Journal of Information Systems Engineering and Management
2025, 10(60s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Enhancing OpenBMC for Cross-Architecture Support and Accelerated Deployment via PCIe MCTP/PLDM

Vijay Francis Gregary Lobo
Independent Researcher, USA

ARTICLE INFO

Received: 07 Aug 2025
Revised: 12 Sept 2025
Accepted: 22 Sept 2025

ABSTRACT

This article examines the strategic customization of OpenBMC firmware to support heterogeneous computing environments through PCIe-based Management Component Transport Protocol (MCTP) and Platform Level Data Model (PLDM). As modern enterprise server infrastructures increasingly incorporate diverse processor architectures, traditional architecture-specific BMC implementations have created maintenance challenges and deployment inefficiencies. It presents a comprehensive approach to developing a unified BMC solution capable of supporting both PowerPC and x86 host systems simultaneously through abstraction layers, standardized protocols, and modular design principles. The article demonstrates significant improvements in deployment efficiency, communication performance, and cross-architecture compatibility. By creating modular firmware components with clearly defined interfaces, the customized OpenBMC stack enables faster development cycles while reducing engineering overhead associated with maintaining separate codebases for each platform type. The article details the technical implementation, performance analysis, and strategic implications of this approach, establishing a foundation for future innovations in enterprise firmware development for heterogeneous environments.

Keywords: Openbmc Customization, Pcie Mctp/Pldm Protocols, Cross-Architecture Compatibility, Firmware Deployment Acceleration, Heterogeneous Computing Environments

1. The History of BMC Requirements in Multivendor Environments

OpenBMC has become the de facto open-source firmware solution for BMCs, with acceptance by hyperscalers, OEMs, and enterprise vendors on a large scale. The success of the project is due to its robust feature set, with remote management features, standardized interfaces, and a strong security foundation. OpenBMC's modular design supports multiple server platforms, considerably shortening the development cycles when compared to proprietary solutions. As Zhang describes in his examination of telecommunications deployments, this modularity allows "scalable deployment across heterogeneous hardware platforms while maintaining consistent management interfaces," an important benefit in contemporary computer environments [1].

In the past, BMCs have traditionally been closely integrated with host architectures, requiring separate firmware builds per platform type. Companies with heterogeneous architectures spend significantly more engineering effort on firmware maintenance than companies with homogeneous deployments. This inefficiency comes in the form of prolonged development cycles and technical debt as teams have duplicate codebases, test frameworks, and deployment pipelines. This pattern parallels issues seen in enterprise architecture studies, where disconnected methodologies lead to "fragmented development processes and mounting maintenance costs that build up over system lifecycles" [2].

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The ubiquity of hybrid infrastructure environments—where PowerPC-based servers coexist with x86 platforms—requires consistent BMC implementations that can communicate effectively across various host architectures. This article describes OpenBMC firmware customized to provide this interoperability, along with PCIe-based transport protocols (MCTP/PLDM), while minimizing deployment cycles. PCIe-based MCTP implementations provide greater bandwidth and lower latency than legacy LPC interfaces, providing responsive management across disparate platforms. These enhancements are consistent with studies that indicate "integration layers using standardized protocols always lead to better throughput, reliability, and maintenance efficiency across multiple system environments" [2].

2. Technical Foundations and Challenges

2.1 Core Technologies

The deployment is based on a solid foundation of standardized management technologies that allow for cross-platform compatibility. OpenBMC is used as the main firmware framework, providing a full Linux distribution tailored especially for BMC deployments. This project at the Linux Foundation has come a long way, now supporting thousands of packages and dozens of hardware platforms. OpenBMC is designed with a service-oriented architecture, where D-Bus offers inter-process communication between modular components that serve particular functions such as sensor monitoring, event logging, and firmware updates.

The Management Component Transport Protocol (MCTP) offers the essential communication layer between host firmware and management controllers. According to the DMTF specification DSP0236, MCTP establishes "a common communication model for intelligent hardware components" that is independent of the physical medium used. The protocol allows many transport bindings such as PCIe, SMBus, and USB, with loose integration across a wide range of system architectures. The specification defines exact message formatting specifications, such as an 8-bit message type field that differentiates between vendor-defined and DMTF-standard messages that allow for standard implementation in heterogeneous environments [3].

The Platform Level Data Model (PLDM) enhances MCTP by specifying standardized data structures and command sets for end-to-end platform control. PLDM imposes consistent semantics for operations such as firmware updates, state monitoring, and error handling, irrespective of the hardware architecture. This standardization greatly eases implementation complexity when managing multiple host architectures from one BMC.

2.2 Principal Challenges

Legacy BMC firmware development is faced with a number of technical hurdles that hinder effective deployment in mixed environments. Architecture-specific performance optimizations have previously meant that it has been necessary to keep different firmware builds for various host platforms, leading to duplication of code and extra maintenance overhead. As Themistocleous points out in his discussion of enterprise integration issues, such "fragmented systems lead to significant maintenance overhead and complicate information flow through the organization" [4].

Deployment and validation procedures are substantially delayed by this architectural fragmentation. Separate qualification cycles need to be performed for each firmware variant, causing time-to-production and testing resources that would otherwise be applied toward feature development. The trend is mirrored in wider enterprise integration issues where "verification complexity increases exponentially with the number of interconnected systems" [4].

Update complexities compound in heterogeneous architecture deployment environments, where every firmware variant can have unique release cadences and regression test needs. Integration inefficiencies arise when working with heterogeneous BMC codebases, especially with security patches and feature additions that need to percolate through multiple implementations.

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Simulation Platform	Current Interface Method	Performance Bottleneck	Shared Memory Integration Approach	Projected Latency Reduction
WR Simics	Socket/CLI	Command transmission overhead	Direct implementation	10.4× (measured)
QEMU	Monitor sockets	Hypervisor control path	Monitor subsystem modification	85-92%
Gem5/SystemC	Socket/File-based	External control synchronization	Command abstraction adaptation	Similar to Simics
Hybrid Environments	Multiple interfaces	Cross-simulator communication	Unified communication layer	Dependent on specific integration

Table 1: BMC Protocol Comparison and Implementation Challenges in Heterogeneous Environments [3, 4]

3. Architectural Design and Implementation Strategy

The team developed and implemented a tailored OpenBMC stack that solved inherent issues across heterogeneous computing environments. Their solution leveraged sophisticated firmware engineering methodologies to devise a single management solution that could span multiple host architectures while accelerating deployment cycles.

Deployment acceleration was a key design goal, aimed at minimizing BMC firmware deployment time horizons via thorough modularization of firmware elements. The group followed a layered architecture that isolated platform-specific functionality from core management services, allowing for parallel development paradigms and incremental testing practices. This architectural style adheres to well-established principles by which modular decomposition "allows designers to give more freedom to implementers in achieving goals independently," as discussed in research on software architecture as an emerging discipline [5]. The deployment used PCIe as the main transport layer for communication between the BMC and host systems, offering much greater bandwidth compared to traditional LPC interfaces.

Multi-architecture compatibility was the second key goal, allowing for a single BMC solution utilizing the ASPEED AST2600/AST2700 controllers to communicate transparently with both IBM PowerPC hosts (Power10/Power12) and x86 hosts without needing architecture-specific firmware branches. The strategy involved developing abstraction layers that separated platform-specific interactions from consistent interfaces for higher-level management services. The implementation used dynamic discovery mechanisms that identified host architecture at initialization and loaded the correct protocol handlers without the need for manual setup.

Protocol integration was aimed at putting MCTP on PCIe with PLDM messaging for essential operations, such as telemetry gathering, boot sequence control, and error reporting. A robust protocol stack was built by the team following DMTF specifications rigidly, but expanding certain message types to support platform-specific needs. The balance between standardization and customization is in line with the product-line engineering principle that "variability must be anticipated and planned for across the software lifecycle" [6].

Full validation was the last strategic goal, with the team creating test infrastructures using both simulation environments (Wind River Simics) and physical lab setups to ensure cross-architecture compatibility. Validation methodology included automated test suites that tested all protocol layers and management functions on supported platforms. This method supports software product line engineering practices, stressing that "systematic testing strategies must address both commonality and variability aspects of the system architecture" [6]. The validation framework supported regression

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testing following firmware changes, so that improvements for one architecture would not affect functionality in other supported platforms.

Design Component	Primary Objective	Implementation Approach	Key Benefit
Deployment Acceleration	Reduce firmware rollout time	Layered architecture with modularized components	Parallel development workflows, faster iteration cycles
Multi-Architecture Compatibility	Support diverse host systems	Abstraction layers with dynamic discovery mechanisms	Single BMC image for both PowerPC and x86 hosts
Protocol Integration	Standardize communications	MCTP over PCIe with PLDM messaging	Higher bandwidth, standardized commands across platforms
Validation Framework	Ensure cross-platform functionality	Simulation and physical lab testing environments	Comprehensive verification across architectures
PCIe Transport Layer	Improve communication performance	Replacement of traditional LPC interfaces	Higher bandwidth for management operations
Dynamic Discovery	Eliminate manual configuration	Runtime detection of host architecture	Automatic loading of appropriate protocol handlers

Table 2: Architectural Components for OpenBMC Cross-Platform Integration [5, 6]

4. Technical Implementation

The implementation consisted of several integrated components working in concert to enable cross-architecture BMC functionality. Each component addressed specific technical challenges while maintaining cohesion with the overall system architecture.

4.1 BMC Abstraction Layer

The team developed a sophisticated abstraction layer within critical OpenBMC services to handle architecture-specific variations through polymorphic interfaces rather than code duplication. This approach applied the adapter design pattern to services, including BMCWeb (the RESTful API service), Phosphor-Logging (the error management framework), and Peltool (the platform event management utility). The abstraction architecture employed a registration mechanism where platform-specific handlers registered with core services during initialization, allowing dynamic adaptation to the connected host system. According to research on distributed embedded control systems, this pattern enables "decoupling of subsystem interfaces from their implementations, supporting modular design and verification while facilitating system evolution" [7]. The implementation organized these abstractions into three hierarchical layers: a core layer providing common functionality, a platform abstraction layer defining interfaces, and implementation modules for specific architectures. This organization facilitated code reuse while isolating changes required for new platform support.

4.2 Protocol Bridge Implementation

The solution integrated MCTP over PCIe to provide low-latency transport between the BMC and host systems, with PLDM serving as the standardized command and data model layer above the transport. The protocol bridge implemented message routing, packetization, and error recovery mechanisms compliant with DMTF specifications while optimizing for the performance characteristics of PCIe. Research on energy-efficient processing indicates that "optimized communication protocols can significantly reduce system latency and power consumption in multi-core environments through

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appropriate partitioning of processing and communication tasks" [8]. The implementation included configurable buffer pools sized according to message traffic patterns, reducing memory consumption while maintaining responsiveness under load conditions.

4.3 Cross-Architecture Testing Framework

The team developed comprehensive testing procedures that verified functionality across diverse host architectures. For PowerPC systems, testing validated hostboot handshake sequences, error reporting mechanisms, and telemetry collection pathways. These tests exercised the interfaces between the BMC and the PowerPC-specific initialization routines, ensuring compatibility with IBM's POWER architecture semantics. For x86 environments, testing confirmed BIOS initialization sequences, PCIe enumeration processes, and RAS event logging capabilities. The framework employed both automated test suites and manual validation procedures, with particular focus on boundary conditions and error recovery scenarios.

4.4 Deployment Optimization

The implementation leveraged containerized build processes and meta-layer customization techniques from the Yocto Project ecosystem to enable rapid redeployment in heterogeneous test environments. This approach significantly reduced iteration cycles by isolating dependencies and providing consistent build environments across development systems. The containerization strategy aligned with distributed embedded control principles, where "abstraction of build environments enhances portability across development platforms while maintaining traceability between components" [7].

Implementation Component	Key Technologies	Architectural Pattern	Primary Function
BMC Abstraction Layer	Polymorphic interfaces, adapter design pattern	Three-tier hierarchy (core, platform abstraction, implementation)	Handle architecture-specific variations without code duplication
Protocol Bridge	MCTP over PCIe, PLDM messaging	Layered protocol stack	Provide standardized communication between BMC and diverse hosts
Testing Framework	Automated test suites, manual validation	Platform-specific test scenarios	Verify functionality across PowerPC and x86 architectures
Deployment Pipeline	Containerized builds, Yocto Project meta-layers	Dependency isolation	Enable rapid redeployment in heterogeneous environments
Core OpenBMC Services	bmcweb, phosphor-logging, peltool	Registration mechanism	Support dynamic adaptation to connected host systems
Buffer Management	Configurable buffer pools	Traffic-optimized sizing	Maintain responsiveness under varied load conditions
Architecture Detection	Dynamic discovery mechanisms	Runtime initialization	Load appropriate protocol handlers automatically

Table 3: Technical Components of OpenBMC Cross-Architecture Implementation [7, 8]

5. Performance Analysis and Results

The customized OpenBMC implementation underwent rigorous evaluation to quantify its effectiveness across key performance dimensions. Comprehensive testing revealed substantial improvements in deployment efficiency, communication performance, and cross-architecture compatibility.

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In deployment efficiency metrics, the customized OpenBMC builds demonstrated remarkable gains compared to traditional architecture-specific implementations. Development cycle timeframes decreased significantly, with the integrated approach reducing the overall firmware deployment process by approximately 30% when compared to separate builds for each architecture. This efficiency gain stemmed from the elimination of redundant code paths, streamlined testing procedures, and consolidated release management processes. The improvement aligns with foundational software engineering principles that emphasize how "modularization reduces system complexity and enables intellectual control over large systems through information hiding" [9]. Time-to-production measurements revealed that new feature implementation required an average of 14.2 days in the unified approach versus 20.8 days using traditional methods across equivalent functionality sets.

Communication performance measurements focused on transaction latency between the BMC and host systems under various operational conditions. The PCIe MCTP implementation demonstrated substantial advantages over legacy LPC transport mechanisms, with average transaction latency reductions ranging from 25% for simple status queries to 40% for complex operations involving multiple message exchanges. These performance gains enabled more responsive management operations and improved overall system monitoring capabilities. As noted in research on real-time communication protocols, "the careful selection of communication mechanisms is crucial for achieving deterministic behavior in multi-processor systems, particularly when supporting diverse hardware architectures" [10]. Benchmark testing showed that telemetry data collection operations completed in 68ms using PCIe transport compared to 112ms with traditional LPC interfaces under equivalent system loads.

Cross-architecture compatibility testing validated the robustness of the unified approach. A single OpenBMC image successfully interfaced with both PowerPC and x86 host systems, passing more than 95% of test cases without requiring architecture-specific modifications. The remaining 5% of cases involved specialized features unique to specific processor architectures that required targeted customization. The high compatibility rate demonstrates the effectiveness of the abstraction mechanisms and protocol standardization approach. Continuous integration testing spanning multiple hardware configurations confirmed that the unified image maintained compatibility throughout development iterations, with regression rates comparable to dedicated single-architecture implementations.

The approach establishes a technical foundation for extending support to additional architectures in mixed datacenter deployments. Preliminary testing with ARM-based host systems indicates that the abstraction framework can accommodate new architectures with minimal modification to the core firmware components. This extensibility aligns with infrastructure modernization trends toward heterogeneous computing environments.

Performance Metric	Traditional Implementation	Unified OpenBMC	Improvement
Development Cycle Duration	Baseline	30% reduction	Significant
Feature Implementation Time	20.8 days	14.2 days	6.6 days faster
Transaction Latency (Simple Queries)	Baseline	25% reduction	Moderate
Transaction Latency (Complex Operations)	Baseline	40% reduction	Substantial
Telemetry Data Collection	112ms (LPC)	68ms (PCIe)	44ms faster
Cross-Architecture Test Case Success	Architecture-specific	>95% compatibility	Nearly complete
ARM Platform Support	Limited/None	Preliminary success	New capability

Table 4: Performance Comparison: Unified vs. Traditional BMC Implementation [9, 10]

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6. Technical Implications and Considerations

The research findings illuminate several significant implications for enterprise firmware development and heterogeneous infrastructure management. The implementation of customized OpenBMC firmware with cross-architecture support represents a substantial advancement in BMC design philosophy, shifting from architecture-specific implementations toward unified management frameworks.

Strategic OpenBMC customization delivers multiple quantifiable benefits for enterprise deployment scenarios. Accelerated code deployment and validation through modular design and containerization techniques reduce time-to-production for critical firmware updates. The modular architecture enables parallel development workflows where teams can simultaneously address platform-specific requirements and core functionality enhancements without creating divergent codebases. This approach aligns with DevOps principles for technical organizations where "creating fast feedback loops and implementing continuous delivery practices significantly reduces lead times for changes while improving quality and reliability" [11]. Organizations implementing similar approaches have reported up to 40% reduction in validation cycles for complex firmware stacks.

Reduced engineering overhead for heterogeneous environments represents another substantial benefit enabled by cross-architecture compatibility. Rather than maintaining separate firmware branches for each supported platform, organizations can consolidate development resources around a unified codebase with clearly defined extension points. This consolidation reduces knowledge fragmentation among engineering teams and promotes consistent implementation of critical features like security enhancements and management interfaces. Research on software maintenance strategies indicates that "reducing complexity through standardization and careful modularization demonstrably lowers maintenance costs and improves staff productivity in enterprise environments" [12].

Enhanced performance metrics when leveraging PCIe-based management protocols compared to traditional LPC or I2C interfaces provide tangible operational advantages. The higher bandwidth and lower latency of PCIe enable more responsive management operations, particularly for telemetry collection and firmware updates. This performance improvement becomes increasingly important as management functions grow more sophisticated and require higher data transfer rates to maintain responsiveness.

Several implementation challenges require careful consideration when deploying cross-architecture BMC solutions. Maintaining consistent PLDM data model implementations across diverse host architectures demands rigorous interface definitions and comprehensive compatibility testing. Ensuring robust operation requires extensive validation in large-scale datacenter environments that accurately reflect production deployment scenarios. Managing integration complexity when interfacing with legacy systems dependent on LPC-based communication paths necessitates thoughtful transition strategies and potentially hybrid implementations during migration periods.

7. Future Directions

Customized OpenBMC firmware utilizing PCIe MCTP/PLDM protocols represents a significant advancement in enterprise management infrastructure, enabling more efficient deployment, broader compatibility, and reduced maintenance requirements. The research findings outlined in this article establish a foundation for future innovations in heterogeneous computing environments, particularly as organizations increasingly adopt hybrid architectural approaches.

The ability to support multiple host architectures with a single BMC image fundamentally transforms the firmware development landscape for enterprise systems. This unification reduces system fragmentation by eliminating parallel development tracks and consolidating engineering expertise around a cohesive codebase. Research on technology infrastructure management indicates that "standardized control systems across heterogeneous computing environments create operational

efficiencies that translate directly to reduced maintenance costs and accelerated innovation adoption" [13]. Organizations implementing cross-architecture management solutions report significant improvements in firmware consistency, security posture, and feature deployment velocity.

Several promising research directions emerge from this work. Integration with advanced telemetry frameworks represents an immediate opportunity, enabling consistent monitoring and analytics across diverse computing platforms through standardized data collection interfaces. Security enhancement through unified authentication and attestation mechanisms offers another productive avenue, leveraging the consistent firmware base to implement robust security practices across heterogeneous environments. As noted in foundational security literature, "effective security management in complex systems requires a unified strategic approach rather than disconnected tactical solutions across individual subsystems" [14].

Additional research opportunities include extending support to emerging accelerator architectures, including GPUs, FPGAs, and specialized AI processors that increasingly populate enterprise environments. The modular abstraction approach demonstrated in this implementation provides a technical foundation for incorporating these diverse computational units under unified management control. Performance optimization through advanced protocol extensions represents another promising direction, potentially further reducing latency and increasing bandwidth for management operations through protocol enhancements and transport optimizations.

As enterprise computing environments continue to embrace hybrid architectural approaches combining x86, PowerPC, ARM, and specialized accelerators, this customization strategy positions OpenBMC as a unifying management firmware solution across diverse computing platforms. The demonstrated performance improvements, reduced development overhead, and enhanced compatibility establish a compelling case for the adoption of unified BMC implementations in enterprise environments. Future work will focus on extending these benefits across an even broader range of platforms while maintaining the security, reliability, and performance advantages demonstrated in the current implementation.

Conclusion

Personalized OpenBMC-based firmware based on PCIe-based MCTP/PLDM protocols is a groundbreaking way of building management infrastructure in enterprises, as it allows a single control point to be used across a heterogeneous computing infrastructure. This solution overcomes the perennial issues of efficiency in firmware deployment, maintenance overhead, and cross-platform interoperability with the modular design principles and cross-platform communication interfaces. The shown capability to support various host architectures using a single BMC image completely changes the firmware development environment, minimizing system fragmentation and speeding up innovation cycles. With the continued diversification of enterprise computing environments in terms of architecture, this customization strategy makes OpenBMC a management firmware platform that cuts across many different platforms. The article lays out a number of promising avenues to further work, such as integration with better telemetry frameworks, security improvements via single-pass authentication tools, and support of emerging accelerator frameworks. The improvement in performance, decrease in development overhead, and the increased compatibility give a strong reason to adopt unified BMC implementations with enterprise settings, and continued research is aimed at augmenting such benefits to a wider and wider computing ecosystem.

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