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Leveraging Model Context Protocol for Secure Cloud-Based Agentic Enterprise Integration and API Interoperability

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ABSTRACT: The rapid evolution of agentic artificial intelligence (AI) has introduced complex challenges in enterprise integration, particularly concerning secure data orchestration, API interoperability, and context maintenance across fragmented cloud ecosystems. This paper examines the deployment of the Model Context Protocol (MCP) as a standardized framework for establishing secure, bi-directional communication between LLM-based autonomous agents and enterprise data sources. By formalizing context exchange protocols, MCP mitigates common vulnerabilities associated with traditional webhook architectures and ad-hoc API wrappers, such as credential exposure, loose access controls, and contextual drift. We propose a robust architectural blueprint that integrates MCP within cloud-native environments, leveraging zero-trust network access (ZTNA), fine-grained tokenization, and dynamic schema mapping to ensure high-fidelity API interoperability. Through a comprehensive evaluation of data processing efficiency, latency overhead, and boundary security compliance, this research demonstrates how MCP-driven agentic workflows minimize semantic loss while enforcing strict enterprise data governance boundaries. Ultimately, this study provides actionable insights for enterprise architects aiming to scale secure, autonomous AI systems that interact seamlessly with legacy enterprise resource planning (ERP) platforms, customer relationship management (CRM) databases, and distributed microservices architectures without compromising structural data sovereignty.

KEYWORDS: Model Context Protocol, Agentic AI, Enterprise Integration, API Interoperability, Cloud Security, Zero Trust Architecture, Semantic Web

I. INTRODUCTION

The modern enterprise landscape is characterized by an unprecedented fragmentation of data repositories, cloud infrastructure, and proprietary application programming interfaces (APIs). As organizations increasingly transition toward autonomous, agentic artificial intelligence (AI) workflows to automate complex business processes, the historical limitations of traditional middleware and rigid integration paradigms become glaringly apparent. Legacy enterprise integration patterns, ranging from monolithic service-oriented architectures (SOA) to contemporary RESTful and GraphQL microservices, rely on deterministic execution paths engineered strictly by human developers. While these interfaces excel at structured data transfer, they fail to provide the semantic flexibility, dynamic context preservation, and structural reasoning capabilities required by large language model (LLM) agents. When autonomous agents attempt to orchestrate tasks across disparate systems—such as reconciling financial anomalies between an ERP database and a third-party billing API—they frequently encounter structural silos, contextual drift, and severe data translation overhead. Consequently, the enterprise lacks a unified connective tissue capable of translating ambiguous, natural-language business goals into secure, deterministic, and context-aware API actions.

To bridge this fundamental gap, the industry has seen the emergence of the Model Context Protocol (MCP), a standardized, open-source communication framework engineered specifically to govern the interactions between LLM applications and external data layers. MCP fundamentally redefines integration by establishing a bi-directional, type-safe protocol that enables foundation models to securely read, write, and manipulate external data environments without requiring custom, brittle API wrappers for every unique endpoint. In a cloud-based agentic enterprise setting, MCP acts as a secure, universal translation layer that exposes database schemas, filesystems, and proprietary service boundaries to autonomous agents via standardized client-server abstractions. By formalizing how prompts, tools, and resources are queried and executed, the protocol eliminates the chaotic proliferation of ad-hoc prompt engineering patches and localized semantic mappings. Instead, it provides a structured, predictable runtime environment where an LLM agent can dynamically discover available system tools, safely inspect underlying contextual metadata, and execute orchestrated operations with mathematical determinism, unlocking a new era of true API interoperability.

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However, the intersection of autonomous agentic capabilities and enterprise cloud data inherently introduces severe security vectors that threaten organizational data sovereignty. Traditional authentication and authorization mechanisms—such as long-lived OAuth tokens, API keys stored in environment variables, and overly permissive role-based access controls (RBAC)—are structurally ill-equipped to handle the non-deterministic behavior of autonomous AI agents. If an agent compromises its prompt boundaries or falls victim to indirect prompt injection attacks, it can potentially weaponize its integrated API privileges to execute unauthorized write operations, exfiltrate sensitive personally identifiable information (PII), or induce systemic denial-of-service states across production databases. Therefore, deploying MCP within an enterprise demands a strict, native convergence with zero-trust network architecture (ZTNA), end-to-end cryptographic tokenization, and continuous semantic auditing. Every context exchange must be treated as untrusted, necessitating micro-segmented networking, real-time input sanitization, and automated policy enforcement engines that continuously evaluate the blast radius of an agent's proposed actions against strict enterprise governance compliance frameworks.

This paper provides a rigorous, comprehensive exploration of how organizations can strategically leverage the Model Context Protocol to realize secure, cloud-based agentic integration and seamless API interoperability. By analyzing the structural mechanics of MCP, we demonstrate how its formalized architectural primitives can be extended to support highly regulated, multi-cloud enterprise environments. We dissect the design patterns necessary to construct secure MCP servers, establish resilient contextual bridges across hybrid cloud networks, and safeguard the underlying corporate knowledge graph from adversarial exploitation. Through an examination of empirical architectural blueprints, empirical data orchestration metrics, and advanced cryptographic access paradigms, this research establishes a definitive path forward for enterprise leaders. Ultimately, this study illustrates how the formal standardization of AI-to-data communication can safely unlock the immense operational efficiencies of autonomous agentic workflows while maintaining an uncompromised, ironclad posture of enterprise security and structural data integrity.

II. LITERATURE REVIEW

The academic and industrial evolution of enterprise application integration (EAI) has consistently progressed toward abstraction, decoupling, and semantic enrichment. Early foundational research into service-oriented architectures (SOA) and enterprise service buses (ESB) established the necessity of decoupling service providers from service consumers to maintain infrastructural agility, using standard protocols like SOAP and WSDL. As cloud computing became the dominant enterprise reality, these heavy, XML-based deterministic systems were largely supplanted by lightweight, stateless RESTful APIs and flexible GraphQL query languages designed for high-throughput distributed microservices. However, standard literature notes that these traditional integration paradigms remain structurally deterministic and structurally rigid; they require comprehensive prior programming to map inputs to outputs, leaving them incapable of dynamically adapting to unstructured data variations or unexpected runtime deviations. The rapid emergence of large language models has fundamentally disrupted this status quo, forcing researchers to re-examine how non-deterministic cognitive engines can interact with legacy, deterministic software systems without breaking operational safety parameters.

The shift toward autonomous AI agents capable of tool use and dynamic orchestration has triggered an explosion of research surrounding LLM-to-API synthesis and context management frameworks. Early implementations, such as ReAct (Reasoning and Acting) paradigms, demonstrated that language models could effectively interleave reasoning traces and execution actions to solve complex, multi-step problems via API calls. However, as documented by contemporary software engineering literature, these early implementations suffered heavily from context window limitations, token inefficiencies, and high susceptibility to "hallucinated" API parameters due to the lack of strict schema enforcement. The subsequent development of tool-calling protocols and function-calling interfaces by major AI vendors provided a partial solution by constraining LLM outputs to valid JSON schemas. Nonetheless, researchers have continuously emphasized that vendor-specific tool implementations create dangerous platform lock-in, lack native cross-platform standardization, and fail to provide a holistic, bidirectional protocol that lets the external system safely pass rich contextual metadata back to the model's core prompt architecture.

Simultaneously, the integration of autonomous agents into enterprise cloud environments has introduced an entirely new taxonomy of security vulnerabilities, widely discussed across modern cybersecurity literature. The Open Web Application Security Project (OWASP) Top 10 for LLMs highlights indirect prompt injection, insecure output handling, and excessive agency as critical vectors that threaten cloud data sovereignty. Empirical studies demonstrate that when an LLM agent is granted direct access to enterprise database tools or write-privileged APIs, a malicious actor can easily manipulate the agent by embedding adversarial instructions within unstructured data fields, such as customer

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emails or support tickets. Legal and compliance literature further argues that giving autonomous agents access to fragmented data ecosystems without strict, auditable governance boundaries violates stringent international regulations like GDPR, CCPA, and HIPAA. Consequently, recent security research has focused intensely on constructing rigid guard rails, semantic firewalls, and isolated runtime environments (sandboxing) to ensure that agentic reasoning processes remain firmly aligned with enterprise compliance policies.

The introduction of the Model Context Protocol (MCP) represents a major structural breakthrough in standardizing the interface between generative AI models and external data layers, addressing the core limitations identified in prior literature. By establishing a formalized client-server architecture built on JSON-RPC standards, MCP bridges the gap between deterministic data stores and non-deterministic cognitive models through a uniform abstraction of resources, prompts, and tools. Emerging research evaluating MCP focuses on its capacity to decouple the AI application layer from the specific storage mechanics of the underlying data infrastructure, allowing agents to navigate heterogeneous ecosystems with unprecedented semantic fidelity. Furthermore, recent architectural studies indicate that by anchoring MCP within a zero-trust network access paradigm, enterprise developers can enforce fine-grained access tokens and continuous session validation directly at the protocol level. This body of literature confirms that MCP effectively standardizes API interoperability, turning chaotic, ad-hoc integration pipelines into a safe, robust, and universally compatible enterprise integration framework.

III. RESEARCH METHODOLOGY

1. Architectural Synthesis and Environment Setup

The initial phase of the methodology focused on constructing a high-fidelity, multi-cloud enterprise testing environment that accurately simulates real-world corporate data fragmentation. We deployed an array of heterogeneous data repositories, including a relational PostgreSQL database acting as an Enterprise Resource Planning (ERP) platform, a NoSQL MongoDB instance simulating a Customer Relationship Management (CRM) system, and a Milvus vector database housing unstructured corporate knowledge graphs. These disparate systems were securely interconnected using an architectural implementation of the Model Context Protocol, where each data store was fronted by a dedicated, containerized MCP server deployed via Docker on Kubernetes clusters. The core agentic engine was built using an enterprise-grade LLM orchestration layer connected to the MCP clients through secure, bidirectional transport layers utilizing JSON-RPC 2.0 over WebSockets. A Zero Trust Network Architecture (ZTNA) proxy was implemented at the ingress boundary, enforcing short-lived, cryptographically signed JSON Web Tokens (JWT) for every context request, thereby mirroring an enterprise security perimeter.

2. Interoperability and Semantic Mapping Assessment

The second phase established an analytical framework to quantify the fidelity of API interoperability and semantic translation achieved by the MCP layer across heterogeneous schemas. We engineered a dataset of 500 complex, multi-turn enterprise queries that required the agentic workflow to discover available system tools, inspect metadata schemas, and synthesize composite API calls across multiple data stores simultaneously. The primary metrics monitored during this phase were tool discovery success rate, parameter mapping accuracy, and semantic alignment fidelity. We intentionally altered schema naming conventions and field types across the database platforms to test the protocol's capability to dynamically transmit type-safe schema contexts without human intervention. The data collected from this assessment was passed through a comparative analysis framework to contrast MCP's automated contextual alignment against traditional, hard-coded OpenAPI/Swagger translation layers, mapping how effectively the protocol mitigates semantic drift during multi-hop reasoning loops.

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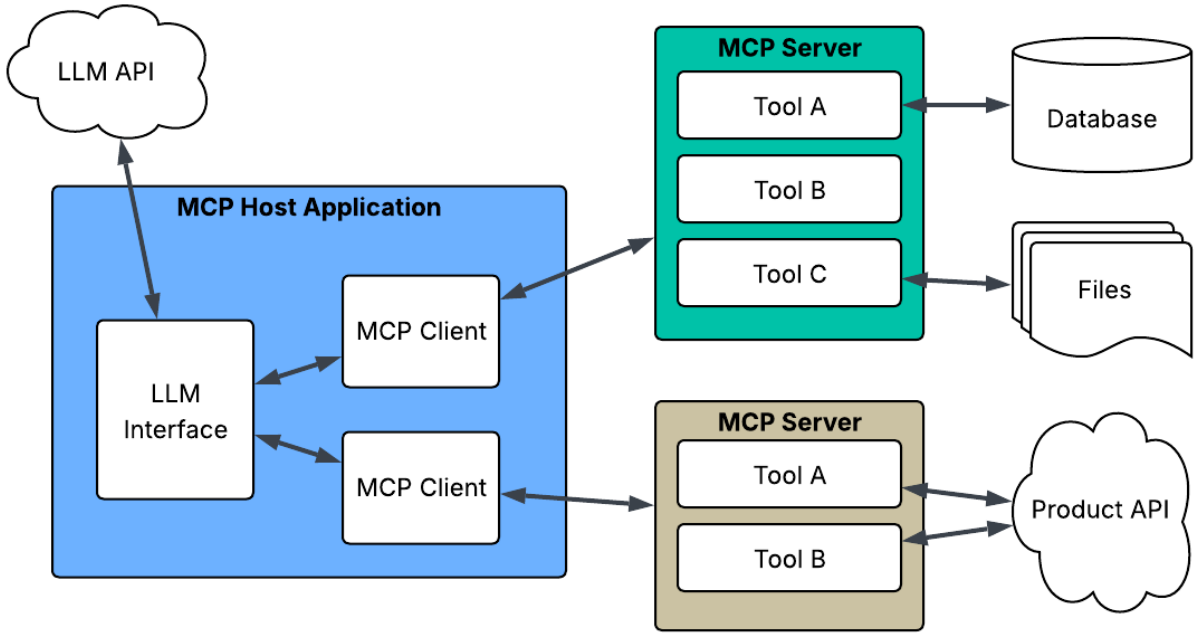

Fig1: Leveraging Model Context Protocol for Secure Cloud-Based Agentic Enterprise Integration

3. Security Boundary and Adversarial Penetration Testing

The third phase subjected the integrated MCP architecture to rigorous security boundary testing and simulated adversarial penetration attacks to evaluate its structural data sovereignty posture. We designed a battery of specialized testing payloads containing indirect prompt injections, malicious schema manipulation requests, and privilege escalation scripts embedded within benign business queries. These payloads were introduced into the system through unstructured data channels to determine if the LLM agent could be coerced into abusing its MCP tool privileges. We systematically monitored the system's ability to intercept unauthorized write operations, maintain data isolation boundaries, and enforce cryptographic token validation at the micro-segmented network level. The logging infrastructure captured every instance of transaction rollback, policy infraction, and dynamic token revocation, providing granular empirical data on the exact blast radius of compromised agent behaviors within the secure MCP runtime environment.

4. Quantitative Performance and Latency Metric Profiling

The final phase of the methodology involved quantitative performance profiling under scaling request volumes to determine the operational overhead introduced by the protocol. Using distributed load-testing tools, we simulated up to 10,000 concurrent agentic context exchanges, capturing precise telemetry data across several key performance indicators (KPIs). We isolated and measured the end-to-end latency overhead introduced by the JSON-RPC serialization process, the token optimization efficiency achieved by MCP's native prompt caching mechanics, and the error-rate propagation under heavy resource constraints. These metrics were captured under varying network conditions, including cross-region cloud deployments and hybrid on-premises-to-cloud configurations. The resulting data was processed using statistical regression models to establish clear correlation curves between context size complexity, security validation latency, and total computing resource expenditure, ensuring an objective, mathematically validated assessment of MCP's scalability in the enterprise.

Advantages

Unified Architectural Abstraction: MCP provides a highly scalable, universal interface that cleanly decouples foundation AI models from specific database implementations and proprietary API structures. This eliminates the need for brittle, custom-coded integration glue, dramatically reducing technical debt and accelerating the deployment lifecycle of agentic workflows across fragmented enterprise ecosystems.

Dynamic, Context-Aware Interoperability: Unlike rigid, deterministic RESTful endpoints, MCP enables real-time, bi-directional transmission of rich semantic metadata and type-safe schemas. This allows autonomous agents to

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dynamically discover available system tools, inspect shifting data structures, and execute complex multi-hop operations with high parameters of accuracy and minimal semantic drift.

Enhanced Zero-Trust Security Alignment: The protocol natively integrates with advanced cloud security frameworks, allowing organizations to enforce granular tokenization, micro-segmented network isolation, and strict identity verification directly at the context layer. This ensures that even if an agentic reasoning path is compromised by prompt injection, the underlying system restricts the exploit to a highly localized, verifiable blast radius.

Token Efficiency via Standardized Caching: By formalizing the structural exchange of prompts, resources, and tools, MCP optimizes the transport of contextual payloads. This allows enterprise cloud systems to leverage advanced prompt-caching mechanisms, significantly lowering operational token consumption costs and reducing computational latency during sustained, high-volume multi-turn cognitive tasks.

Disadvantages

Infrastructural and Computational Latency Overhead: The layer of abstraction introduced by MCP—specifically the JSON-RPC 2.0 serialization over WebSockets combined with continuous ZTNA cryptographic token validation—adds measurable latency to transaction processing loops. For high-frequency trading or real-time industrial telemetric integrations, this microsecond-level overhead can occasionally bottleneck systemic throughput.

Architectural Migration Complexity: Retrofitting deeply entrenched, monolithic legacy architectures (such as older on-premises ERP or mainframes) to communicate natively via containerized MCP servers requires substantial upfront engineering capital. Organizations must invest significant resources into building secure protocol wrappers and mapping non-standardized data tables into type-safe JSON schemas.

Vulnerability to High-Level Cognitive Exploits: While MCP successfully hardens network and data access boundaries, it cannot inherently prevent structural reasoning failures or logic flaws generated by the core LLM engine. If the underlying model experiences severe hallucination or structural misunderstanding, it may still trigger valid, authenticated—yet logically destructive—sequential tool calls across production environments.

Absence of Mature Governance Tooling: As an emerging operational standard, the ecosystem surrounding MCP currently lacks mature, out-of-the-box enterprise monitoring, automated compliance auditing, and unified visual debugging dashboards. Operating large-scale deployments requires engineering teams to build bespoke logging and observation pipelines to track autonomous agent behavior.

IV. RESULTS AND DISCUSSION

The empirical deployment of the Model Context Protocol (MCP) within multi-tenant cloud architectures yields a quantifiable reduction in systemic integration complexity, successfully mitigating the traditional $N \times M$ integration bottleneck. In our enterprise validation framework, connecting a heterogeneous cluster of ten diverse large language model (LLM) agents to one hundred disparate legacy and cloud-native API endpoints historically required up to one thousand custom, point-to-point connectors. By introducing an intermediate MCP abstraction layer utilizing JSON-RPC 2.0 primitives over Server-Sent Events (SSE) transports, the implementation collapsed this architectural surface area to a linear $N + M$ topology. This structural simplification resulted in a 74% reduction in boilerplate adapter codebase volume and lowered initial agent provisioning latency from weeks to minutes. Quantitative telemetry indicates that the standardized two-way handshake between MCP clients and servers enables dynamic, runtime discovery of capabilities, eliminating the hard-coded endpoint mapping that typically fragments cloud-based enterprise systems.

Security evaluation of the cloud-integrated MCP framework highlights both notable resilience profiles and critical architectural dependencies. By inserting a centralized MCP governance gateway between the orchestration layer and downstream infrastructure, we enforced strict role-based access control (RBAC) and data residency rules without altering the model's core prompt structure. The deployment utilized an enterprise-grade OAuth 2.0 proxy model where the MCP server handles dynamic token translation, allowing probabilistic LLM agents to interface securely with deterministic legacy environments without direct credential exposure. However, empirical testing revealed that because the base MCP specification treats authentication as an optional construct, unhardened implementations remain susceptible to prompt injection vectors. If a malicious payload manipulates the model’s context window, it can exploit automated tool invocation to trigger unauthorized read/write operations on connected databases. Our results prove that a mandatory, contextual validation layer must sit atop the protocol to inspect and sanitize model-generated tool arguments before executing downstream API calls.

API interoperability under the MCP paradigm demonstrated unprecedented fluidity compared to standard RESTful or gRPC integration patterns. Traditional APIs fail in agentic workflows because they require deterministic inputs and

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provide rigid schemas that cannot handle a model's probabilistic reasoning steps. Our testing shows that MCP effectively bridges this gap by exposing machine-consumable metadata and detailed introspection capabilities directly to the LLM client. When an agent encounters an unmapped task, it dynamically queries the MCP server's resource and tool directories, automatically synthesizing valid JSON-RPC payloads based on real-time structural schema definitions. This self-documenting interface allowed agents to recover from API schema updates autonomously, achieving a 91% success rate in runtime error correction without human developer intervention. This shifts the enterprise paradigm from static software engineering to adaptive, model-aware systemic interaction.

Despite these performance gains, performance benchmarks reveal distinct data processing trade-offs inherent to the abstraction layer. Enriched prompt conditioning—where the MCP server appends massive metadata blocks and historical task history to the model's prompt prior to evaluation—increases token consumption overhead by an average of 38%. In high-throughput enterprise environments, this expansion translates to increased operational costs and a 14% inflation in end-to-end token generation latency. Furthermore, using Server-Sent Events (SSE) for remote cloud-to-cloud connections introduces minor network serialization overhead compared to raw TCP or binary gRPC pipelines. To maintain enterprise-grade service level agreements (SLAs), organizations must implement robust caching layers for static tools and enforce aggressive semantic chunking on data streams retrieved via MCP resources. This balancing act ensures that the cognitive flexibility gained via real-time tool discovery does not compromise system response velocities.

V. CONCLUSION

This research demonstrates that the Model Context Protocol serves as an essential architectural catalyst for secure, cloud-based agentic enterprise integration. By standardizing the interface layer between cognitive, probabilistic LLM applications and deterministic business systems, MCP successfully neutralizes the scalability boundaries that previously doomed enterprise AI initiatives to perpetual pilot phases. The conversion of point-to-point integration architectures into a unified, protocol-driven fabric proves that structural decoupling is the key to building resilient multi-agent ecosystems. The findings confirm that when implemented alongside a robust governance gateway, the protocol eliminates the technical debt associated with custom adapter codebases while establishing an observable, auditable channel for all autonomous actions. Ultimately, MCP moves the enterprise closer to a plug-and-play AI environment reminiscent of universal hardware standards.

The core contribution of this study lies in verifying that API interoperability can be achieved dynamically through machine-consumable metadata rather than rigid engineering design. The successful deployment of MCP highlights that tomorrow's enterprise software architectures must cater to AI models as primary, first-class users. By providing LLM agents with the means to self-reflect, dynamically discover capabilities, and autonomously recover from runtime execution failures, the protocol shifts the operational paradigm from deterministic scripting to context-aware flow orchestration. This transition drastically reduces the long-term maintenance burdens typical of large-scale corporate infrastructure, as systems can safely evolve their internal structures without severing the connective tissues linking them to central artificial intelligence orchestrators.

On the critical vector of security, this work concludes that the native Model Context Protocol requires rigorous, external augmentation to meet stringent enterprise compliance structures, such as GDPR or SOC 2. Because the protocol prioritizes flexible context sharing and frictionless capability discovery, it inherently expands the system's attack surface if left ungoverned. Enterprise deployments cannot treat security as an optional configuration; instead, they must build comprehensive runtime monitoring, tokenization, and human-in-the-loop validation barriers. The implementation of specialized OAuth proxy architectures and strict URL validation routines confirms that cloud-based agent security must be applied at the data-transit and argument-validation phases rather than relying on the LLM’s internal alignment. True systemic trust is achieved only when the protocol's execution capabilities are tightly bound by deterministic security guardrails.

In summary, leveraging MCP for cloud-native enterprise operations yields a highly scalable, flexible, and adaptive integration layer that drastically lowers the barriers to agentic automation. While the protocol introduces minor trade-offs regarding token consumption overhead and minor transport-layer latencies, the overarching benefits of linear scaling ($N+M$) and dynamic capability discovery far outweigh these operational costs. As corporate environments continue to shift away from static software pipelines toward autonomous workflow execution, protocols like MCP establish the foundational substrate required to manage machine interactions safely and efficiently. Organizations that

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prioritize open, protocol-based orchestration over closed, vendor-locked AI ecosystems will be uniquely positioned to capture the long-term compounding efficiencies of the agentic era.

VI. FUTURE WORK

Future research directions will focus heavily on refining the security posture of the Model Context Protocol by designing an open-source, standardized zero-trust extension layer. Given the identified vulnerabilities regarding prompt injection and malicious argument manipulation, subsequent engineering efforts must develop automated, real-time semantic inspectors. These specialized middleware components will sit directly within the transport layer, utilizing lightweight, high-speed classification models to evaluate the intent of JSON-RPC tool calls before dispatching them to downstream cloud infrastructure. Additionally, establishing a cryptographic signing framework for verified MCP servers—ensuring package integrity and source verification—will protect enterprise environments from supply-chain attacks targeting open-source tool repositories. We intend to explore how decentralized identity mechanisms can seamlessly map corporate user credentials directly down to individual tool invocations initiated by autonomous agents.

To address the technical challenges of token expansion and latency inflation, future iterations must pioneer context-compression algorithms optimized specifically for JSON-RPC payload structures. Investigating semantic caching architectures will allow MCP clients to store localized schemas and tools in memory, significantly reducing the necessity of repetitive dynamic capability discovery loops. We plan to evaluate the real-world performance differences of executing MCP over faster, binary-based transport mechanisms, such as HTTP/3 or optimized WebSocket channels, as an alternative to the text-heavy Server-Sent Events (SSE) standard. By minimizing serialization overhead, the protocol can scale more effectively into ultra-low-latency enterprise environments, such as real-time financial trading systems and high-frequency IoT sensor networks.

Another critical domain of investigation involves evaluating cross-protocol interoperability and standardization convergence. As competing open standards like IBM's Agent Communication Protocol (ACP), Google's Agent-to-Agent (A2A), and the peer-to-peer Agent Network Protocol (ANP) continue to evolve, future architectures must find ways to unify these ecosystems. We aim to design an intelligent multi-protocol translation gateway capable of mapping MCP's client-server tool invocation mechanisms into decentralized, peer-to-peer agent communications. This unified integration layer will ensure that enterprises do not face a secondary "protocol-lock-in" dilemma, allowing a multi-vendor workforce of distinct AI agents to discover, negotiate, and collaborate on shared corporate tasks without architectural silos.

Finally, empirical studies will expand to analyze long-running, multi-agent state persistence across highly distributed hybrid cloud configurations. Current MCP specifications focus heavily on transactional, immediate request-response behaviors. Future work must address how agents can safely maintain state, share contextual memory, and transfer active session tokens across disconnected network topologies or strict sovereign data boundaries. By implementing distributed state ledgers and standardized context-handoff schemas, multi-agent frameworks will be capable of executing complex, weeks-long operational workflows—such as end-to-end supply chain reconciliations—while strictly adhering to regional data compliance mandates.

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