software with protected resources enables QOS, multicast, filters, MPLS and other sophisticated packet processing functions without performance compromise.
Operations	One, common JUNOS code base streamlines deployment, patches and software upgrades with multiple tools for platform implementation and management.
Routers	All features are available on the industry's only service provider quality routers for the enterprise: the J- and M-series from Juniper Networks.

Table 1: SUPOR Advantages

Security – The level of security in any network is always set by the weakest link, so device-level security is a fundamental consideration for each and every network node. The software modularity of the JUNOS architecture fundamentally defends against infrastructure attacks by always protecting the processing resources of the control plane. The control functions are always available for updates such as new filter terms, and the

router can always exchange control messages with other systems.

The console port never locks up or slows down as in legacy equipment. Operations is always in control. Filters to block distributed DOS attacks can always be added without taking the router out of service. Using the next-generation CLI of JUNOS is fast and easy with changes entered into an offline editor and then committed to the router in one quick update.

Another key security consideration is the number of supported filter terms. Juniper Networks routers support many filters per interface, providing granular control over traffic without impacting system performance. IT staff can define controls to block, rate limit or monitor specific flows and applications, proactively stifling problems before they are even recognized and without making performance tradeoffs.

Uptime – As networks are primarily software controlled, improving the dependability and resiliency of software is essential to better network stability. JUNOS was built for stability using modern operating system design principles, including a modular program architecture and a robust, protected memory architecture. JUNOS ensures that changes in one module do not proliferate into other areas. Each processing function is independent and self-sufficient.

The modular software design of JUNOS also supports fast restart and upgrade of individual modules, as there is no need to reboot the entire chassis. For example, if the routing protocol process fails or needs to be restarted for any reason, forwarding continues with Graceful Restart. The same mechanisms also allow the user to upgrade a specific JUNOS module without rebooting the entire system.

Juniper Networks extends its software dependability beyond code reliability with administrative features designed to prevent operational errors. Configuration error is one of the top reasons for network and security failures. The JUNOS CLI with its advanced change management functions helps to reduce operational risks and downtime. Its intelligent, hierarchical organization is well suited to operations tasks, with a number of capabilities built-in to ease overall network deployment and configuration.

Performance – The protected processing of JUNOS provides organizations with comprehensive, real-time granular control over network traffic. Not only is a comprehensive performance management toolbox available, but the routers sustain high forwarding rates even as more and more advanced routing services are turned on. Organizations no longer have to choose between high throughput and tight traffic control.

Juniper Networks routers enable support of real-time applications such as voice and video with high quality of service(QOS). The advanced set of QOS tools within JUNOS includes multiple levels of granular QOS per-port, per-logical circuit (DLCI, VC/VP, VLAN), and per-channel (to DS0) for traffic prioritization. Available QOS mechanisms include classification, rate limiting, shaping, weighted round robin scheduling, strict priority queuing, weighted random early detection, random early detection, and packet marking.

Staff can count on Juniper Networks QOS features when needed most – during periods of congestion. The dedicated hardware of M-series and the advanced scheduling mechanisms of J-series ensure resource availability for the QOS tasks, even under high traffic load.

Operations – Common JUNOS software across all platforms and implementations eases operations with straightforward software updates and upgrades. With just one code train, JUNOS enables fast certification of releases and full interoperability between products. Managing the router with the structured JUNOS CLI is more intuitive and less error prone than editing commands using ASCII-based CLIs.

Additionally, the modular software design of JUNOS supports a licensing model that enables timely convergence between business requirements and operating system features. Through its licensing, JUNOS provides the flexibility to upgrade software features, and even add interfaces on multi-port cards in the J-series. As an organization's needs change, licensing supports fast activation of new capabilities, without lengthy upgrade projects to test and certify new software and without truck rolls to individual sites.

Interoperability and Adoption

Deploying Juniper Networks routers provides new levels of security, uptime and performance but also introduces interoperability considerations and potential changes to operations functions and staff. Juniper Networks provides the tools and support to manage the introduction of new routing equipment into the network and to operations teams.

Juniper Networks has many years of experience in providing, designing and implementing solutions that interoperate with Cisco IOS-based platforms. Juniper Networks systems are deployed side-by-side with the devices worldwide in thousands of corporate, government, and education networks, as well as in the 25 largest service provider networks in the world.

Customers using Juniper Networks routers for the first time will find many available tools and support services to assist them. The CLI of the JUNOS operating system is intuitive – easy-to-learn and use -- especially for experienced network operations staff who typically pick up the key functions in just a few hours. For new staff, Juniper Networks provides the J-Web browser-based interface. The JUNOS software includes JUNOScript, a robust XML-based API that eases scripting and systems integration. Additionally, a strong Customer Service and Support group offers 24X7 support, extensive education and professional services, technical documentation and many online tools, including an IOS-to-JUNOS translator to convert Cisco CLI to JUNOS CLI.

Summary

JUNOS is an advanced software solution that aligns network capabilities with business requirements, enabling organizations to meet their diverse set of business and operations needs. The modular, coherent design of the JUNOS software is fundamentally different from legacy router OS that is hindered by a commingled software architecture.

JUNOS overcomes the operations challenges of legacy OS by ensuring that operations staff is always in full control, providing strong security with high system stability and delivering predictable performance, without compromise, all on a uniform code base.

The performance and integrity of JUNOS are proven in the world's largest IP networks, including the top 25 service provider networks in the world. By running the modular JUNOS software on protected system resources, Juniper Networks routers combine reliability with the flexibility to enable advanced routing, QOS, filtering, security and administrative policies, and usage and performance monitoring.

The many benefits of the advanced architecture design of JUNOS and Juniper Networks routers can be remembered with the mnemonic S-U-P-O-R. Juniper Networks delivers new levels of Security, Uptime, Performance, and Operations in Routers. Juniper Networks routing platforms provide the best infrastructure foundation to build the secure and assured networks demanded by today's dynamic IP traffic flows.