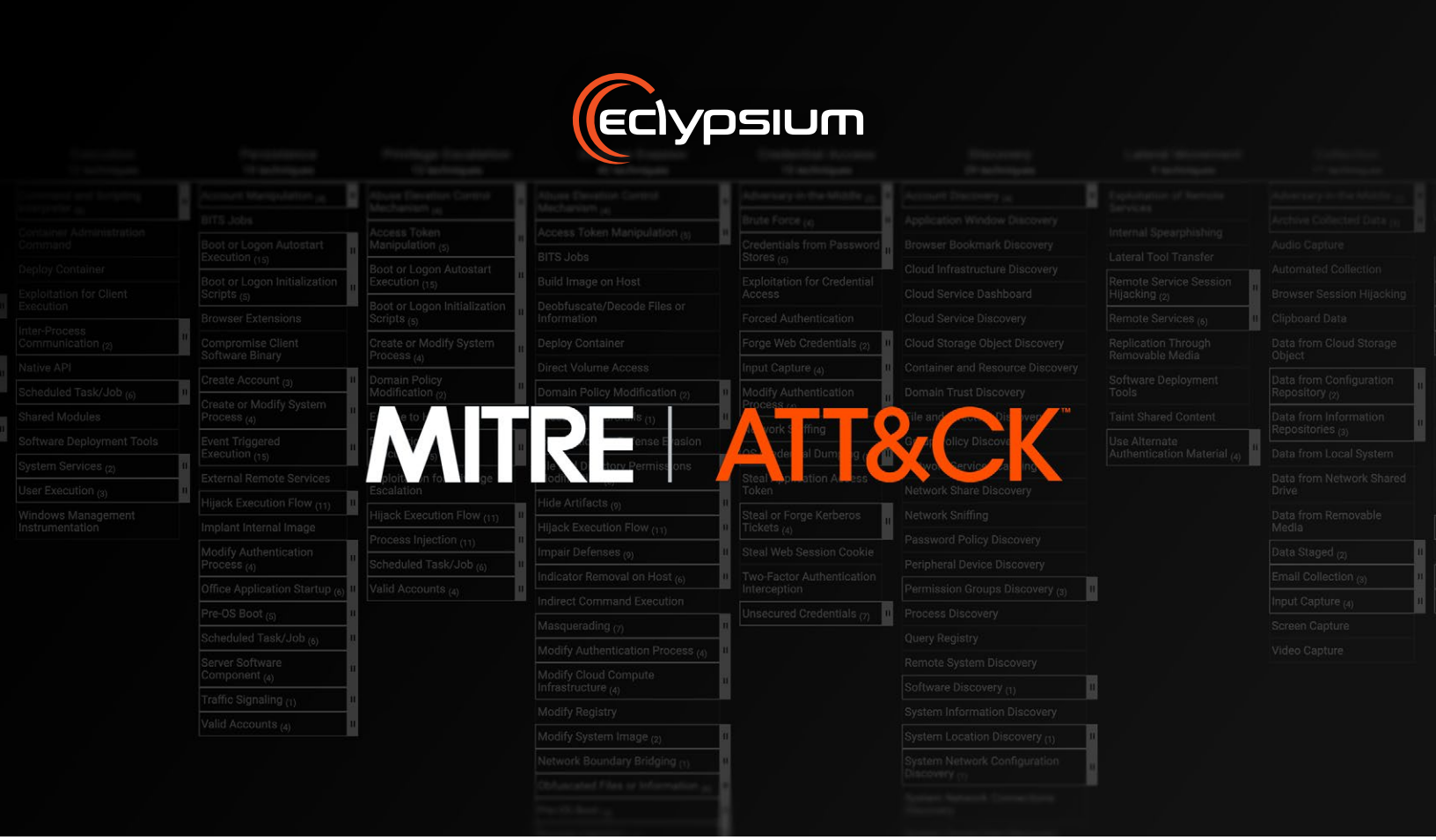


FIRMWARE AND MITRE ATT&CK

As cybersecurity exploits and attacks have increased, few tools have proven as essential at stemming the tide and aiding defenders as the MITRE ATT&CK® framework. MITRE ATT&CK is a global, curated knowledge base that models and defines specific cyber adversary behavior "in the wild." The goal is to detail adversarial attack methods, lifecycles and known target platforms, and thereby enable defenders to see not only who and what they're up against, but precisely how to counter specific assaults.

Firmware is critical software that is embedded within every device. This is true whether enterprises deploy devices locally or rent them from cloud platforms. In either case, firmware is the first code to run and some of the most privileged code on any device, the bedrock that everything else relies on. Any compromise of this critical layer can undermine and subvert everything above it including the operating system, applications, and security controls.

It should be no surprise then that firmware also plays a critical role in modern cyberattacks, serving as a highly popular initial infection vector, as well as providing some of the most powerful methods of security evasion, persistence, and command-and-control.

In this paper, we'll analyze how firmware security—meaning boot integrity, component code, and hardware configurations—applies to the ATT&CK framework. In addition to covering firmware-specific attacker techniques and sub-techniques named in the framework, we'll also analyze the key role that strong firmware security plays in mitigating risk and disrupting threats across various phases of an attack. Specifically, readers will learn:

- Background on the ATT&CK Framework
- The role firmware in ATT&CK tactics and techniques
- Examples of real-world firmware attacks and risks
- Countermeasures and practices to mitigate firmware risks

MITRE ATT&CK BACKGROUND_

The MITRE ATT&CK Framework is a "globally-accessible knowledge base of adversary tactics and techniques based on real-world observations." The terms "tactics" and "techniques" have a specific meaning in the context of ATT&CK. The MITRE ATT&CK Philosophy Paper (PDF) defines the terms as follows:

1. **Tactics** - Tactics represent the "why" of an ATT&CK technique or sub-technique. It is the adversary's tactical objective: the reason for performing an action.
2. **Techniques** - Techniques represent "how" an adversary achieves a tactical objective by performing an action.

For example, Persistence is a tactic, and Pre-OS Boot is a technique used to establish persistence. In the most recent iteration of ATT&CK (last modified in November of 2021) there are 14 tactics and 218 underlying techniques. Of these 14 tactics, 2 are designated as PRE or preparatory steps, while the remaining 12 focus on the active phase of the attack.

The 14 tactics include:

- Reconnaissance (PRE)
- Resource Development (PRE)
- Initial Access
- Execution
- Persistence
- Privilege Escalation
- Defense Evasion
- Credential Access
- Discovery
- Lateral Movement
- Collection
- Command and Control
- Exfiltration
- Impact

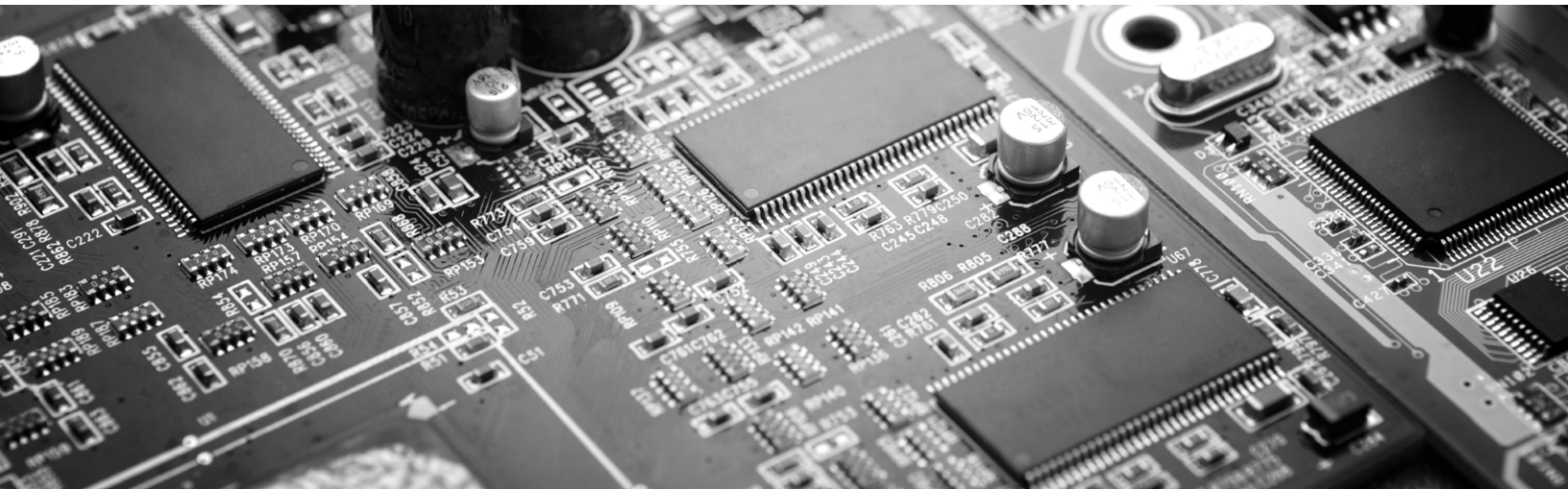
It is worth noting that ATT&CK maintains separate matrices for Enterprise, Mobile, and ICS target types. While the underlying techniques vary between the matrices, the core tactics remain largely the same with the exception of small differences in the ICS matrix. For this document, we will use the Enterprise matrix as a reference, knowing that the core concepts apply to all versions of ATT&CK.

FIRMWARE AND ATT&CK_

Firmware is the most fundamental code on any given device. From the first moment that a device starts up to its every runtime operation to end-of-life, firmware is the gateway from the world of code to the physical processing and sharing of information required in all of computing. It is the bedrock that higher layer abstractions such as operating systems and applications rely on.

It used to be assumed that firmware code was sacrosanct: pristine, untouched, "black box" code. This caused cybersecurity teams to overlook firmware, or to provide a litany of reasons why they didn't want to assess, manage and secure it. Now, of course, many attackers know firmware better than defenders do. And compromising this firmware layer gives them the chance to subvert virtually any and all controls running in the "higher layers" of operating systems and applications.

Nation-state threat actors have heavily invested in firmware-level threats for this reason, and those techniques and tools have trickled down to more financially motivated threat actors. However, firmware remains relatively unguarded in many organizations. This combination of motive, means, and opportunity creates considerable risk that we can see in the context of the ATT&CK Framework.



RECONNAISSANCE_

Reconnaissance is the first of the PRE tactics, and involves a variety of active and passive adversary techniques to identify target assets and vulnerabilities that can be targeted in later phases of the attack. Hardware and firmware play a key role in this technique. Vulnerabilities within the firmware of network devices such as VPNs have become one of the most popular initial access vectors into enterprises. Firmware vulnerabilities in particular have become a favored initial vector in these attacks because firmware is rarely updated as often as other code, and because exploiting these vulnerabilities can give an attacker full control over the device. Additionally, threat actors can scan to identify externally facing devices including servers, routers, and other infrastructure. Because of the lack of updates mentioned earlier, attackers can often infer the presence of firmware vulnerabilities based on the observed hardware version of the device.

Relevant ATT&CK Techniques	• Active Scanning – Vulnerability Scanning • Gather Host information – Hardware – Firmware • Network Security Appliances
References and Further Reading	• Widespread exploitation of VPN vulnerabilities • Publicly discoverable vulnerabilities in MikroTik routers
Firmware Countermeasures	Reconnaissance techniques are difficult to directly mitigate as they typically take advantage of systems and information that is inherently exposed to the public. However, this means it is all the more important for organizations to have highly reliable visibility of all their devices and any vulnerabilities they may have, so that any issues can be addressed before they are found by attackers.

RESOURCE DEVELOPMENT_

The second of the two PRE tactics, Resource Development allows an adversary to acquire infrastructure that will support the active phases of the attack. This could be acquiring servers or network devices that could provide command-and-control as well as trusted relationships with which to further expand in the environment. It is possible for attackers to implant firmware backdoors in networking devices such as switches as well as servers supporting bare-metal cloud services. These backdoors could be used by attackers to send malicious traffic and could persist even after the server is reprovisioned and used by other customers. Customers should independently verify the integrity of all networking gear and bare metal cloud assets not only to ensure the security of their data and assets, but also to ensure their hardware is not used as part of other attacks.

Relevant ATT&CK Techniques	• Compromise Infrastructure

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References and Further Reading	• Backdoors in bare metal cloud services • CISA advisory on BlackTech threat group • Network Devices Whitepaper
Firmware Countermeasures	Scan all bare metal cloud assets to verify the integrity of the firmware and identify any vulnerabilities.

INITIAL ACCESS_

Initial Access is the first of the active phases of the ATT&CK Tactics, and firmware has proven to be one of the most popular vectors for initial access in real-world attacks. At a high level, firmware can be exploited remotely over networks, in the technology supply chain, or by attackers with physical access to a device.

Firmware within enterprise network devices such as VPNs, routers, and security appliances have become top targets across a wide range of threat actors. The trend was observed in Russian, Chinese, and Iranian state-based threat actors and quickly spread to financially motivated attackers including more than 20 ransomware groups and all five of the top ransomware groups. Exploiting vulnerabilities in the firmware and integrated code of these devices provide attackers with direct access into an enterprise with the ability to deliver malware to other users and devices.

Attackers can also gain access by compromising the technology supply chain of a device. Modern supply chains involve dozens of suppliers and subcontractors, providing attackers with many opportunities to compromise a device before it is ever delivered to the enterprise customer. Additionally, supply chains can be compromised via official vendor update processes as was observed in the highly-damaging Solar Winds attacks. In total, the Breaking Trust project has identified 139 supply chain attacks and disclosures from the past ten years.

Attackers can also use physical access to compromise systems, often exploiting firmware within system components. For example, vulnerable components can expose devices to DMA attacks, which can allow attackers to directly read and write to system memory, and extend control over the execution of the kernel itself.

Relevant ATT&CK Techniques	• Exploit Public-Facing Application (e.g. VPN, network devices) • Supply Chain Compromise • External Remote Services - (e.g. Intel AMT, BMCs) • Replication Through Removable Media
References and Further Reading	• Network Devices Whitepaper • Supply Chain Risks • DMA Security and Zero Trust • Compromise by BIOS Disconnect • Remote UEFI Attacks

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Firmware Countermeasures	• Proactively discover all devices within an enterprise including network devices • Proactively scan devices for vulnerabilities and prioritize any vulnerabilities used in real-world attacks • Verify the integrity of all system and component firmware of acquired devices • Verify all firmware updates and monitor firmware behavior following updates • Scan device components for vulnerabilities that would allow physical access attacks.

EXECUTION_

Attackers can compromise device boot processes in order to execute malicious code during or after boot. Alternatively, attackers can directly take advantage of component vulnerabilities to gain execution within system memory. Previously referenced DMA attacks provide an example where attackers can gain execution directly within system memory. This can allow an attacker to execute kernel code on the system, insert a wide variety of kernel implants, and perform a host of additional activities such as spawning system shells or removing password requirements. And as with all types of code, attackers can use social engineering to trick users into running the attacker's code such as malware that updates firmware or tricking users into performing malicious firmware updates.

Relevant ATT&CK Techniques	• Replication Through Removable Media • User Execution
References and Further Reading	• Abusing WPBT to Gain Malicious Code Execution • Evil Maid Attacks • FinSpy UEFI and MBR Bootkit • DMA Attacks
Firmware Countermeasures	• Scan devices to identify components that are vulnerable to DMA attacks and verify that all vendor DMA protections are properly enabled. • Scan devices for vulnerabilities that could allow attackers to compromise the firmware or boot process. • Verify that all available vendor protections are enabled and properly configured including protections included with UEFI, chipset vendor, OS vendor, and any OEM-specific protections.

PERSISTENCE_

Persistence has always been one of the key reasons attackers seek to target firmware. Firmware code is integrated into system components themselves, instead of residing on traditional storage drives. This not only hides the attacker's code from traditional security scans but also ensures the code will persist even if a system's drives are completely erased, re-imaged or even replaced. The FIN8 ransomware group modified backup files in compromised NetScaler appliances to have a webshell

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that persisted even after the device was updated and rebooted.

Attackers continue to escalate their use of firmware implants and backdoors across a wide range of enterprise devices. UEFI implants such as LoJax, MosaicRegressor, and MoonBounce can target any UEFI-based system including laptops and servers. The recent HP iLOBleed implant provides an example of an implant that can target firmware within the powerful baseboard management controllers (BMCs) that enable out of band management of enterprise servers.

TrickBot provides an example of just how common such threats are becoming in the wild and how malware infections can quickly turn into persistent firmware backdoors. Already one of the most widespread and powerful trojans in the industry, TrickBot recently introduced new functionality dubbed TrickBoot, which automatically finds weaknesses in devices that allow the malware to establish persistence within an infected device's system firmware. Attackers can also apply this strategy by hiding within unused regions of memory in firmware known as "code caves".

Additionally, attackers can establish persistence by gaining control of a device's boot process to ensure their malicious code is always run during startup. Firmware rootkits and vulnerabilities such as BootHole can allow an attacker to execute their code before the operating system is even loaded.

Relevant ATT&CK Techniques	• Pre-OS Boot Techniques • Boot or Logon Initialization Scripts
References and Further Reading	• TrickBoot functionality for ongoing persistence • HP iLOBleed • MoonBounce • LoJax • MosaicRegressor • Code caves and hiding code in firmware
Firmware Countermeasures	• Scan devices to identify any vulnerable components or misconfigurations that would allow attackers to write to firmware or compromise the boot process. • Proactively verify the integrity of all firmware to identify any signs of implants or firmware compromise, particularly after any known malware incident. • Verify that all available vendor protections are enabled and properly configured including protections included with UEFI, chipset vendor, OS vendor, and any OEM-specific protections.

PRIVILEGE ESCALATION_

Security teams often think of privilege escalation in the context of escalating from users privileges (Ring 3) to Administrator privileges or seeking out kernel privileges (Ring 0) at the system level. And while these are the highest privileges available to the OS, firmware sits beneath the kernel. As a result, malicious code in the firmware can subvert the kernel and thus possess even higher privileges, often referred to as Rings -1 through -3.

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Attackers have a variety of techniques at their disposal to escalate privileges to these “negative” rings, both with user or administrator privileges. This involves a top-down approach to compromising firmware that can allow any standard malware infection to escalate privileges to the underlying firmware layer. This can include the use of malicious or vulnerable device drivers, the aforementioned BootHole vulnerability, and a number of other firmware or boot vulnerabilities.

Relevant ATT&CK Techniques	• Exploitation for Privilege Escalation • Boot or Logon Initialization Scripts
References and Further Reading	• Escalation via BootHole on devices even when protected by Secure Boot. • Escalation via driver vulnerabilities • SMM Vulnerabilities
Firmware Countermeasures	• Scan devices to identify any vulnerable components or misconfigurations that would allow attackers to write to firmware or compromise the boot process. • Make sure that devices are using the latest stable OS and bootloaders, and that the dbx revocation database is up to date. • Verify that all available vendor protections are enabled and properly configured including protections included with UEFI, chipset vendor, OS vendor, and any OEM-specific protections. • Scan devices for malicious bootloaders and exploit code

DEFENSE EVASION_

Compromising a device’s firmware and boot process gives attackers the opportunity to subvert security controls running at the level of the operating system. Firmware also directly controls the functions of device components in ways that may not be visible to the operating system itself. For example, the well-publicized Equation Group implants used malicious firmware to create hidden sections within a drive that were invisible to the operating system itself. This also meant that security tools were blind to these areas of the drive, allowing attackers to hide malicious code and evade security scans.

Additionally, rootkits and other malicious code execution within the UEFI environment can allow attackers to directly patch the OS kernel itself. This makes it possible to silently disable security features within the OS or third-party security tools. The Hacking Team implant, and the derivative MosaicRegressor UEFI implants, are well-known examples of sophisticated tools that use UEFI rootkits in order to evade traditional security controls.

Relevant ATT&CK Techniques	• Rootkit • Pre-OS Boot

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References and Further Reading	• Exploiting BootHole to install bootkits on devices. • Hacking Team and MosaicRegressor Implants • Equation Group SSD implants • Demonstration of Firmware-Based Evasion
Firmware Countermeasures	• Scan devices to identify any vulnerable components or misconfigurations that would allow attackers to write to firmware or compromise the boot process. • Make sure that devices are using the latest stable OS and bootloaders, and that the dbx revocation database is up to date. • Verify that all available vendor protections are enabled and properly configured including protections included with UEFI, chipset vendor, OS vendor, and any OEM-specific protections. • Scan devices for malicious bootloaders and exploit code

CREDENTIAL ACCESS_

Modern devices go to great lengths to protect passwords and credentials on the device. In addition to using firmware threats to steal credentials from system memory (e.g. DMA attacks), attackers can use side-channel analysis to extract credentials from even the most secure components of a system including the Trusted Platform Module. Additionally, firmware attacks against routers and networking gear can allow attackers to perform machine-in-the-middle attacks to steal credentials or intercept MFA challenges.

Relevant ATT&CK Techniques	• Credentials From Password Stores • Adversary-in-the-Middle • Exploitation for Credentialed Access
References and Further Reading	• TPMFail to extract private authentication keys • Router vulnerabilities that can enable machine-in-the-middle attacks. • Spectre and Meltdown to steal passwords • ROCA vulnerability to steal keys from TPM
Firmware Countermeasures	• Scan devices for vulnerabilities in TPM, processors, and other components that can enable side-channel attacks or collection of credentials. • Discover all network devices and identify vulnerable or out of date firmware.

COMMAND AND CONTROL / EXFILTRATION_

Firmware and hardware components can be used by attackers to establish command-and-control channels that are fully independent of the host operating system. For example, Intel's AMT firmware runs inside the management engine (ME) chip

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and contains its own network stack independent of the operating system. Attackers such as the PLATINUM group have used these capabilities as command-and-control and exfiltration channels that avoid any host-based controls running on the device.

Additionally, compromised firmware on network devices and interfaces can be used to reroute traffic, enabling both command-and-control and data exfiltration.

Relevant ATT&CK Techniques	• Non-Application Protocol • Ingress Tool Transfer
References and Further Reading	• PLATINUM using AMT to bypass Windows firewall • TrickBot use of MikroTik routers for C2
Firmware Countermeasures	• Scan devices for vulnerabilities in AMT and ensure AMT features are properly secured. • Identify all network devices and IoT components and scan for vulnerabilities. • Verify the integrity of AMT firmware and network device firmware.

IMPACT_

With access to system firmware or firmware on device drives, attackers can easily destroy data, disable components, or disable the system entirely. The BlackEnergy attacks on critical infrastructure in Ukraine in 2014 provided an example of the incredible potential for attackers to cause damage via firmware. Fast forward just a few years and the same concept has gained traction with ransomware such as EFILock ransomware, which uses malicious bootloaders to disrupt the boot process and gain control over victim machines, or the more recent iLOBleed implant, designed to "brick" HPE servers by manipulating the "integrated lights out" functions in their baseboard management controllers (BMCs).

Relevant ATT&CK Techniques	• Data Destruction • Disk Wipe • Firmware Corruption • System Shutdown and Reboot
References and Further Reading	• Using firmware to remotely brick a server • Russian attack on SATCOM networks • MBR Wipers - Hermetic Wiper. WhisperGate, NotPetya • Impacts of attacks on Ukrainian powergrid • QNAP ransomware targeting NAS firmware • VPNFilter attacks

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Firmware Countermeasures	• Scan devices to identify any vulnerable components or misconfigurations that would allow attackers to write to firmware or compromise the boot process. • Proactively verify the integrity of all firmware to identify any signs of implants or firmware compromise.

CONCLUSIONS AND NEXT STEPS_

While ATT&CK covers a broad range of activities, this paper seeks to superimpose a firmware-oriented perspective over the framework and introduce some of the many ways firmware can be used and abused in modern attacks and bridge those technical and procedural gaps

However, it is far from an exhaustive list. As some of the most privileged and powerful code on a device, there are virtually unlimited ways that attackers can use firmware maliciously. In this example, the Cybersecurity and Infrastructure Security Agency (CISA) has used ATT&CK to map Trickbot malware tactics to a number of deep and hard-to-detect techniques, down to and including UEFI firmware compromise.

Firmware risks extend to virtually every phase of an attack, and it requires security teams to take a consistent and comprehensive approach to firmware security within their organizations. As a result, this examination of MITRE ATT&CK through a "firmware lens" may pose new challenges and concerns for cybersecurity strategists and their teams. However, it is important to note that as threat actors continue to shift their focus to firmware, new security tools are also available that can help security teams incorporate and automate firmware security into their existing practices.

Built on industry-leading expertise and research, the Eclypsium supply chain security platform makes it easy for organizations to protect the IT infrastructure that powers their operations. Eclypsium helps security teams to protect critical hardware, firmware, and software from supply chain attacks. With Eclypsium, you gain instant expertise into the below-the-OS attack surface and can quickly and simply implement critical security controls: asset inventory, vulnerability management, and threat detection. If you would like to learn more, we recommend the following resources:

- Take a tour of the Eclypsium platform.
- To stay up to date with latest firmware security news, please subscribe to the Below the Surface Threat Report
- To learn more about Eclypsium, please contact our team at info@eclypsium.com.

ABOUT ECLYPSIUM_

Eclypsium's cloud-based platform provides digital supply chain security for critical software, firmware and hardware in enterprise infrastructure. Eclypsium helps enterprises and government agencies mitigate risks to their infrastructure from complex technology supply chains. For more information, visit eclypsium.com.

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