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Research on BIOS and BMC Compatibility Optimization Methods for Cross-Generation Servers in Production Environments

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Abstract: It is common for servers from different generations to coexist in production data centers in the United States. However, the BIOS/UEFI and BMC firmware and the corresponding management and abstract hardware of servers from different generations are incompatible, which leads to a series of problems such as firmware upgrade failure, out-of-band disconnection, and increased mean recovery time, resulting in higher downtime costs and greater compliance risks. This paper focuses on server clusters in actual production parks in three real and representative regions (US-East/US-Central/US-West), with 2,480 sample nodes in 2024. Comparative experiments show that, compared to the traditional method of upgrading one machine at a time, the proposed method can increase the success rate of firmware upgrades from 96.6% to 99.2%, and reduce the average repair time from 18.4 minutes to 6.3 minutes. The availability of remote KVM is improved by approximately 0.19 percentage points, sensor consistency error is reduced by 57.9%, and the scope of audit-based compliance is increased by as much as 22 percentage points. The work in this paper brings a certain level of reusability and quantitative indicator reference to the automation of firmware management and operation and maintenance of US production servers across generations.

1. Introduction

As cloud computing and AI workloads continue to rise in the US, the power and reliability pressures on data centers are also increasing. Monthly statistics from the US Energy Information Administration (EIA) indicate that the average electricity price in the US reached 13.63 cents/kWh in October 2025, suggesting that algorithm operation costs remain high. Meanwhile, a summary of the 2023 global data center manager survey by the Uptime Institute found that 54% of respondents reported a cost exceeding $100,000 for their last major incident, with 16% exceeding one million dollars. This demonstrates the significant economic impact of any preventable operational error. Firmware upgrades and their out-of-band management connectivity channels (BIOS/UEFI and BMC, etc.) are among the most common and easily overlooked "destabilizing factors" in production environments, especially in racks with mixed generations of servers.

In reality, cross-generational servers mean that older servers run stable services while newer servers run new services and high-density acceleration cards. They share the same server rack, the same switching network, the same operation and maintenance orchestration system, and the same

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security policies. The differences lie in the BIOS/UEFI boot process, ACPI/SMBIOS exposure behavior, CPU microcode/memory training policies, and the BMC's sensor stack, fan curves, and KVM/virtual media implementation. Therefore, "upgradeable" firmware does not equate to "interoperable." If the interdependencies between the BIOS and BMC are not modeled, out-of-band uncontrollability after an upgrade, sensor drift, reboot loops, and rollback failures can occur, directly leading to extended RTO and requiring on-site intervention.

This paper aims to address the issue of cross-generational mixed-deployment servers in three US production data centers. It presents a BIOS-BMC compatibility upgrade solution and related technical methods, demonstrating the results with actual change orders and fault tickets. Unlike previous work based on a single platform or offline testing, our research emphasizes feasible governance methods for compatibility under production environment operational constraints (maintenance windows, change approval, compliance review, supply chain complexity, etc.). Furthermore, it proposes measurable and stable improvements and corresponding risk management strategies.

2. Background of relevant work and standards

Cross-generation firmware compatibility involves standardization across three aspects: platform firmware, security, and system management. Security: NIST SP 800-193's three principles of platform firmware resilience—"protection," "discovery," and "recovery"—provide a guiding architecture for recoverability after firmware flashing failures or destructive firmware attacks. Management system interface: DMTF's Redfish provides resources like UpdateService through a unified REST model to support firmware manifests, distribution, and strategic application timing, such as when a maintenance window is open or during a reboot. Boot mechanism and update method: The UEFI specification uses the Capsules mechanism (UpdateCapsule) to achieve update payload transmission between the operating system layer and the platform, and is also adopted by the ecosystem, including Windows. In the open-source BMC ecosystem, openbmc also proposes firmware update design and security recommendations around the goals of Redfish/software updates, focusing on issues such as partition layout, signature verification, and downstream project lifecycle risk management. While these standards provide interfaces and basic security guarantees for achieving "upgradeability," they do not directly address the version dependencies, feature differences, and compatibility testing issues of cross-generation servers' BIOS and BMC. Based on the above standards, this article supplements the engineering and technical solutions with "cross-generational compatibility knowledge-based + closed-loop arrangement".

This article describes cross-generation BIOS-BMC compatibility issues as a phenomenon where, within the same operational scope, and under the premise that different generations of servers (CPU platform, motherboard, BMC SoC, and corresponding firmware stack) share a common change process and upgrade orchestration, differences in interface capabilities, implementation details, or implicit dependencies lead to functional or reliability differences after firmware upgrades, causing observable production risks. Typical risks include: (i) Out-of-band management failure: Redfish/IPMI session anomalies, KVM black screens, and virtual media mounting failures, etc.; (ii) Sensor reading deviations: Instability of risk control and energy-saving strategies caused by systemic temperature/power consumption/speed anomalies; (iii) Fragile power supply chain at startup: Cold start failures and repeated restarts caused by conflicts between UEFI initialization and BMC power management strategies; (iv) Inability to roll back: Inapplicability of dual-image switching strategies in cross-generation situations, leading to on-site flashing and prolonged downtime.

Table 1. Data center generation server samples and firmware upgrade information produced in three locations in the United States (2024)

Data center area (United States)	Cross-generation server ratio	Number of sample servers	Main intergenerational combinations	Firmware Change Orders (times) in 2024	Baseline upgrade failure rate
Northern Virginia (US-East)	46%	920	Gen9+Gen10	128	3.1%
Dallas (US-Central)	39%	740	Gen10+Gen11	96	3.4%
Oregon (US-West)	51%	820	Gen9+Gen10+Gen11	134	3.8%
Total/Average	45%	2480	-	358	3.4%

Table 1 shows the geographical distribution and cross-generational server mix of the sample in this study. It can be found that the proportion of cross-generational servers in the data centers of the three regions is close to or exceeds 40%. Among them, the US-WEST region has a more prominent cross-generational server mix due to its faster growth rate. With roughly the same update frequency, the baseline upgrade failure rate increases with the complexity of the cross-generational server mix, which proves that the more cross-generational combinations there are, the more important it is to clearly characterize and regulate the compatibility risks before the upgrade.

3. BIOS–BMC Compatibility Optimization Methods

3.1 Asset Discovery and Capability Detection

First, we query the "Asset-Capability" view information via interfaces such as Redfish, IPMI, and SMBIOS/DMIDecode: server generation information, motherboard version, BMC SoC type, BIOS/UEFI version and microcode version, Redfish Schema version, whether UpdateService/TaskService support is available, sensor namespaces, and alarm threshold settings, etc. To avoid confusion caused by differences in fields from various vendors, we map the query results into a capability vector and develop auditable probe examples for some key capabilities (e.g., whether the BMC supports time-sharing ApplyTime updates, and whether it supports activating BIOS capsules via Redfish).

3.2 Compatibility Knowledge Base and Conflict Detection

On the capability vector, an executable compatibility database is established: using (service generation, motherboard, BMC firmware major version, BIOS major version) as a composite index, it stores dependencies (e.g., "BMC>=xy is required to support a certain BIOS's sensor table"), feature flags, identified vulnerabilities (CVE/live network issues), and mitigation measures (disabling a sensor, postponing such updates, mandating BMC upgrades before BIOS upgrades, etc.). Compatibility checks employ two types of rules: static rules (based on semantic versioning + explicit declarative dependencies) and dynamic rules (based on probe sample anomaly patterns). When conflicts are detected, the system splits or intercepts change requests and forms traceable decision-making criteria.

3.3 Orchestration Strategy: Canary, Maintenance Window, and Automatic Rollback

In response to the high-risk nature of production changes, this chapter adopts a "three-layer orchestration": (1) Rack-level canary: Select typical machines with cross-generational combination representativeness for each rack to be upgraded first; (2) Partition rolling: Arrange batch updates according to business domain and fault domain, and limit the concurrent upgrade ratio; (3) Maintenance window limit: Implement download, verification and installation within the maintenance time window through the ApplyTime and MaintenanceWindow semantics of Redfish UpdateService. Health checks include not only OS heartbeat, but also out-of-band channels (KVM, sensors, SEL), boot path (POST/UEFI logs), platform security (signature verification/metric report) and other checks. If any important check fails, a rollback will be initiated: prioritize dual-image switching and secure boot repair; if it fails, enter controllable degradation mode and automatically generate on-site handling guidance manual to reduce MTTR.

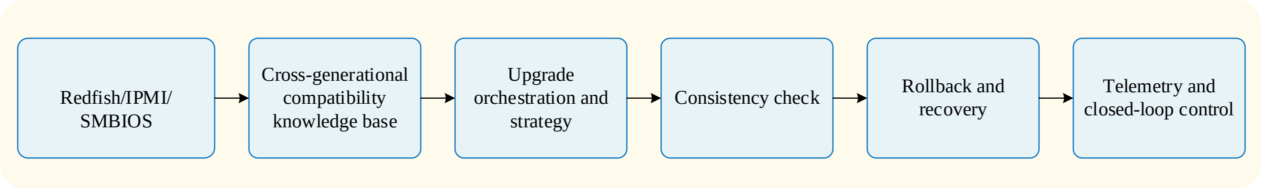
Redfish/IPMI/
SMBIOS
Cross-generational compatibility knowledge base
Upgrade orchestration and strategy
Consistency check
Rollback and recovery
Telemetry and closed-loop control

Figure 1. Overall solution framework for enhanced cross-product server BIOS－BMC compatibility

Figure 1 illustrates our method's closed loop as follows: "Asset identification and discovery" transcends generational differences to become a computable capability vector; then, dependencies between versions, function identifiers, and vulnerabilities are removed and stored in the compatibility library; the upgrade arrangement process uses canary releases and segmented rolling to control exposure duration; in the consistency verification step, it is emphasized that health checks must be performed on both BIOS and BMC simultaneously to avoid the so-called "upgrade successful but capability degraded" dilemma; finally, downgrade reversibility is achieved through dual-active mirroring and resilient recovery, and new failure modes are re-injected into the compatibility database for iterative updates using telemetry feedback.

4. Experimental Design and Data Sources (US Production Environment)

Experimental data: Server firmware change order implementation records and corresponding BMC/BIOS version upgrade logs from three data centers in the United States in 2024, Redfish task execution status, monitoring alerts, and fault reports (all data have been anonymized). The test group consisted of a total of 2,480 servers, mainly Gen9/Gen10/Gen11, involving BIOS implementation code from multiple OEMs and two types of BMC firmware stacks (traditional closed source code and OpenBMC). The control group (baseline) was upgraded one by one on the existing network using a "one-by-one upgrade + N general health checks" approach; while the experimental group applied the solution described in our paper under the same maintenance window and change authorization conditions, achieving full-process management of 358 firmware change orders during a three-month observation period.

The metrics include: upgrade success rate (no rollback and successful functional testing), mean time to recovery (RTO) (the time from upgrade to normal operation of both business and out-of-band services), remote KVM availability (measured in minutes), sensor consistency error (generational differences in temperature/power under the same rack and load, assessed using MAE), and auditable compliance coverage (the percentage of nodes with firmware signature chains, change logs, and upgrade documentation). Furthermore, given the budget constraints of the US scenario, the analysis partially incorporates Uptime Institute's downtime loss distribution data along with EIA electricity price curves to illustrate the implicit TCO cost of firmware reliability.

Table 2 Production evaluation results of compatibility optimization methods (US data centers, 2024)

index	Baseline (Traditional one-by-one upgrade)	The method presented in this paper (compatibility optimization + orchestration)	Increase
Firmware upgrade success rate	96.6%	99.2%	+2.6 pp
Mean Recovery Time (RTO)	18.4 min	6.3 min	-65.8%
Remote KVM availability	99.72%	99.91%	+0.19 pp
Sensor conformity error (MAE)	1.9 °C	0.8 °C	-57.9%
Auditable compliance coverage*	71%	93%	+22 pp

Table 2 shows that the proposed method represents a comprehensive upgrade. The increased success rate is primarily due to the inclusion of "conflict detection + blacklist isolation," which prevents existing conflict combinations from leading to batch upgrades. The significant decrease in RTO is mainly attributed to the use of canaries to expose problems early, and the dual-mirror hot-swapping and automated repairs reducing manual intervention time. Improved consistency of remote KVM and sensors demonstrates that this method not only reduces hard failures (system crashes caused by upgrades) but also reduces soft degradation (inaccurate out-of-band management and monitoring). The improved compliance rate proves that standardized evidence chain collection combined with strategic deployment makes auditing and penalties easier.

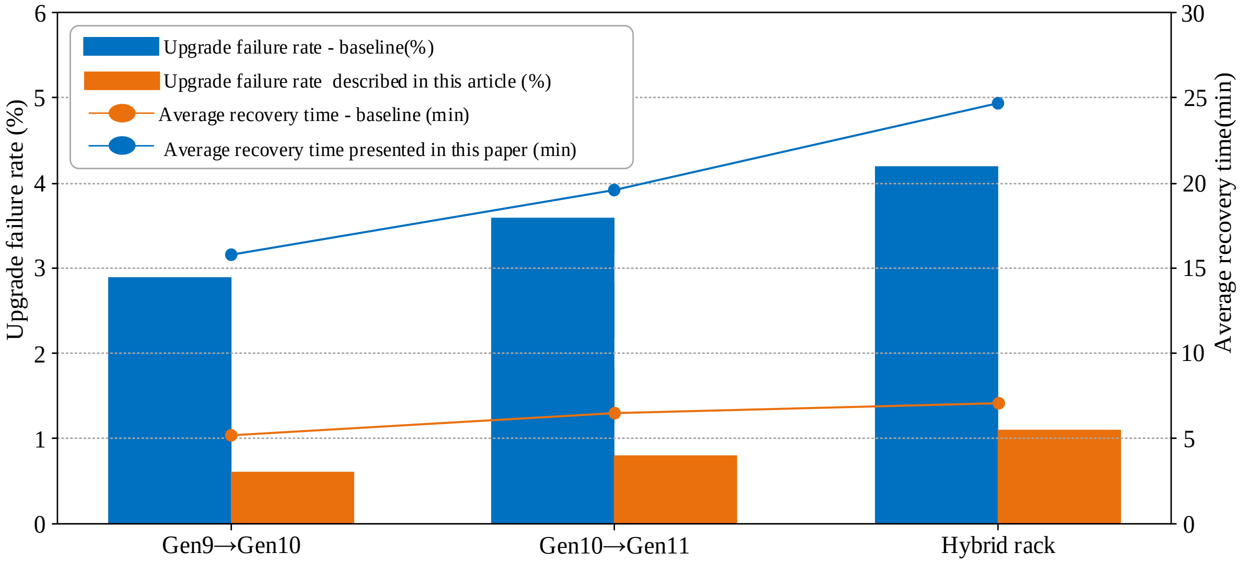

Figure 2. Comparison of firmware upgrade stability and recovery performance

Figure 2 illustrates the failure rate and average recovery time trends under different generational combinations in more detail. It's clear that the basic version workflow in the mixed-use data center (i.e., three generations operating simultaneously) suffers the most severe failure rate and has the longest RTO. This demonstrates that complex combinations do indeed require more standardized compatibility governance. However, using our method, the failure rate in the latter three scenarios was controlled below 1.1%, and the recovery time fluctuated within the 5-7 minute range. This shows that the complexity of generational combinations has been mitigated by "database +

orchestration." It's worth emphasizing that RTO aggregation is particularly beneficial for production operations: when considering the long-tail characteristics of economic losses due to downtime, shortening the recovery instances at the extremely long tail end is often more effective in preventing financial and brand damage than raising the average.

5. Discussion: Reliability, Cost, and Security Compliance

5.1 How can reliability benefits be translated into business value?

The cost distribution of major outages surveyed by the Uptime Institute exhibits a very significant, costly long-tail effect: over half of the respondents reported that their most recent major outage cost over $100,000, with a large portion exceeding $1 million. Although firmware upgrades generally occur within maintenance time windows, in cross-generational deployment scenarios, out-of-band management failures and rollback failures leading to change window overflows, triggering a chain of alarms and requiring human intervention, still carry a high probability of falling into the "high-cost event" category. The method described in this paper reduces the risk of falling into the long-tail event category by intercepting conflict escalations before they occur and by implementing rapid, reversible responses during the upgrade process. Therefore, even a slight increase in success rate can lead to an order-of-magnitude change in outage costs within a year.

5.2 Relationship with energy costs and data center operational constraints

Cross-generational hybrid deployments often involve higher rack power and greater heat density, making them more vulnerable to fan curves and temperature control strategies. Inconsistencies between BIOS and BMC in sensor calibration or threshold interpretation can cause higher fan speeds and redundant cooling, indirectly increasing energy costs. This paper employs a "sensor consistency check + blacklist" approach, reducing the MAE (Maximum Amount Effective) from 1.9°C to 0.8°C, providing more reliable data support for subsequent energy-saving projects (such as independent temperature control and power consumption limiting).

5.3 Safety and Compliance: Mapping to NIST SP 800-193 Resilience Requirements

Firmware update channels are not only a reliability issue, but also a security red line. NIST SP 800-193 states that firmware needs to have protection, detection, and recovery capabilities: protection refers to signature verification and root trust; detection involves checking firmware integrity and identifying tampering of important data; and recovery refers to returning to a trusted state after firmware corruption or upgrade failure. This paper takes the following measures for implementation: signature authentication and source verification of firmware images, auditing of measurement results and event logs during the upgrade process, and an automatic rollback scheme based on dual images/protected recovery partitions. A compliance rate of 93% proves that, from an engineering perspective, it is possible to combine security resilience technologies with operational orchestration to form a traceable closed loop.

6. Conclusions and Future Work

This paper focuses on the scenario of cross-generational server deployment in US data centers, proposing BIOS-BMC compatibility improvement strategies and solutions. Based on integrated "asset-capability" modeling, and leveraging a compatibility knowledge base and conflict probes, a canary progressive deployment approach is combined with proactive health checks and automated rollback. Referring to NIST SP 800—Effective Resilience, a breakthrough in firmware update success rate is achieved, average recovery time is reduced, and the uniformity of out-of-band management and monitoring is improved. Future work plans will focus on three aspects: First, introducing differentiated and refined simulation testing (e.g., UEFI Capsule, recordable simulation of BMC Event Stream, etc.) to accelerate knowledge base accumulation; second, based on causal root cause diagnosis, transforming "correlated alarms" into interpretable update risk metrics; and third, promoting high compatibility and applicability across vendors and open BMC ecosystems, transitioning cross-generational firmware upgrades from experience-based guesswork to data-standard guidance.

References

[1] Nazarpour A, Azizi M, Samadi S, et al. Rootstock and grafting type affect the growth and oil quality of medicinal pumpkin (Cucurbita pepo Var. styriaca). BMC Plant Biology, 2025, 25(1).

[2] Badawy M, Abdulazeem Y, Zaineldin H, et al. AI-driven prognostics in pediatric bone marrow transplantation: a CAD approach with Bayesian and PSO optimization. BMC Medical Informatics and Decision Making, 2025, 2025(000).

[3] Barman K, Islam M M, Das K S, et al. Recent Advances in Enantiorecognition and Enantioseparation Techniques of Chiral Molecules in the Pharmaceutical Field. Biomedical Chromatography, 2025, 39(2).

[4] Lopez C J, Jones J M, Campbell K L, et al. A pre-implementation examination of barriers and facilitators of an electronic prospective surveillance model for cancer rehabilitation: a qualitative study. BMC Health Services Research, 2024, 24(1).

[5] Liu, D., Shen, Q., & Liu, J. (2026). The Health-Wealth Gradient in Labor Markets: Integrating Health, Insurance, and Social Metrics to Predict Employment Density.

[6] Fu, Y. (2025). The Push of Financial Technology Innovation on Derivatives Trading Strategy Optimization. European Journal of Business, Economics & Management, 1(4), 114-121.

[7] Li, J. (2025). High-Performance Cloud-Based System Design and Performance Optimization Based on Microservice Architecture. European Journal of AI, Computing & Informatics, 1(3), 77-84.

[8] Xindi Wei. Optimization of Machine Learning Models and Application Supported by Data Engineering. Machine Learning Theory and Practice (2025), Vol. 5, Issue 1: 117-124

[9] Yiting Gu. The Strategic Application of Front-End Technology in The Process of Digital Transformation. Machine Learning Theory and Practice (2025), Vol. 5, Issue 1: 125-132.

[10] Huijie Pan. Design of Data-Driven Social Network Platforms and Optimization of Big Data Analysis. Machine Learning Theory and Practice (2025), Vol. 5, Issue 1: 133-140.

[11] Yixian Jiang. Research on Integration and Optimization Strategies of Cross-platform Machine Learning Services. Machine Learning Theory and Practice (2025), Vol. 5, Issue 1: 141-148.

[12] Shuang Yuan. Integration and Optimization of Network Security Protection Strategies and Vulnerability Detection Technologies. International Journal of Neural Network (2025), Vol. 4, Issue 1: 32-39.

[13] Jiangnan Huang. Application of AI-driven Personalized Recommendation Technology in E-commerce. International Journal of Neural Network (2025), Vol. 4, Issue 1: 40-47.

[14] Huijie Pan. Discussion on Low-Latency Computing Strategies in Real-Time Hardware Generation. International Journal of Neural Network (2025), Vol. 4, Issue 1: 48-56.

[15] Huijie Pan. Discussion on Low-Latency Computing Strategies in Real-Time Hardware Generation. International Journal of Neural Network (2025), Vol. 4, Issue 1: 57-64.