NullSec Kernel Configuration: A Security-Hardened Linux Kernel

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Abstract

NullSec Linux is a security-hardened distribution designed for high-assurance environments. This report documents the kernel configuration that forms the foundation of NullSec's security posture, covering memory protection mechanisms (KASLR, SLAB hardening, stack protection), access control (capabilities, namespaces, seccomp, Landlock), network hardening (nftables, connection tracking, protocol restriction), filesystem security (dm-verity, IMA, fscrypt), audit infrastructure, cryptographic subsystem configuration, reproducible build process, and performance impact analysis. The configuration represents a comprehensive defense-in-depth approach with 3-7% performance overhead.

1 Introduction

NullSec is a security-hardened Linux distribution designed for high-assurance environments where system integrity and attack-surface minimization are paramount. Central to NullSec is a carefully curated kernel configuration that enables every available security mechanism while maintaining practical usability for server and workstation deployments.

This report documents the kernel configuration choices made for NullSec Linux, covering memory protection, access control, network hardening, filesystem security, audit infrastructure, cryptographic subsystem, build process, and performance considerations. Each section explains the rationale for specific CONFIG options and their security implications.

The NullSec kernel is based on the mainline Linux 6.8 kernel with a minimal set of out-of-tree patches for additional hardening. All patches are submitted upstream and are maintained in a public repository for community review and audit.

2 Memory Protection

Memory corruption vulnerabilities remain the most common class of kernel exploits. NullSec enables every available memory protection mechanism to raise the cost of exploitation and detect corruption early.

2.1 KASLR and Address Space Layout

Kernel Address Space Layout Randomization (KASLR) is enabled with CONFIG_RANDOMIZE_BASE=y and CONFIG_RANDOMIZE_MEMORY=y. The kernel image is loaded at a random offset chosen at boot time, and physical memory regions are shuffled to prevent predictable address layouts.

Function-level granularity randomization (CONFIG_FG_KASLR=y) goes further by randomizing the

order of individual functions within the kernel text segment. This defeats gadget-based attacks even when the base address is leaked, as individual function offsets remain unknown.

```
# Memory protection CONFIG options
CONFIG_RANDOMIZE_BASE=y
CONFIG_RANDOMIZE_MEMORY=y
CONFIG_FG_KASLR=y
CONFIG_STACKPROTECTOR_STRONG=y
CONFIG_INIT_STACK_ALL_ZERO=y
CONFIG_HARDENED_USERCOPY=y
CONFIG_FORTIFY_SOURCE=y
CONFIG_INIT_ON_ALLOC_DEFAULT_ON=y
CONFIG_INIT_ON_FREE_DEFAULT_ON=y
CONFIG_PAGE_TABLE_ISOLATION=y
```

2.2 SLAB Hardening

The SLAB allocator is configured with CONFIG_SLAB_FREELIST_RANDOM=y to randomize the order of free objects, making heap spraying less predictable. CONFIG_SLAB_FREELIST_HARDENED=y adds integrity checks to the freelist pointer, detecting corruption before it can be exploited.

Object initialization is enforced with CONFIG_INIT_ON_ALLOC_DEFAULT_ON=y, which zeros all slab objects on allocation. This prevents information leaks from recycled memory and eliminates an entire class of use-after-free exploitation primitives.

2.3 Stack Protection

Stack canaries are enabled with CONFIG_STACKPROTECTOR_STRONG=y, which inserts canary values before the return address on all functions with local arrays or address-taken variables. The strong variant covers significantly more functions than the basic mode.

CONFIG_INIT_STACK_ALL_ZERO=y ensures that all local variables are initialized to zero, preventing information leaks through uninitialized stack memory. Combined with CONFIG_GCC_PLUGIN_STRUCTLEAK_BYREF_ALL=y, this covers all possible leak vectors.

3 Access Control

3.1 Capabilities and Namespaces

NullSec uses Linux capabilities to decompose the traditional root privilege into fine-grained permissions. The default configuration drops all capabilities for new processes and requires explicit capability grants through file capability attributes or systemd service definitions.

User namespaces are enabled (CONFIG_USER_NS=y) but restricted through a sysctl that requires CAP_SYS_ADMIN to create new user namespaces. This prevents unprivileged namespace creation,

which has been a frequent source of privilege escalation exploits.

```
# Access control CONFIG options
CONFIG_SECURITY=y
CONFIG_SECURITY_SELINUX=y
CONFIG_SECURITY_APPARMOR=y
CONFIG_SECURITY_YAMA=y
CONFIG_USER_NS=y
CONFIG_SECCOMP=y
CONFIG_SECCOMP_FILTER=y
CONFIG_SECURITY_LANDLOCK=y
CONFIG_BPF_UNPRIV_DEFAULT_OFF=y
CONFIG_SECURITY_LOCKDOWN_LSM=y
```

3.2 Seccomp and System Call Filtering

Seccomp-BPF (CONFIG_SECCOMP_FILTER=y) allows processes to install system call filters that restrict which syscalls can be invoked. NullSec ships default seccomp profiles for all bundled services, reducing the attack surface to the minimum required syscall set.

The Landlock LSM (CONFIG_SECURITY_LANDLOCK=y) provides unprivileged sandboxing that restricts file access and network operations. Applications can opt into Landlock restrictions without requiring administrator configuration, enabling defense in depth.

4 Network Hardening

4.1 Netfilter Configuration

NullSec uses nftables as the primary firewall framework, replacing the legacy iptables infrastructure. The kernel configuration enables CONFIG_NF_TABLES=y along with all protocol-specific helpers for IPv4, IPv6, ARP, and bridging.

Connection tracking (CONFIG_NF_CONNTRACK=y) is enabled with aggressive timeout defaults. Established connections time out after 120 seconds (down from the default 432000), and half-open connections are limited to prevent SYN flood resource exhaustion.

```
# Network hardening CONFIG options
CONFIG_NF_TABLES=y
CONFIG_NF_CONNTRACK=y
CONFIG_SYN_COOKIES=y
CONFIG_IP_NF_IPTABLES=n
CONFIG_NET_DROP_MONITOR=y
CONFIG_INET_DIAG=y
CONFIG_TCP_CONG_BBR=y
CONFIG_IPV6_SEG6_LWTUNNEL=n
CONFIG_NET_SCHED=y
CONFIG_NET_CLS_BPF=y
```

4.2 Protocol Hardening

SYN cookies (CONFIG_SYN_COOKIES=y) are enabled to protect against SYN flood attacks without consuming server resources for half-open connections. The kernel's TCP stack is configured with BBR congestion control for improved throughput on lossy links.

Unused network protocols are disabled at compile time rather than runtime. This includes DCCP (CONFIG_IP_DCCP=n), SCTP (CONFIG_IP_SCTP=n for non-server builds), and various tunneling protocols that expand the attack surface without providing benefits for most deployments.

5 Filesystem Security

5.1 dm-verity and Integrity

dm-verity (CONFIG_DM_VERITY=y) provides transparent block-level integrity verification using a Merkle tree of hash values. The root hash is signed and verified at boot time, ensuring that the root filesystem has not been tampered with.

The Integrity Measurement Architecture (CONFIG_IMA=y) extends integrity verification to individual files. IMA maintains a measurement log of all accessed files and can enforce policies that prevent execution of files whose measurements don't match a reference list.

```
# Filesystem security CONFIG options
CONFIG_DM_VERITY=y
CONFIG_DM_VERITY_VERIFY_ROOTHASH_SIG=y
CONFIG_IMA=y
CONFIG_IMA_APPRAISE=y
CONFIG_EVM=y
CONFIG_FS_VERITY=y
CONFIG_ENCRYPTED_KEYS=y
CONFIG_FS_ENCRYPTION=y
CONFIG_DM_CRYPT=y
CONFIG_TRUSTED_KEYS=y
```

Extended Verification Module (CONFIG_EVM=y) protects file metadata (ownership, permissions, extended attributes) from tampering by maintaining HMACs over the security-relevant attributes. This closes a gap where an attacker could bypass IMA by modifying file permissions rather than content.

6 Audit Infrastructure

The Linux audit subsystem (CONFIG_AUDIT=y, CONFIG_AUDITSYSCALL=y) is enabled to provide comprehensive logging of security-relevant events. NullSec ships an audit rule set that logs all privilege escalations, file access to sensitive paths, and network connections to external addresses.

Audit logs are forwarded to a remote log aggregation server using an encrypted transport. The kernel's audit buffer is sized generously (CONFIG_AUDIT_TREE=y, audit_backlog_limit=8192) to

prevent log loss during burst activity.

```
# Audit and logging CONFIG options
CONFIG_AUDIT=y
CONFIG_AUDITSYSCALL=y
CONFIG_AUDIT_TREE=y
CONFIG_INTEGRITY_AUDIT=y
CONFIG_SECURITY_SELINUX_AVC_STATS=y
CONFIG_PRINTK_TIME=y
CONFIG_BUG_ON_DATA_CORRUPTION=y
CONFIG_PANIC_ON_OOPS=y
```

7 Cryptographic Subsystem

NullSec configures the kernel's cryptographic subsystem with modern algorithms and disables legacy ciphers. AES-GCM and ChaCha20-Poly1305 are the primary symmetric ciphers, with hardware acceleration (AES-NI, CLMUL) enabled where available.

The kernel's random number generator is configured with CONFIG_RANDOM_TRUST_CPU=n to avoid trusting the CPU's built-in RNG as the sole entropy source. Instead, entropy is collected from multiple independent sources including interrupt timing, disk I/O timing, and a hardware RNG if available.

8 Build Process

The NullSec kernel is built with Clang/LLVM rather than GCC, enabling additional sanitizers and security features. CONFIG_CC_STACKPROTECTOR_STRONG=y, CONFIG_CFI_CLANG=y (Control Flow Integrity), and CONFIG_SHADOW_CALL_STACK=y (on aarch64) are enabled.

The build process is fully reproducible: given the same source tree and configuration, the output binary is bit-for-bit identical regardless of the build environment. This is achieved by fixing all build timestamps and randomization seeds.

```
# Build hardening CONFIG options
CONFIG_CC_STACKPROTECTOR_STRONG=y
CONFIG_CFI_CLANG=y
CONFIG_LTO_CLANG_FULL=y
CONFIG_SHADOW_CALL_STACK=y  # aarch64 only
CONFIG_TRIM_UNUSED_KSYMS=y
CONFIG_MODULES=y
CONFIG_MODULE_SIG=y
CONFIG_MODULE_SIG_FORCE=y
CONFIG_MODULE_SIG_SHA512=y
CONFIG_KEXEC_SIG=y
```

Kernel modules must be signed with a SHA-512 RSA key (CONFIG_MODULE_SIG_FORCE=y). Unsigned modules are rejected at load time. The signing key is generated during the build process

and the private key is discarded after signing, preventing post-build module injection.

9 Performance Considerations

Security hardening inevitably introduces performance overhead. NullSec benchmarks indicate an overall throughput reduction of 3-7% compared to a vanilla kernel, primarily due to KASLR, stack initialization, and page table isolation.

The most significant overhead comes from CONFIG_PAGE_TABLE_ISOLATION (KPTI), which mitigates Meltdown-class attacks at the cost of TLB flush overhead on every kernel entry and exit. On workloads with frequent system calls, this accounts for 2-4% overhead.

- - KASLR: < 0.5% overhead (one-time boot cost)
- - Stack initialization: 1-2% on stack-heavy workloads
- - KPTI: 2-4% on syscall-heavy workloads
- - SLAB hardening: < 0.5% on allocation-heavy workloads
- - IMA: 1-3% on file-access-heavy workloads
- - CFI: < 1% overhead on indirect-call-heavy code

10 Conclusion

The NullSec kernel configuration represents a comprehensive defense-in-depth approach to Linux security. By enabling every available hardening mechanism and disabling unnecessary features, the attack surface is minimized while maintaining practical usability.

The 3-7% performance overhead is an acceptable trade-off for the significant security benefits provided. Organizations deploying NullSec can be confident that their kernel is configured according to current best practices and that exploitation of memory corruption vulnerabilities requires bypassing multiple independent defense layers.

2.4 Guard Pages and Vmap Stack

CONFIG_VMAP_STACK=y places kernel stacks in virtually mapped memory with guard pages at both ends. A stack overflow triggers a page fault on the guard page rather than silently corrupting adjacent memory, converting a potential exploitation primitive into a controlled kernel panic.

Thread-local storage regions are similarly protected with guard pages. The gap between the stack and TLS region is enforced by the virtual memory allocator, preventing stack-based overflows from reaching thread-local data structures.

```
# Guard page and stack CONFIG options
CONFIG_VMAP_STACK=y
CONFIG_THREAD_INFO_IN_TASK=y
CONFIG_GCC_PLUGIN_STACKLEAK=y
CONFIG_STACKLEAK_TRACK_MIN_SIZE=100
CONFIG_STACKLEAK_METRICS=n
```

```
CONFIG_KASAN=y  # debug builds only
CONFIG_KASAN_INLINE=y
CONFIG_UBSAN=y  # debug builds only
```

The GCC STACKLEAK plugin (CONFIG_GCC_PLUGIN_STACKLEAK=y) erases the kernel stack before returning to user space, preventing information leaks through residual stack data. The minimum size threshold is set to 100 bytes to balance security with performance overhead.

In debug builds, Kernel Address Sanitizer (KASAN) and Undefined Behavior Sanitizer (UBSAN) are enabled to catch memory corruption and undefined behavior during development and testing. These are disabled in production builds due to their significant performance overhead (2-3x slowdown).

The combination of guard pages, stack canaries, and stack erasure creates a layered defense for the kernel stack. An attacker must bypass all three mechanisms to achieve reliable stack-based exploitation, significantly raising the difficulty bar.

- - Guard pages detect overflow before corruption
- - Stack canaries detect corruption before return
- - STACKLEAK prevents information leaks after return
- - KASAN catches use-after-free and buffer overflow in debug
- - UBSAN catches integer overflow and alignment issues

Performance impact of guard pages is negligible since guard page faults only occur during actual overflow events, which should never happen in correct code. The STACKLEAK cleanup adds approximately 0.1% overhead to system call return paths.

3.3 Yama and PTRACE Restrictions

The Yama LSM (CONFIG_SECURITY_YAMA=y) restricts ptrace operations to prevent unauthorized process inspection and manipulation. By default, NullSec sets kernel.yama.ptrace_scope=2, which restricts ptrace to processes with CAP_SYS_PTRACE.

This prevents unprivileged users from attaching debuggers to other users' processes, which is a common technique for credential theft and process manipulation. Developers who need ptrace for debugging can request the capability through a controlled privilege escalation mechanism.

```
# Yama and additional LSM CONFIG options
CONFIG_SECURITY_YAMA=y
CONFIG_SECURITY_LOADPIN=y
CONFIG_SECURITY_SAFESETID=y
CONFIG_LOCK_DOWN_KERNEL_FORCE_CONFIDENTIALITY=y
CONFIG_STATIC_USERMODEHELPER=y
CONFIG_SECURITY_DMESG_RESTRICT=y
CONFIG_SECURITY_PERF_EVENTS_RESTRICT=y
CONFIG_KPROBES=n  # production only
```

CONFIG_SECURITY_DMESG_RESTRICT=y prevents unprivileged users from reading the kernel log buffer, which often contains sensitive information such as hardware addresses, kernel pointers,

and security event details.

Performance monitoring is restricted (CONFIG_SECURITY_PERF_EVENTS_RESTRICT=y) to prevent side-channel attacks that exploit hardware performance counters. Access to perf events requires CAP_PERFMON, which is granted only to authorized monitoring tools.

The kernel lockdown feature (CONFIG_LOCK_DOWN_KERNEL_FORCE_CONFIDENTIALITY=y) prevents even root from modifying the running kernel's code or reading sensitive data through /dev/mem, /dev/kmem, or module parameters. This is essential for maintaining integrity even when root is compromised.

LoadPin (CONFIG_SECURITY_LOADPIN=y) restricts kernel module and firmware loading to files on the same filesystem as the initial module load. This prevents an attacker with write access to a writable filesystem from loading malicious kernel modules.

- - ptrace restricted to CAP_SYS_PTRACE holders
- - dmesg restricted to privileged users
- - perf events require CAP_PERFMON
- - Kernel lockdown in confidentiality mode
- - Module loading restricted to boot filesystem
- - Static usermodehelper prevents helper binary replacement

4.3 Network Namespace Isolation

Network namespaces provide per-container network isolation. NullSec configures network namespaces with strict default firewall rules that deny all traffic until explicitly allowed. Each namespace gets its own loopback interface and routing table.

The veth pair driver is enabled for container networking, allowing communication between network namespaces through virtual Ethernet device pairs. Traffic between containers is subject to netfilter rules in both the source and destination namespaces.

```
# Network namespace and isolation CONFIG options
CONFIG_NET_NS=y
CONFIG_VETH=y
CONFIG_BRIDGE=y
CONFIG_BRIDGE_NF_EBTABLES=n
CONFIG_NETFILTER_XT_MATCH_CGROUP=y
CONFIG_CGROUP_NET_PRIO=y
CONFIG_CGROUP_NET_CLASSID=y
CONFIG_NET_CLS_CGROUP=y
CONFIG_TCP_CONG_BBR=y
CONFIG_DEFAULT_TCP_CONG="bbr"
```

Traffic prioritization uses cgroup-based classification (CONFIG_CGROUP_NET_PRIO=y) to ensure that security-critical services receive network bandwidth priority over optional services. QoS policies are defined in the systemd service definitions.

The bridge module (CONFIG_BRIDGE=y) is enabled for virtual machine and container bridge networking, but the legacy ebtables interface is disabled in favor of nftables bridge filtering, which provides better performance and a more consistent filtering language.

DNS resolution within containers is handled by a stub resolver that forwards queries to the host's DNS-over-TLS resolver. This ensures all DNS traffic is encrypted regardless of the container's own DNS configuration.

- - Default-deny firewall in each network namespace
- - veth pairs for inter-namespace communication
- - cgroup-based traffic prioritization
- - nftables bridge filtering (no legacy ebtables)
- - BBR congestion control as default
- - DNS-over-TLS for all container DNS queries

Network namespace creation is rate-limited through a custom BPF program that prevents namespace exhaustion attacks. A maximum of 256 network namespaces is allowed per user, with burst creation limited to 10 per second.

5.2 Filesystem Encryption

NullSec supports both block-level encryption (dm-crypt via CONFIG_DM_CRYPT=y) and file-level encryption (fscrypt via CONFIG_FS_ENCRYPTION=y). Block-level encryption protects against offline attacks, while file-level encryption provides per-user key separation on multi-user systems.

The default cipher for dm-crypt is AES-256-XTS with a key derived from the user's passphrase using Argon2id. The Argon2id parameters (memory=1GB, iterations=4, parallelism=4) are chosen to resist GPU-based brute-force attacks while keeping boot time reasonable.

```
# Encryption subsystem CONFIG options
CONFIG_DM_CRYPT=y
CONFIG_FS_ENCRYPTION=y
CONFIG_FS_ENCRYPTION_ALGS=y
CONFIG_CRYPTO_AES_NI_INTEL=y
CONFIG_CRYPTO_CHACHA20_X86_64=y
CONFIG_CRYPTO_POLY1305_X86_64=y
CONFIG_CRYPTO_ARGON2=y
CONFIG_CRYPTO_USER_API_SKCIPHER=y
CONFIG_ENCRYPTED_KEYS=y
CONFIG_TRUSTED_KEYS=y
```

Trusted keys (CONFIG_TRUSTED_KEYS=y) are sealed by the TPM and can only be unsealed on the same hardware. This enables disk encryption keys to be bound to the specific machine, preventing offline attacks that involve moving the disk to another system.

File-level encryption uses per-file keys derived from a master key stored in the kernel keyring. Each file's content and filename are encrypted with unique keys, providing forward secrecy: even if one file's key is compromised, other files remain protected.

The key hierarchy is managed through the Linux keyring subsystem. User keyrings are created at login and populated with the decrypted master keys. When the user logs out, the keys are removed from memory, making the encrypted files inaccessible.

- - AES-256-XTS for block-level encryption
- - Argon2id key derivation with anti-GPU parameters
- - TPM-sealed trusted keys for hardware binding
- - Per-file keys with forward secrecy
- - Automatic key cleanup on user logout
- - Hardware-accelerated AES-NI and ChaCha20

Performance overhead of filesystem encryption is mitigated by hardware acceleration. On systems with AES-NI support, the throughput penalty is under 5% for sequential I/O and under 10% for random I/O. Systems without hardware acceleration fall back to ChaCha20, which provides acceptable software performance.

6.1 Audit Rule Architecture

NullSec's audit rule set is organized into layers: a base layer that logs mandatory events (authentication, authorization, capability use), a system layer that logs service management events, and an optional application layer that logs application-specific events configured by individual services.

The base audit rules are compiled from a declarative YAML specification that maps security objectives to audit system calls and file watches. This abstraction layer makes it easier to audit the audit configuration itself and ensures completeness against the security policy.

```
# Base audit rule examples
-w /etc/shadow -p wa -k shadow_access
-w /etc/passwd -p wa -k passwd_access
-w /etc/sudoers -p wa -k sudoers_access
-a always,exit -F arch=b64 -S execve -k exec_log
-a always,exit -F arch=b64 -S connect -k net_connect
-a always,exit -F arch=b64 -S accept -k net_accept
-a always,exit -F arch=b64 -S init_module -k module_load
-a always,exit -F arch=b64 -S ptrace -k ptrace_use
-a always,exit -F arch=b64 -S mount -k mount_activity
```

File integrity monitoring is implemented through audit file watches on critical system files. Changes to /etc/shadow, /etc/passwd, /etc/sudoers, and other security-relevant files generate audit events that are immediately forwarded to the central log server for analysis.

The audit subsystem is configured to panic the system (CONFIG_PANIC_ON_OOPS=y) when the audit backlog exceeds the maximum buffer size. This prevents an attacker from overwhelming the audit system to suppress event logging during an attack.

Log rotation is handled by a dedicated service that compresses and archives audit logs daily. Archived logs are signed with an ed25519 key to ensure tamper evidence. A hash chain links

consecutive archives, so deletion or modification of any archive is detectable.

Real-time alerting is implemented through an audit dispatcher that processes events as they are generated. The dispatcher evaluates events against a rule set and sends alerts via multiple channels (syslog, email, webhook) for high-severity events such as privilege escalation or unauthorized file access.

- - Layered rule architecture: base, system, application
- - YAML-based declarative rule specification
- - File integrity monitoring for critical paths
- - System panic on audit buffer overflow
- - Signed and hash-chained log archives
- - Real-time alerting for high-severity events

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