FTOS: A Modular and Portable Switch/Router Operating System
Optimized for Resiliency and Scalability

Introduction
As Ethernet switch/routers continue to scale in terms of link speed and port density, device resiliency is becoming an indispensable system attribute. For example, high degrees of traffic aggregation mean that even short periods of interrupted operation can disrupt a large number of traffic flows and users, potentially violating numerous SLAs.

The best approach to maximizing the reliability, resiliency and stability of switch/routers involves the application of sound design principles:

• Eliminating single points of failure in as many system components as possible, including both hardware and software
• Constraining any failures that do occur to only one system component or subsystem
• Ensuring that when a subsystem fails, becomes compromised, or needs updating, the recovery can be accomplished quickly without disrupting the continued operation of the overall system
• Minimizing the number of operating systems, code branches and releases in development across product lines

These principles are the basis for the Force10 Networks Resiliency Architecture shown in Figure 1, which allows the FTOS switch/routers to continue network operations during a number of fault conditions. These include the failure of hardware components, software faults and restarts, link failures, protocol restarts, and attempts by intruders to disrupt normal traffic flow. Force10 Networks adopted the multi-layered resiliency architecture model after a comprehensive analysis of the causes of system crashes and all potential sources of catastrophic system failure, which showed that the majority of network disruptions are due to software failures and user mistakes. By focusing development efforts to improve manageability and serviceability in FTOS, Force10 Networks is taking a proactive approach to reducing network downtime. A switch/router software environment that features higher reliability and consistent functionality and management capabilities contributes to a significant reduction in operational expenses, which is a major component of the total cost of ownership (TCO) for the network.

As Figure 1 depicts, device resiliency involves a combination of mutually supportive hardware and software features that work together to maximize the reliability and availability of the device.

Force10 Networks switch/router product lines depend on the software resiliency provided by the FTOS operating system, which incorporates an extensive range of control plane and management features for ultra high-performance L2 switching and L3 routing.

The remainder of this paper discusses the FTOS software architecture and focuses on the functionality and features that maximize portability, system scalability and stability, software resiliency and overall system resiliency by complementing the resiliency features at the other layers of the Resiliency Architecture.
FTOS Software Portability, Modularity and Resiliency

FTOS is based on NetBSD, a highly portable, open source operating system that has been optimized for networking applications. From the perspective of a switch/router operating system, NetBSD has three unique advantages:

1. An unparalleled degree of protocol maturity and stability derived from its roots in BSD Unix.
2. A modern kernel architecture, featuring process modularization and memory protection.
3. A high degree of portability across multiple hardware architectures allowing a wide selection of control processors (NetBSD currently supports 17 microprocessor families and over 50 distinct hardware platforms).

When these processes need to share information, the exchanges are all channeled through a robust inter-process communication (IPC) mechanism, which allows processes to communicate while maintaining memory protection between them.

The hardware abstraction layer (HAL) is a layer of software that decouples FTOS from the specific details of the underlying hardware. The primary function of HAL is to isolate the modular processes from a major rewrite whenever the FTOS is ported to a different hardware platform. A more detailed description of HAL and the benefits it provides are the subject of a companion white paper: The Hardware Abstraction Layer: Enabling FTOS to Span the Switching and Routing Infrastructure with a Consistent Feature Set and Unified Management

The major features and benefits of the FTOS architecture include:

- **Modularization**
  With process modularization and separation from kernel space, switch/router control plane functions can be modified independently by eliminating the "Spaghetti Code" effect that causes unexpected interactions between functions. Because these changes are separate from the kernel, the possibility of introducing instability to the underlying operating system is eliminated. By the same token, new control-plane features and processes can be developed and tested in parallel without disrupting existing ones.

- **Protected Memory**
  The FTOS memory architecture allocates a separate protected address space for each independent process and its associated subsystems. Communications between subsystems within the same process can happen directly via sharing of the process’ protected memory space, maximizing control-plane performance. On the other hand, communication between different processes is restricted to the IPC message

Figure 2 shows the general architectural structure of the FTOS software system that has been built on NetBSD. The basis of the system is the kernel whose functions are limited to providing a stable operating system and performing tasks such as memory allocation and scheduling. Other applications that traditionally execute in the kernel in a monolithic network operating system have been moved to user space where they run as independent, modular processes. Separate processes have been created for:

- Layer 2 functions and protocols (STP, LACP, etc.)
- Layer 3 functions and protocols (IS-IS, OSPF, BGP, static routing)
- Various system services and management functions (SNMP, CLI, etc.)
- Security services and protocols (SSH, TACACS+/RADIUS, ACLs)
The processor architecture used in the E-Series and C-Series allows the creation of a manager/agent relationship between the RPM processors and the line card processors. Each RPM processor’s FTOS compilation needs to include only the required cross-platform functional modules, while the line card processor’s FTOS version includes only the appropriate platform-specific modules plus the cross-platform modules needed to support the manager/agent relationship. The additional processing power allows the E-Series and C-Series switch/router control planes to scale to support very large system and network configurations.

### Integrated Software Development and Quality Assurance

Force10 has leveraged the modularity of the FTOS architecture to fully integrate testing of code directly into the development process. This unique and revolutionary development process incorporates automatic regression testing of every block of new code and every new feature before integration into a new FTOS build. This process assures the integrity of new code with full regression testing of every new feature and improves developer productivity by providing automated QA feedback directly to the programmer.

### Linear, Sequential OS Evolution for All Switch/Router Product Lines

Because of the modularity of FTOS, a number of software developers can work in parallel to create new features that will be embedded in separate processes. The modularity and integrated QA described above ensure that unexpected interactions will not occur. These attributes make it practical for FTOS to be based on a single linear succession of OS releases, as shown in Figure 3, without the complexity of parallel software upgrade paths supporting different feature sets, a fairly common practice among vendors of non-modular switch/router operating systems.
Consistent Features/Functionality Across Platforms

A consistent set of switch/router features throughout the LAN infrastructure from the data center and core to the wiring closet and branch office simplifies network design and facilitates consistent implementation of end-to-end QoS and security policies. Table 1 shows the range of consistent, cross-platform FTOS functionality and highlights the value of a single switch/router OS that spans the entire network.

Distributed Processing in the FTOS Control Plane

In order to achieve massive scalability together with unparalleled resiliency, the Force10 Networks switch/routers use a fully distributed architecture with all packet forwarding decisions made by the data plane ASICs, and all control functions performed by the switch/router CPU(s) running FTOS.

In the E-Series and C-Series modular switch/routers, FTOS processing is distributed across processors on each route processor module (RPM), plus an additional processor on each line card. On the E-Series RPM, an FTOS CPU is dedicated to each of three functional areas: Layer 3 processes, Layer 2 processes, and management/control processes, as shown in Figure 3. The modularity of FTOS allows the individual control plane processes to be readily partitioned among the three RPM processors. In the C-Series and S-Series switch/routers, there is a single FTOS CPU that performs all control plane and management functions.

Distribution of control processes greatly increases the processing capacity of the control plane, providing massive scalability and processing power. Resiliency is also significantly improved because failure of a process on a CPU will not affect the other two functions. Dedicated memory for each of the three RPM CPUs provides an additional

<table>
<thead>
<tr>
<th>Feature</th>
<th>E-Series</th>
<th>C-Series</th>
<th>S-Series</th>
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<tbody>
<tr>
<td>Unix-like NetBSD modular OS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>One source tree for all platforms</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>One FTOS version for all platforms</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Modular feature development and QA</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Feature parity between FTOS versions</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Industry standard CLI with ease of use features</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Identical CLI on all platforms</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>High-end management and CLI features</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>In-service debugging and diagnostic features</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
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</table>

Table 1. Cross platform features/functionality of FTOS enabled by HAL

Figure 4. Distributed processing control plane with FTOS on the E-Series platform
level of physical memory protection across the functional areas. These complement the logical memory protection across processes provided by each CPU’s instance of FTOS.

Additional resiliency features within the E-Series and C-Series control planes include:

- Error correcting code (ECC) or parity protected memory is used in both the control plane and data plane to ensure data integrity. (ECC memory is also used in the S-Series switch/routers.)

- Out-of-band (OOB) switched Ethernet is used for communications within the control plane and for communication between the control plane and the line cards.

- Each line card has its own CPU dedicated to protocol housekeeping functions such as sFlow or BFD. Local processing reduces messaging between line cards and preserves OOB bandwidth.

**Summary of FTOS Benefits for System Resiliency**

In addition to providing software resiliency through modularity and memory protection, FTOS architectural features are highly complementary to the resiliency features at other layers of the Force10 Resiliency Architecture. FTOS plays a significant role at each level of the architecture:

**Hardware Redundancy:** FTOS is a key enabler of the scalable, multi-CPU, distributed processing control plane. FTOS also provides the control for automated hitless failover and hitless forwarding on the E-Series switch/router product line.

**Software Resiliency:** As previously described, FTOS eliminates the causes of many potential catastrophic system failures by restricting software problems to specific processes preventing them from affecting the entire system.

<table>
<thead>
<tr>
<th>Management Processor</th>
<th>Layer 3 Processor</th>
<th>Layer 2 Processor</th>
<th>Line Card Processor</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CLI</td>
<td>• RIP</td>
<td>• L2 Manager</td>
<td>• Interface Agent</td>
</tr>
<tr>
<td>• Telnet/SSH</td>
<td>• OSPF</td>
<td>• ARP Manager</td>
<td>• L2 Agent</td>
</tr>
<tr>
<td>• SNMP</td>
<td>• IS-IS</td>
<td>• xSTP (STP, RSTP, MSTP, PVST+)</td>
<td>• L3 Agent</td>
</tr>
<tr>
<td>• AAA</td>
<td>• BGP</td>
<td>• VRRP</td>
<td>• ACL Agent</td>
</tr>
<tr>
<td>• Logging</td>
<td>• LACP</td>
<td>• VRPP</td>
<td>• sFlow Agent</td>
</tr>
<tr>
<td>• Chassis Manager</td>
<td>• VRRP</td>
<td>• IGMP</td>
<td>• BFD Agent</td>
</tr>
<tr>
<td>• Configuration Manager</td>
<td>• Unicast Route Table Manager</td>
<td>• PIM</td>
<td>• HA Agent</td>
</tr>
<tr>
<td>• Interface Manager</td>
<td>• ACL Manager</td>
<td>• MSDP</td>
<td>• Line Card Manager</td>
</tr>
<tr>
<td>• HA Manager</td>
<td></td>
<td>• Multicast Route Table Manager</td>
<td>• Line Card Inservice Diagnostics</td>
</tr>
<tr>
<td>• RPM and Data Plane Inservice Diagnostics</td>
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Table 2. Example listing of processes running on each CPU on the E-Series platform

**Protocol Resiliency:** FTOS provides many resilient protocols, such as STP, FRRP, VRRP, and OSPF and BGP graceful restart.

**Link Resiliency:** FTOS rapidly detects ECMP or LAG link failures assuring rapid failover of traffic to the redundant links/paths.

**Manageability and Serviceability:** FTOS includes many features that are beneficial for management, debugging and troubleshooting of the system. The FTOS kernel monitors all processes to ensure operations are within normal limits of resource utilization. FTOS also provides system-wide monitoring for out-of-range environmental conditions and other fault conditions, such as unsynchronized configurations of line cards. Timely fault reporting and automated fault correction help to minimize system interruption. Furthermore, the modularity of the software simplifies tracing of software errors to specific processes and facilitates the remedial action required to return the system to full operation.
Conclusion

Through tight integration of hardware and software resiliency features, FTOS plays a very important role in helping the Force10 switch/router product lines to set new standards in system-wide reliability, stability and high availability. All network environments that require high availability in order to assure service delivery or to guarantee the timely execution of business-critical applications can derive significant benefits from the role that the fine-grained modularity of FTOS plays in the Force10 Resiliency Architecture.

Today’s network administrator is facing a number of challenges, such as:

- Increased focus on reliability and manageability because of greater business reliance on the network
- Assimilation of real-time applications (VoIP and video)
- Assuring satisfactory application performance with QoS
- Scaling the network to meet escalating bandwidth requirements
- Ensuring security in the face of a more fluid network environment

All of these challenges are considerably easier to meet where the underlying network infrastructure has been consolidated to minimize overall network complexity, including the complexity implicit with a diversity of network operating systems.

With HAL-enabled FTOS running across the entire spectrum of Force10 Networks’ switch/routers (E-Series, C-Series and S-Series), it is now possible to maximize the consolidation of the end-to-end switched infrastructure in all three critical dimensions:

1. Switching platform hardware for supporting simplified network topologies with unmatched scalability for 10 GbE, and eventually 40 and 100 GbE.
2. Network OS software with FTOS scaling across the wiring closet, data center and core of the network.
3. Network management with a single interface and management framework spanning the entire network.